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Influence of beef carcass chilling rate on steak case life and quality traits

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Objective

The objective of this research was to determine the influence of beef carcass weight on carcass chilling, pH decline, color, case life and tenderness of steaks from the round, loin, rib, and chuck.

Study Description

Twelve head of fed beef cattle were harvested at the SDSU Meat Laboratory over two days. Carcasses were allotted into two weight groups based on hot carcass weight (HCW): Heavyweight (HW) and Lightweight (LW). Data logging thermometers were placed in the left side of each carcass within the round, loin, rib, and chuck primals to track temperature decline. Carcass measurements including 12th rib fat thickness, ribeye area and marbling score were collected approximately 48 hours postmortem. Steaks from each primal were collected to measure Warner-Bratzler shear force (WBSF), objective and subjective color.

Take Home Points

Results from this study suggest that beef carcass weight does impact carcass chilling rate during the first 48 hours postmortem. Prolonged temperature decline in the round, combined with increased toughness of eye of round steaks from heavyweight carcasses at early aging periods could suggest negative meat quality effects due to this increase in weight. Since the round holds most of a carcass' muscle weight, this could lead to a substantial amount of product being affected.

Introduction

Over the past 30 years, the average beef carcass weight has increased from 747 pounds in 1995 to 867 pounds in 2016 according to the 2016 National Beef Quality Audit. Additionally, the 2016 National Beef Quality Audit concluded that 12.4% of all carcasses recorded had hot carcass weights greater than 1000 pounds (Boykin et al., 2017). However, these increases in hot carcass weight have come with minimal changes to cooling systems and protocols involved with chilling beef carcasses. Many packers are still utilizing chilling systems that were designed decades ago. These systems were designed for use on carcasses that were a much lighter weight, on average, than the beef carcasses that have been harvested in industry recently (Savell, 2012). Therefore, it stands to reason that if chilling methods have not changed to adapt to increasing carcass weights, it is possible that heavy weight carcasses are at risk of ineffective chilling. Previous research from Kim et al. (2012) investigated heat toughening of strip loins and concluded that increased antemortem temperatures decreased postmortem proteolysis and increased shear force values of loin steaks resulting in tougher steaks. However, little published research exists to determine the direct influence of carcass weight on postmortem chilling. A NCBA funded study conducted by the SDSU Meat Science group, showed that heavyweight carcasses do not chill as quickly as lightweight carcasses in a large commercial plant and

resulted in increased tenderness in strip loin steaks from Heavyweight carcasses when compared to strip loin steaks from Lightweight carcasses. The same study also concluded that Denver cut and eye of round steaks from Heavyweight carcasses had increased L* (lighter) and b* (more yellow) values when compared to Denver cut and eye of round steaks from Lightweight carcasses. Additionally, Denver cut, strip loin and eye of round steaks from Heavyweight carcasses had increased a* (more red) values than steaks from Lightweight carcasses (Egolf, 2021). Another study from the University of Idaho found that top round steaks from Overweight carcasses had increased L* and b* values compared to top round steaks from Average weight carcasses (Lancaster et al. 2020).

Throughout the chilling process, there are many biological changes occurring in the carcass simultaneously: the start of muscle pH decline, postmortem proteolysis, and ultimately the conversion of muscle to meat. As the carcass is chilling, any number of mechanisms may be affected, and any number of subtle changes in carcass temperature or pH could impact meat quality traits such as meat color, shelf life, and tenderness.

Therefore, we hypothesized that heavyweight carcasses would experience slower temperature and pH decline leading to ultimate differences in meat color, decreased case life, and result in tougher steaks when compared to lightweight carcasses.

Experimental Procedures

Carcass Chilling

Twelve finished beef cattle from a single feedlot were harvested at the South Dakota State University Meat Laboratory over two slaughter dates. These cattle were selected to fit within one of two weight ranges based on live weight: 1100 – 1350 lbs or 1450 – 1600 lbs. After slaughter, carcasses were allotted to one of two weight groups based on hot carcass weight: Heavyweight (HCW = 992 ± 17lbs) or Lightweight (HCW = 769 ± 17 lbs). Upon cooler entry, data logging thermometers (ThermaData stainless steel USB temp data logger; ThermoWorks, American Fork, UT) were placed in the left side of each carcass in the round, loin, rib, and chuck. An 8-inch data logger was placed in the round approximately 6 inches below the Achilles tendon. In the loin, a 4-inch temperature logger was placed opposite the third lumbar vertebrae. In the rib, a 4-inch logger was placed opposite the eighth rib. Also, an 8-inch data logger was placed in the pocket between the chuck and the brisket so that the tip of the temperature logger would rest near the scapula. All 8-inch and 4-inch temperature data will be referred to as deep muscle temperature. To track sub-surface temperature of each carcass, a second temperature logger (Multitrip multiuse temperature recorder; Temprecord International Ltd, Auckland, New Zealand) was placed in each of the primals beneath the surface of the subcutaneous fat; except in the round, where the logger was placed beneath the surface of the Semitendinosus muscle (eye or round), due to lack of fat in the location. Once in the cooler, carcasses were exposed to an average air temperature of 38.0 ± 1.2°F and sprayed intermittently with water chilled to an average of 41°F.

Thermal Imaging

Thermal images were captured using a forward-looking infrared camera (FLIR C3, FLIR Systems, Wilsonville, OR) at eight locations on the carcass. Emissivity setting of the camera was 0.95. Images of the round, loin, rib, and chuck were recorded on both the fat and split side of the carcass at five timepoints after cooler entry throughout the chilling period: Cooler entry (0hr), 3, 6, 12, and 24hr post cooler entry. These images were analyzed using FLIR Tools (FLIR Systems, Wilsonville, OR) to determine average surface temperature of the carcass in the round, loin, rib and chuck.

pH Decline

Postmortem pH was measured at eight time points (cooler entry (CE), 2, 4, 6, 8, 12, 24, and 48hr postmortem) throughout the chilling period. The *Semitendinosus* (eye of round), *Longissimus lumborum* (strip loin steak), *Longissimus thoracis* (ribeye), and the *Serratus ventralis* (Denver cut) were sampled for pH analysis at each time point. Immediately following sample removal, each sample was diced into small pieces and five grams of muscle tissue was homogenized in a 50 mL solution containing 5 mMol of sodium iodoacetate and 150 mMol

of potassium chloride (Bendall, 1973). A Thermo Scientific, Orion 370 benchtop pH meter was used to measure pH.

Carcass Evaluation and Sample Collection

Approximately 48hr postmortem, carcass measurements were recorded including ribeye area (REA), 12th rib fat thickness (FT) and marbling score from each individual carcass. Yield grade was calculated using carcass measurements. The eye of round (IMPS #171C), strip loin (IMPS #180), ribeye roll (IMPS #112A), Denver cut (IMPS #116G), and kidney, pelvic and heart (KPH) fat were collected from the left side of the carcass during fabrication, and their individual weights were recorded. Each muscle was portioned into 1-inch steaks for various analyses. Four steaks from each muscle were aged for either 5, 10, 14, or 21 days postmortem for evaluation of Warner-Bratzler shear force (WBSF). An additional steak was designated for use in a 10-day trained color panel immediately following fabrication.

Warner-Bratzler Shear Force

Steaks designated for WBSF were thawed for 24 hours at 37°F before being cooked on an electric clamshell grill to an internal peak temperature of 160°F. A thermometer (Model 35140, Cooper-Atkins Corporation, Middlefield, CT) was used to record peak internal temperature. After cooking, steaks were cooled for 12hr before six cores (0.5 in. diameter) were removed parallel to the muscle fiber orientation (AMSA, 2015). A single shear force measurement was measured from each core using a texture analyzer (Shimadzu Scientific Instruments Inc., Lenexa, KS, Model EZ-SX) with a Warner-Bratzler attachment. All the cores were averaged to determine the shear force value for each steak.

Objective and Subjective Color Panel

Steaks designated for the trained color panel were tray-overwrapped with a high oxygen permeable wrap and placed under a simulated retail display (36.6° ± 1.5°F) for 10 days. Steaks were rotated throughout the display area to ensure even distribution of light exposure among samples. Objective color measurements (L*, a* and b*) were measured using a colorimeter (Chroma Meter CR 410; Konica Minolta, Inc., Tokyo, Japan) on each day of the color panel. Additionally, a set of seven to 12 trained panelists evaluated steaks each day according to standards set forth by AMSA (2012). Steaks from the four previously mentioned muscles were evaluated each for color score (1 = Extremely bright cherry-red, 8 = Extremely dark red), and surface discoloration (1 = No discoloration or 0%, 6 = Extreme discoloration or 81 to 100%).

Statistical Analysis

Statistical analysis was conducted using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for the effects of weight group, time, and their interaction. Carcass data and muscle weights were analyzed as a completely randomized design. Temperature and pH decline, objective and subjective color, and WBSF were analyzed as repeated measures. Covariant structure was determined by the lowest AIC value. Peak temperature was used as a covariate for WBSF values. Slaughter date was used as a random variable. Significance was considered $\alpha < 0.05$. Trends were reported at $0.5 \geq \alpha \leq 0.10$.

Statistical analysis for thermal images was conducted using CORR procedure of SAS (SAS Inst. Inc., Cary, NC) for their Pearson correlation to deep muscle and sub-surface temperature. Positive correlations were determined by $r > 0$. Significance was determined $\alpha < 0.05$.

Results and Discussion

Carcass Characteristics

As expected, Heavyweight carcasses had increased ($P < 0.001$) HCW compared to Lightweight carcasses (Table 1). Heavyweight carcasses tended to have larger ($P = 0.069$) REA compared to Lightweight carcasses (Table 1). No effect of weight group was observed for FT ($P = 0.197$), dressing percent ($P = 0.268$), marbling score ($P = 0.465$), or yield grade ($P = 0.162$; Table 1). Heavyweight carcasses had increased weights of the

eye of round (P = 0.0027), strip loin (P = 0.0031), ribeye roll (P = 0.0001), Denver cut (P = 0.0026) and KPH fat (P = 0.0008) compared to Lightweight carcasses (Table 2).

Carcass Chilling

No effect of HCW or HCW × chilling time interaction (P = 0.9977) was observed for deep muscle temperature decline in the chuck. A HCW × chilling time interaction (P < 0.0001) was detected for deep muscle temperature decline in the rib. Rib primals from Heavyweight carcasses had increased (P < 0.05) temperatures for the first 25hr of chilling compared to Lightweight carcasses but were similar (P > 0.05) for the remainder of the chilling period (Figure 1). No effect of HCW or HCW × chilling time interaction (P = 0.1373) was observed for deep muscle temperature decline in the loin. A HCW × chilling time interaction (P = 0.0092) was detected for deep muscle temperature decline in the round. Temperature in the round was not different (P > 0.05) between weight groups for the first 3hr of chilling, but Heavyweight carcasses had increased (P < 0.05) temperatures for the remainder of chilling (Figure 2). No effect of HCW or HCW × chilling time interaction (P > 0.05) was observed for sub-surface temperature decline in the round, loin, rib or chuck.

Thermal Imaging

Thermal imaging data is presented in Tables 3-6. For the round, fat side temperature was positively correlated (r = 0.5875, P = 0.0446) with deep muscle temperature at 24hr. Split side temperature was positively correlated (r = 0.7492, P = 0.0050) with deep muscle temperature at 24hr. Fat side temperature was positively correlated with sub-surface temperature at 6hr (r = 0.6344, P = 0.0488), 12hr (r = 0.6833, P = 0.0294), and 24hr (r = 0.6837, P = 0.0293).

For the loin, fat side temperature was positively correlated with deep muscle temperature at 6hr (r = 0.6877, P = 0.0133), 12hr (r = 0.7658, P = 0.0037), and 24hr (r = 0.9003, P = <0.0001). Split side temperature was positively correlated with deep muscle temperature at 12hr (r = 0.9053, P = <0.0001) and 24hr (r = 0.8311, P = 0.0008). Fat side temperature was positively correlated with sub-surface temperature at 12hr (r = 0.7316, P = 0.0105) and 24hr (r = 0.9382, P = <0.0001). Split side temperature was positively correlated with sub-surface temperature at 12hr (r = 0.7820, P = 0.0045) and 24hr (r = 0.8111, P = 0.0024).

For the rib, fat side temperature was positively correlated with deep muscle temperature at 12hr (r = 0.8180, P = 0.0011) and 24hr (r = 0.8228, P = 0.0010). Split side temperature was positively correlated with deep muscle temperature at 12hr (r = 0.7082, P = 0.0100) and 24hr (r = 0.6915, P = 0.0127). Fat side temperature was positively correlated with sub-surface temperature at 3hr (r = 0.6459, P = 0.0233), 6hr (r = 0.7956, P = 0.0020), 12hr (r = 0.8347, P = 0.0007), and 24hr (r = 0.9020, P = <0.0001). Split side temperature was positively correlated with sub-surface temperature at 12hr (r = 0.8417, P = 0.0006) and 24hr (r = 0.7465, P = 0.0053).

For the chuck, split side temperature was negatively correlated with deep muscle temperature at 6hr (r = -0.7847, P = 0.0025) and 12hr (r = -0.6331, P = 0.0271). Fat side temperature was positively correlated with sub-surface temperature at 12hr (r = 0.6392, P = 0.0342) and 24hr (r = 0.7354, P = 0.0099). Split side was positively correlated (r = 0.6533, P = 0.0293) with sub-surface temperature at 24hr.

pH Decline

No HCW main effect or HCW × chilling time interaction (P > 0.05) was detected for pH decline in the eye of round, strip loin, ribeye, or Denver cut. As expected, pH declined in each of the four muscles throughout the chilling process to normal values of 5.5-5.7.

Warner-Bratzler shear force and Cook loss

No effect of HCW or HCW × aging day interaction (P > 0.05) was observed for WBSF values in the strip loin, ribeye, or Denver cut steaks. As expected, WBSF values improved for the strip loin (P < 0.0001), ribeye (P = 0.0005), and Denver cut (P = 0.0008), steaks over the aging period (Table 7). A HCW × aging day interaction (P = 0.0149) was detected for WBSF values in eye of round steaks. Eye of round steaks from Lightweight carcasses were more tender (P < 0.05) than Heavyweight steaks at day 5 of aging, but were not different at

10, 14 or 21 days of aging ($P > 0.05$; Figure 3). No HCW effect or HCW × aging day interaction was observed for percent cook loss in steaks from the eye of round ($P = 0.630$), strip loin ($P = 0.880$), ribeye ($P = 0.414$), or Denver cut ($P = 0.467$).

Objective and Subjective Color

No effect of HCW or HCW × day of retail display interaction ($P > 0.05$) was observed for L*, a* or b* in the strip loin, ribeye, or Denver cut steaks (Table 8). A HCW × day of retail display interaction ($P = 0.0001$) was detected for L* values in the eye of round. Eye of round steaks from Heavyweight carcasses were darker (lower L* value; $P < 0.05$) throughout the display period. On day 1 of retail display, Heavyweight eye of round steak L* values decreased ($P < 0.05$), whereas the Lightweight eye of round steaks increased ($P < 0.05$, Figure 4). Eye of round steaks from Heavyweight carcasses had decreased a* ($P = 0.005$) and b* ($P = 0.001$) values than eye of round steaks from Lightweight carcasses (Table 8). Hot carcass weight did not influence ($P > 0.05$) subjective color scores in the eye of round, strip loin, or ribeye steaks (Table 9). Denver cut steaks from Heavyweight carcasses had increased (darker; $P = 0.007$) subjective color scores compared to steaks from Lightweight carcasses (Table 9). No HCW or HCW × day of retail display interaction ($P > 0.05$) was observed for subjective discoloration scores in the eye of round, strip loin, ribeye, or Denver cut steaks throughout the display period (Table 10).

Implications

Results from this study suggest that beef carcass weight does impact carcass chilling rate during the first 48 hours postmortem. Heavier carcasses have prolonged temperature decline in the round, resulting in increased temperature at the time of fabrication, when compared to lighter weight beef carcasses. This, combined with increased toughness of eye of round steaks from heavyweight carcasses at early aging periods, could suggest a negative effect on meat quality due to increased carcass weights. Since the round holds a large percentage of the carcass' muscle weight, this could lead to a substantial amount of product being affected.

Additionally, thermal imaging shows promise as a new and innovative tool for determining chilling rate of beef carcasses. Data from this research project indicates that most fat side and split side thermal imaging surface temperatures were positively correlated to deep internal and sub-surface temperatures after 12hr of chilling. However, further research will be needed to determine the overall effectiveness of using thermal imaging to predict internal temperature of carcasses.

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Tables

Table 1. Least squares means of carcass characteristics for Heavyweight and Lightweight cattle

	Weight Group[1]			
Trait	**Lightweight**	**Heavyweight**	**SEM[2]**	***P*-value[3]**
Hot carcass weight, lbs	769	992	16.8	**<0.001**
Ribeye area, in^2	13.9	15.8	0.68	0.069
12th rib fat thickness, in	0.41	0.54	0.07	0.197
Dressing percent, %	63.2	64.7	0.88	0.268
UYield grade	2.5	3.1	0.32	0.162
Marbling score[4]	445	480	32.5	0.465

[1]Carcasses separated based on hot carcass weight measured after slaughter before entering the chilling cooler.
[2]Standard error of the mean
[3]Probability of difference among least square means
[4]Marbling score: 200=Traces^0, 300=Slight^0, 400=Small^0, 500=Modest^0

Table 2. Least squares means of individual muscle and fat weights for Heavyweight and Lightweight cattle

	Weight Group[1]			
Muscle	**Lightweight**	**Heavyweight**	**SEM[2]**	***P*-value[3]**
Eye of round, lbs	4.56	6.13	0.29	**0.0027**
Strip loin, lbs	10.65	14.46	0.71	**0.0031**
Ribeye roll, lbs	11.22	16.67	0.64	**0.0001**
Denver cut, lbs	3.81	5.29	0.26	**0.0026**
Kidney, pelvic and heart fat, lbs	10.60	17.57	1.06	**0.0008**

[1]Carcasses separated based on hot carcass weight measured after slaughter before entering the chilling cooler.
[2]Standard error of the mean
[3]Probability of difference among least square means

Table 3. Pearson correlation coefficients between deep muscle (4 or 8 inches) temperature and average thermal image temperature of fat side of carcass at each timepoint.

Primal	Statistical Value[2]	Time After Cooler Entry[1]				
		0 h	3 h	6 h	12 h	24 h
Round	r value	-0.0007	0.0807	0.0492	0.4399	**0.5875**
	P-value	0.9982	0.8030	0.8792	0.1524	**0.0446**
Loin	r value	-0.0164	0.3953	**0.6887**	**0.7658**	**0.9003**
	P-value	0.9598	0.2035	**0.0133**	**0.0037**	**<0.0001**
Rib	r value	-0.3947	0.3594	0.5117	**0.8180**	**0.8228**
	P-value	0.2042	0.2512	0.0890	**0.0011**	**0.0010**
Chuck	r value	0.0620	-0.1704	-0.4165	-0.4825	-0.0038
	P-value	0.8481	0.5965	0.1781	0.1121	0.9906

[1]Time temperature was measured after carcass entered chilling cooler.
[2]**r-value:** Correlations were considered lowly correlated at r ≤ 0.35, moderately at 0.36 ≤ r ≤ 0.67, and highly if r ≥ 0.68. ***P*-value**: Probability of difference among correlations.

Table 4. Pearson correlation coefficients between deep muscle (4 or 8 inches) temperature and average thermal image temperature of split side of carcass at each timepoint

Primal	Statistical Value[2]	Time After Cooler Entry[1]				
		0 h	3 h	6 h	12 h	24 h
Round	r value	-0.0876	-0.3311	-0.2754	0.4463	**0.7492**
	P-value	0.7866	0.2931	0.3864	0.1458	**0.0050**
Loin	r value	-0.0906	0.2074	0.5371	**0.9053**	**0.8311**
	P-value	0.7796	0.5178	0.0717	**<0.0001**	**0.0008**
Rib	r value	-0.4735	0.1450	0.3548	**0.7082**	**0.6915**
	P-value	0.1199	0.6529	0.2581	**0.0100**	**0.0127**
Chuck	r value	-0.1442	-0.5357	**-0.7847**	**-0.6331**	0.0228
	P-value	0.6547	0.0727	**0.0025**	**0.0271**	0.9440

[1]Time temperature was measured after carcass entered chilling cooler.
[2]**r-value:** Correlations were considered lowly correlated at r ≤ 0.35, moderately at 0.36 ≤ r ≤ 0.67, and highly if r ≥ 0.68. ***P*-value**: Probability of difference among correlations.

Table 5. Pearson correlation coefficients between sub-surface (2 inches) temperature and average thermal image temperature of fat side of carcass at each timepoint

Primal	Statistical Value[2]	Time After Cooler Entry[1]				
		0 h	3 h	6 h	12 h	24 h
Round	r value	-0.0786	0.4264	**0.6344**	**0.6833**	**0.6837**
	P-value	0.8290	0.2191	**0.0488**	**0.0294**	**0.0293**
Loin	r value	-0.1259	0.4641	0.4527	**0.7316**	**0.9382**
	P-value	0.7123	0.1504	0.1620	**0.0105**	**<0.0001**
Rib	r value	0.3054	**0.6459**	**0.7956**	**0.8347**	**0.9020**
	P-value	0.3344	**0.0233**	**0.0020**	**0.0007**	**<0.0001**
Chuck	r value	0.3579	0.2989	0.5749	**0.6392**	**0.7354**
	P-value	0.2799	0.3719	0.0643	**0.0342**	**0.0099**

[1]Time temperature was measured after carcass entered chilling cooler.

[2]**r-value:** Correlations were considered lowly correlated at r ≤ 0.35, moderately at 0.36 ≤ r ≤ 0.67, and highly if r ≥ 0.68. ***P*-value**: Probability of difference among correlations.

Table 6. Pearson correlation coefficients between sub-surface (2 inches) temperature and average thermal image temperature of split side of carcass at each timepoint

Primal	Statistical Value[2]	Time After Cooler Entry[1]				
		0 h	3 h	6 h	12 h	24 h
Round	r value	-0.1443	-0.0981	0.3291	0.4703	0.6294
	P-value	0.6908	0.7874	0.3532	0.1701	0.0512
Loin	r value	-0.2368	0.1165	0.2535	**0.7820**	**0.8111**
	P-value	0.4833	0.7330	0.4519	**0.0045**	**0.0024**
Rib	r value	0.1647	0.2113	0.5215	**0.8417**	**0.7465**
	P-value	0.6090	0.5097	0.0821	**0.0006**	**0.0053**
Chuck	r value	0.0067	0.0451	0.2221	0.5761	**0.6533**
	P-value	0.9844	0.8952	0.5115	0.0636	**0.0293**

[1]Time temperature was measured after carcass entered chilling cooler.

[2]**r-value:** Correlations were considered lowly correlated at r ≤ 0.35, moderately at 0.36 ≤ r ≤ 0.67, and highly if r ≥ 0.68. ***P*-value**: Probability of difference among correlations.

Table 7. Least squares means of Warner-Braztler shear force values for steaks from various muscles for multiple aging days

	Aging day					
Steak	**5**	**10**	**14**	**21**	**SEM[1]**	***P*-value[2]**
Strip loin steak, kg	5.76[a]	4.42[b]	4.16[b]	3.28[c]	0.31	**<0.0001**
Ribeye, kg	5.51[a]	4.71[b]	3.98[c]	3.75[c]	0.27	**0.0005**
Denver cut, kg	4.21[a]	3.91[ab]	3.71[b]	3.22[c]	0.15	**0.0008**

[1]Standard error of the mean

[2]Probability of difference among least square means

[a,b,c] Superscripts depict differences between aging days within muscle, $P < 0.05$.

Table 8. Least squares means of objective color measurements (L*, a*, b*) values for steaks from various muscles over a 10-day color panel for Heavyweight and Lightweight cattle

		Weight Group[1]			
Steak	**Objective color value[2]**	**Lightweight**	**Heavyweight**	**SEM[3]**	***P*-value[4]**
Eye of round	L*	49.33	46.13	0.48	<**0.001**
	a*	17.39	16.13	0.40	**0.005**
	b*	10.34	8.95	0.21	**0.001**
Strip loin steak	L*	46.30	45.98	0.76	0.773
	a*	15.18	13.96	0.57	0.106
	b*	6.63	6.17	0.25	0.216
Ribeye	L*	47.22	45.99	0.61	0.181
	a*	15.46	14.03	0.78	0.241
	b*	6.94	6.05	0.34	0.098
Denver cut	L*	45.74	46.46	0.98	0.600
	a*	13.07	12.63	0.36	0.354
	b*	6.06	6.29	0.43	0.701

[1]Carcasses separated based on hot carcass weight measured after slaughter before entering the chilling cooler.

[2]**L***: 0 = Black, 100 = White; **a***: Negative values = green; Positive values = red; **b***: Negative values = blue; Positive values = yellow

[3]Standard error of the mean

[4]Probability of difference among least square means

Table 9. Least squares means of subjective color measurements (color score, percent discoloration) for steaks from various muscles over a 10-day trained color panel for Heavyweight and Lightweight cattle

Steak	Subjective color value[2]	Weight Group[1]		SEM[3]	*P*-value[4]
		Lightweight	Heavyweight		
Eye of round	Color score	4.25	4.46	0.19	0.067
Strip loin steak	Color score	5.37	5.62	0.20	0.319
Ribeye	Color score	5.08	5.45	0.20	0.102
Denver cut	Color score	5.98	6.35	0.09	**0.007**
Eye of round	Surface discoloration	3.25	3.29	0.17	0.348
Strip loin steak	Surface discoloration	2.87	2.87	0.24	0.954
Ribeye	Surface discoloration	2.75	2.77	0.22	0.633
Denver cut	Surface discoloration	3.28	3.37	0.20	0.193

[1]Carcasses separated based on hot carcass weight measured after slaughter before entering the chilling cooler.

[2]**Color Score**: 1 = Extremely bright cherry red, 2 = Bright cherry red, 3 = Moderately bright cherry red, 4 = Slightly bright cherry red, 5 = Slightly dark cherry red, 6 = Moderately dark red, 7 = Dark red, 8 = Extremely dark red. **Surface Discoloration**: 1 = No discoloration; 0%, 2 = Slight discoloration; 1-21%, 3 = Small discoloration; 21-40%, 4 = Modest discoloration; 41-60%, 5 = Moderate discoloration; 61-80%, 6 = Extreme discoloration; 81-100%

[3]Standard error of the mean

[4]Probability of difference among least square means

Figures

Figure 1 - Effect of hot carcass weight and chilling time on deep temperature decline in the rib of Heavyweight and Lightweight carcasses

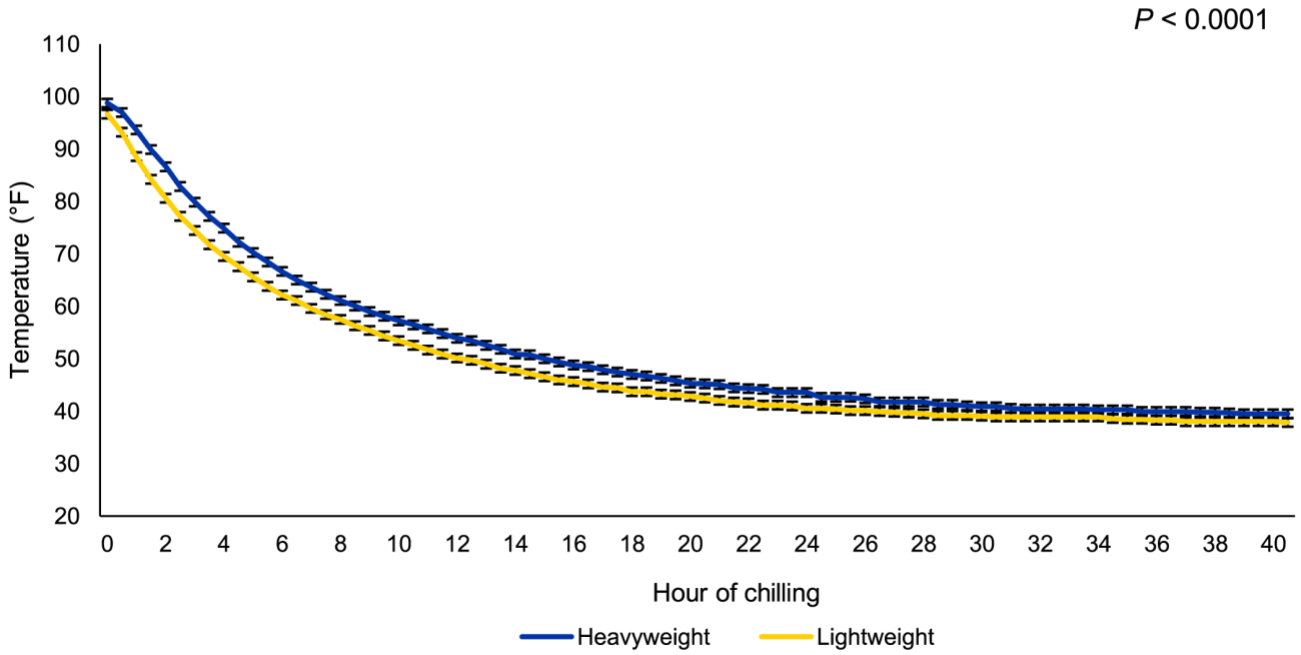

Figure 2 - Effect of hot carcass weight and chilling time on deep temperature decline in the round of Heavyweight and Lightweight carcasses

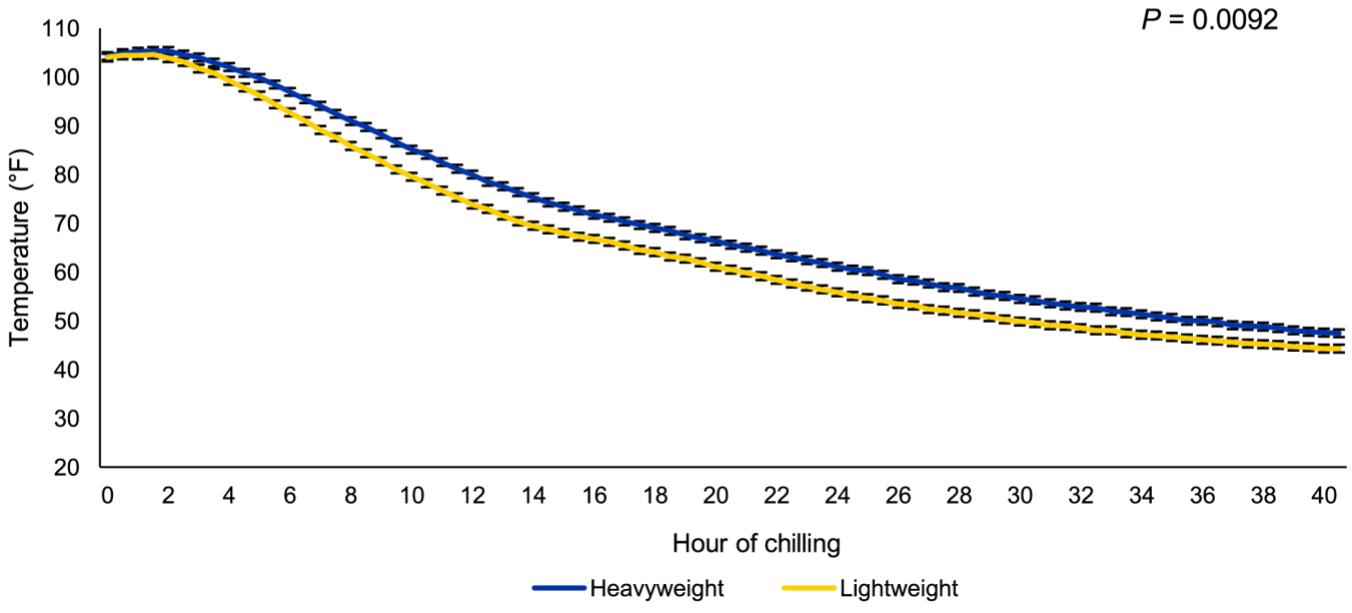

Figure 3 - Effect of hot carcass weight and aging time on Warner-Bratzler shear force (WBSF) values of eye of round steaks *(Semitendinosus)* between Heavyweight and Lightweight carcasses

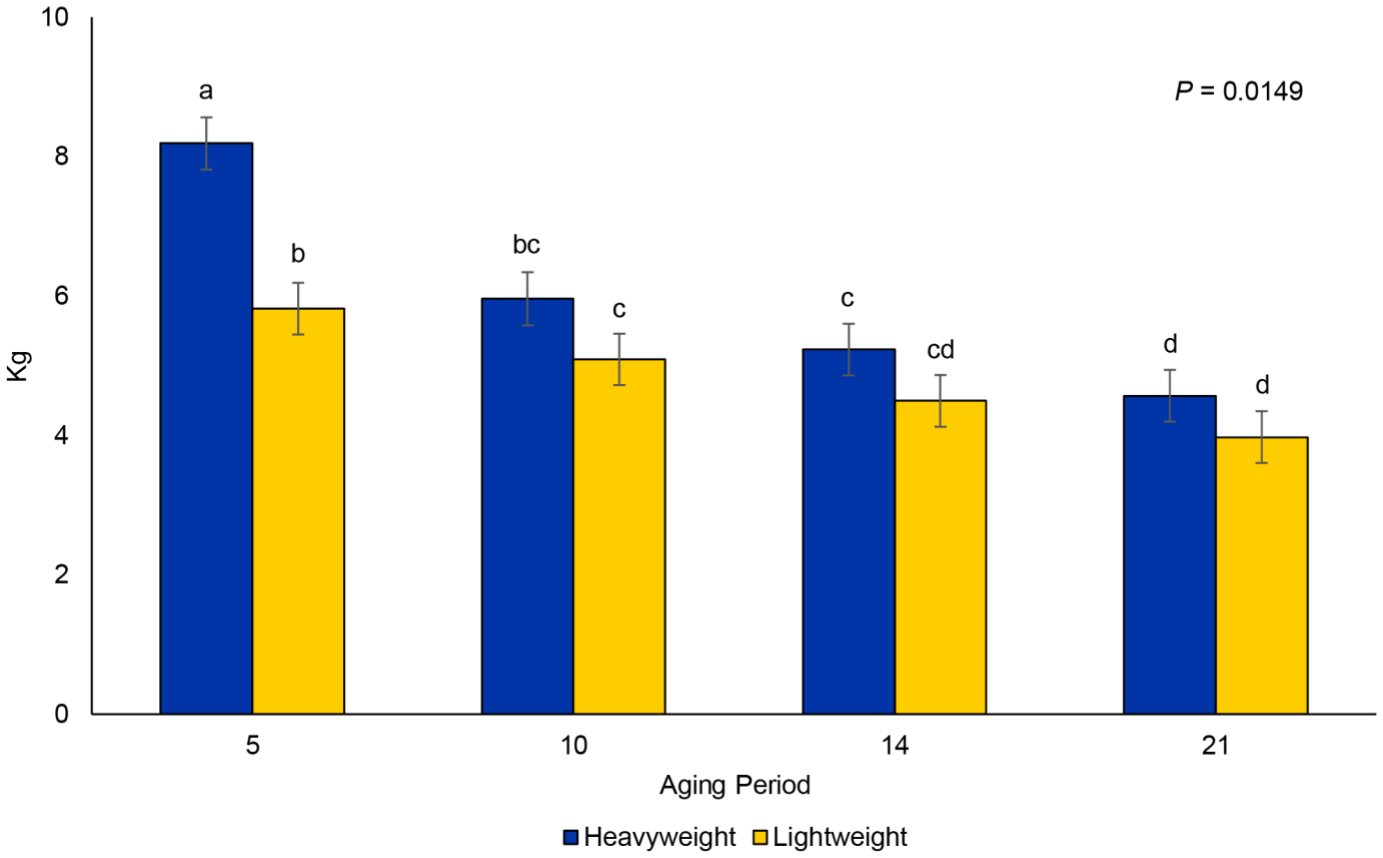

Figure 4 - Effect of hot carcass weight and day of retail display on L* values of eye of round steaks (Semitendinosus) between Heavyweight and Lightweight carcasses