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Carcass chilling method effects on color and tenderness of bison meat

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ABSTRACT

Carcasses were conventionally (C, $n = 9$) or vascularly chilled using the Rinse & Chill® process (RC; n = 9). Muscles (*Longissimus lumborum*, LL; *Triceps brachii*, TB) were processed (LL, steaks; TB, ground), packaged (polyvinyl chloride, PVC; vacuum, VAC), and displayed or stored dark. Measurements included color, purge, pH, sarcomere length, shear force, and cooking loss. Data were analyzed as a split plot design with carcass chilling treatment as whole plot and display day as split plot. Data were analyzed separately by packaging method. RC increased ($P < .05$) cooking loss 1.7% but decreased shear force 24% (C, 42.5 N; $P < .05$) in steaks. RC ground bison packaged in PVC and VAC had greater ($P < .05$) CIE L^*, a^*, and b^* values than C. RC VAC bison steaks had greater ($P < .05$) oxymyoglobin, deoxymyoglobin and decreased ($P < .05$) metmyoglobin than C VAC steaks. RC positively impacted bison steak tenderness and color in ground bison and steaks.

1. Introduction

Bison meat tends to be darker in color than beef (Koch, Jung, Crouse, Varel, & Cundiff, 1995). Pietrasik, Dhanda, Pegg, and Shand (2005) showed that common processes that usually improve meat color stability (injection-enhancement and modified atmosphere packaging) did not have a positive effect on bison steaks. Compared to beef steaks, bison steaks demonstrated faster discoloration, and microbial proliferation was much faster.

Early postmortem after exsanguination the vascular rinse system has been used to rinse out residual blood and deliver substrates that impact various meat quality properties (Farouk & Price, 1994; Koohmaraie, Whipple, & Crouse, 1990; Yancey, Dikeman, Addis, Katsanidis, & Pullen, 2002). The term infusion has been used to describe this process, but it should be understood that because of exsanguination, some of the solution drains out of the vasculature. Farouk and Price (1994) used post-exsanguination vascular infusion to determine the effects on postmortem metabolic changes, water holding capacity, meat color, and palatability in lamb. They found that in both the infraspinatus and *M. Longissimus lumborum* muscles, glycolysis was completed within the first 6 h postmortem when infused with a substrate solution (saccharides, phosphates) whereas in the non-infused control and a substrate solution that included calcium chloride it took 12–24 h for glycolysis to complete. Infused samples were also lighter and yellower than the controls in both fresh and frozen samples.

Some research focused on infusing $CaCl_2$ in lamb, grain-fed Hereford x Angus steer beef, and Brahman-cross beef as a means to enhance proteolysis (Dikeman et al., 2003; Koohmaraie et al., 1990; Koohmaraie, Crouse, & Mersmann, 1989). Dikeman et al. (2003) found that the pH decline was more rapid with the $CaCl_2$ solution and the saccharide, NaCl and phosphate blend solution than the controls for infused beef carcasses. No differences in pH were found at 24 h. Koohmaraie et al. (1990) found that $CaCl_2$ injected beef longissimus muscle accelerated postmortem tenderization as determined by shear force on day 1. In addition, the shear force value of non-injected longissimus muscle decreased by 2.8 kgf during 14 days of postmortem storage whereas the shear value of $CaC1_2$ injected samples decreased by 1 kg.

Yancey et al. (2002) investigated infusion with the 98.52% water, 0.97% saccharides, 0.23% sodium chloride, 0.28% phosphate solution (blend; MPSC, Inc.) while combining vitamin E or vitamin C to influence the flavor profile of beef. They reported that ground beef from blend + E treated carcasses had higher beef-flavor identification than that from non-infused beef carcasses. Blend + C + E treated carcass resulted in greater beef flavor identification than both Blend + E and non-infused carcasses. Vitamin E and vitamin C combined with the blend solution had the potential to positively influence beef flavor identification attribute in ground beef. More recently, Fowler, Claus, and Hopkins (2017) found that Rinse & Chill® lamb had no effect on the rate of pH decline but there was more than a 11-newton reduction in toughness (34% lower shear force) in the *M. longissimus thoracis et lumborum*. Rinse & Chill® also maintained lighter and more yellow longissimus throughout simulated color display in their study. The objective of the present study was to determine the effect of early

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postmortem carcass vascular rinsing and chilling on the color and tenderness of bison bull meat in comparison to meat from conventional carcass chilling.

2. Materials and methods

2.1. Experimental design

Two chilling methods were implemented on carcasses that had an average hot carcass weight of 231.9 kg (standard deviation, 57.5) from 28-month-old bison bulls. Nine carcasses were conventionally chilled (C) and nine were chilled using vascular Rinse & Chill® technology (RC; MPSC, Inc., Hudson, WI) immediately after exsanguination at a commercial plant in Colorado. The RC process involved inserting a catheter into the carotid artery and vascular rinsing out the residual blood from the circulatory system early postmortem using a chilled (3 °C) isotonic substrate solution (98.5% water; balance: glucose, polyphosphates, and maltose; MPSC Inc.) at an application rate of 8% (based on the carcass weight prior to exsanguination). At 24h postmortem, the *M. Longissimus lumborum* (LL) and *M. Triceps brachii* (TB) muscles were excised, vacuum (VAC) packaged, and shipped overnight with freezer ice packs to the University of Wisconsin-Madison (averaged 4.4 °C internal upon delivery). On day 2 postmortem, each individual TB was ground (model 548 J11; Biro Manufacturing Co., Marblehead, Ohio) through two plates (9.53 mm, 4.76 mm). Ground TB (200 g per chilling method) was overwrapped with oxygen permeable polyvinyl chloride film (PVC; oxygen transmission rate, OTR: 22,480 $cm^3/m^2/24$ h at 23 °C; water transmission rate = 496 $g/m^2/24$ h at 37.8 °C and 90% relative humidity; product code 75003815, AEP Industries Inc., South Hackensack, NJ) using a single-roll over-wrapper (product code 38210030, Bunzl-Koch Supplies, Kansas City, MO) on a Styrofoam tray. In addition, a second sample (200 g per chilling method) of the ground TB was VAC packaged (vacuum setting, 10/10; model 2100-C; UltraVac-dual chamber; Koch Equipment LLC., Kansas City, MO) in plastic pouches (2.7 mil thick, OTR 3–6 cc/m2/24 h atm @ 4 °C, 0% relative humidity, blend of very low-density polyethylene and ethylene vinyl acetate copolymer, 18 × 30 cm, product code 9KN81, Sealed Air Corporation). PVC and VAC packaged TB were used for color determination.

Four steaks were cut (2.54 cm thick) from the LL muscles (2 d postmortem) starting from the anterior side. One steak (25.4 mm thick) each was used for color determination (PVC packaged and VAC packaged) and instrumental tenderness and associated cooking loss (VAC packaged) determinations. One steak (VAC packaged) was assigned to sarcomere length determination.

PVC wrapped steaks and PVC wrapped ground bison were continuously displayed in an open-topped refrigerated (1–2 °C) display case (model LCM 1230; Master-Bilt, New Albany, MS) under fluorescent lighting (40 watt, F40/CWX, Sylvania Cool White Deluxe, Danvers, MA) that provided approximately 1076 lx. VAC samples were stored in the dark (1–2 °C).

2.2. Color measurements

Color measurements (CIE $L^*a^*b^*$; reflectance estimators of the chemical states of myoglobin) were obtained on 1, 4, and 7 d except for PVC ground TB which excluded day 7. Six colorimeter measurements and two spectrophotometric measurements were obtained on each LL and TB sample at every time interval. Meat surface color was measured using a colorimeter (model CR-300, 8-mm aperture, 0° viewing angle; Minolta Camera Co., Ltd., Osaka, Japan) calibrated with a standard white plate (No. 18133019; D65 light source; Y = 92.6, x = 0.3162, y = 0.3324) overwrapped with the applicable film. A UV–Visible scanning reflectance spectrophotometer was used to determine the chemical states of myoglobin. The spectrophotometer (model UV-2501, Shimadzu Corporation, Kyoto, Japan) was set to scan from 400 to 700 nm in the reflectance mode (fast scan speed, 1.0 nm sampling interval, 5.0 nm slit width) with an attached integrating sphere (model MPC-2200) and operated with UV Probe software (Version 2.34). The chemical states of myoglobin were estimated by the following reflectance wavelength combinations: deoxymyoglobin (DMb, percentage reflectance at 474 nm /percentage reflectance at 525 nm), metmyoglobin (MMb, % R572 nm/% R525 nm), and oxymyoglobin (OMb, % R610 nm/% R525 nm) recommended by AMSA (2012).

2.3. Purge loss and pH

Other dependent variables included purge (2 d postmortem), pH (7 d postmortem), sarcomere length (9 d postmortem), Warner-Bratzler shear (WBS, 10 d postmortem) and cooking loss (10 d postmortem). Percentage purge was based on the total net weight of the excised muscle in the package before opening the bag and draining the purge. After removing the muscle from the package and allowing it to drain (1 min) the muscle was reweighed to calculated the difference from the net weight to determine the percentage purge (purge weight / net weight times 100). To determine pH, ground samples (in duplicate) were separately homogenized in a mini container (model MC2, Waring Products, Inc., Torrington, CT) using a blender (model 700S, Waring Products, Inc., Torrington, CT). The homogenate was filtered (Whatman no. 1) before readings were taken using a calibrated (4, 7 buffer standards) pH meter (model PB-11-P11-1, Sartorius pH Basic with a glass electrode).

2.4. Laser sarcomere determinations

Samples for laser sarcomere determination (Cross, West, & Dutson, 1981) were cut into roughly 2.5 cm^3 samples and stored in a 5% glutaraldehyde, 0.1 M $NaHPO_4$ buffer (pH = 7.2) solution for 4 h (4 °C). This solution was then replaced with a 0.2 M sucrose, 0.1 M $NaHPO_4$ buffer solution (pH = 7.2) overnight at 4 °C. Muscle fibers (n = 6) were teased out of each fixed sample and measured using a helium-neon laser (model R-30989, 633 nm, 500:1 polarization, 2.0 mW; Newport Corp., Irvine, CA). The distance from the specimen to the diffraction pattern screen was 100 mm and sarcomere length was calculated according to Cross et al. (1981).

2.5. Warner-Bratzler shear force and cooking loss

Steaks were cooked on an electric grill (model GGR50; George Foreman Grill) with the heat dial set a 3.5. A 12-channel thermocouple scanner (model 920000-00; Digi-Sense; Cole-Parmer Instrument Company, Vernon Hills, IL) was used to measure the internal steak temperature by inserting needle probe thermocouples (Type K; Electronic Temperature Instruments LTD West Sussex BN14 8NW UK) into the geometric center of the steak. Four steaks were placed on the grill at a time and each were flipped when the internal temperature reached 41 °C. The steaks were removed from the grill once the temperature was 68 °C. Cooking loss was determined by measuring the raw weight of the steak samples compared to the cooked weight. These steaks were stored overnight in a cooler and brought out in the morning to warm up to room temperature. Eight samples were cut from each steak parallel to the muscle fibers (1-cm wide by 1-cm thick strips parallel to the muscle fibers, minimum length of 2.54 cm) for instrumental tenderness determination (Warner-Bratzler Shear Apparatus, G-R Electric manufacturing, Manhattan, Kansas) with a V-notched blade. Samples were sheared perpendicular to the muscle fibers (AMSA, 2015).

2.6. Statistical analysis

For the statistical analysis, animal served as the experimental unit (random effect). Data were analyzed as a randomized complete block design (RCBD) with chilling method representing the main effect. The

Table 1
Least Square Means on the effects of carcass chilling treatment on two muscles[1].

Dependent variables[2]	LL		TB		
	C	RC	C	RC	SE
pH	5.44[b]	5.43[b]	5.63[a]	5.64[a]	0.012
Purge (%)	0.50[b]	0.88[a]	0.18[c]	0.69[ab]	0.107
Sarcomere Length (μ)	1.77[ab]	1.80[a]	1.61[b]	1.66[ab]	0.059
Cooking Loss (%)	12.74[b]	14.43[a]	na	na	0.574
WBS (N)	42.45[a]	32.12[b]	na	na	2.88

[a-c]Means within a row with unlike superscript letters are different ($P < .05$). SE, standard error of the difference.
[1] Carcass chilling treatment: C = control, RC = Rinse & Chill®; Muscles: LL = *M. longissimus lumborum*, TB = *M. Triceps brachii.*
[2] Dependent variables: pH on raw samples; WBS = Warner-Bratzler Shear.

completely randomized design was used to analyze the effect of chilling method on: ultimate pH, purge, sarcomere length, cooking loss, and WBS. For the dependent color determinations, the data were analyzed as a split plot design in which chilling method (fixed effect) represented the whole plot and day (fixed effect) served as the split plot factor. Main effects (chilling method, day) and their interactions were analyzed. Color data associated with the two packaging methods were analyzed separately because the PVC product was displayed under continuous lighting and the vacuum packaged product was stored in the dark. The SAS MIXED procedure (SAS 9.1.3 Service Pack 3, SAS Institute Inc., Cary, NC, USA) was used to determine significance ($P < .05$) in the model and when significance was found, means were separated using the Least Significant Difference method. Letter assignment to individual means to enable statistical comparisons was achieved using the pdmix800 macro (Saxton, 1998).

3. Results and discussion

3.1. pH

Chilling method did not influence ($P > .05$) the ultimate pH (Table 1). Vascular infusion of beef with a similar solution (Dikeman et al., 2003) also did not alter the ultimate pH. Dikeman et al. (2003) found that the pH decline was more rapid with a calcium chloride solution and a saccharide solution, NaCl and phosphate blend solution than controls for infused beef carcasses but no differences in pH were found at 24 h. Farouk and Price (1994) used post-exsanguination vascular infusion to determine the effects on postmortem metabolic changes and water holding capacity. They found that in both the M. infraspinatus and *M. Longissimus lumborum* muscles, glycolysis was completed within the first 6 h postmortem by infusing 10% vol/wt of a tenderizing blend (NCa; 0.1% maltose, 0.21% glycerin, 0.23% dextrose, 0.14% blend of sodium and potassium tripolyphosphate, no $CaCl_2$ added) whereas in control (Ctr) and NCa plus 0.015 M $CaCl_2$ (WCa) it took 12–24 h for glycolysis to complete. Based on the pH decline findings from both the Dikeman et al. (2003) and Farouk and Price (1994) studies, although not determined in bison, the bison may have had a more rapid pH decline for RC carcasses than in the control carcasses. A faster pH decline could affect protein functionality if the chilled rinsed solution was not able to drop the meat temperature fast enough to counter the impact of a lower pH. This is pertinent as Aberle, Forrest, Gerrard, and Mills (2012) stated that low pH and higher temperature can cause decreased water holding capacity.

3.2. Purge and cooking loss

RC resulted in greater ($P < .05$) purge than C (Table 1) with differences of 0.38% (LL) and 0.51% (TB). RC increased ($P < .05$) cooking loss by 1.7% in the LL. Mixed results have been reported on the impact of RC on purge and cooking loss. In the Farouk and Price (1994) study they found that in samples that were frozen and thawed from infused lamb, RC had greater purge and cooking loss than controls. However, the NCa and WCa treatments had no effect on drip and cooking losses in refrigerated samples. Similarly, Fowler et al. (2017) reported no purge or cooking loss treatment effect associated with lamb LL with a rinse solution identical to that used for bison. Dikeman et al. (2003) reported that the percentage of moisture was greater and the percentage of protein was lower for the longissimus lumborum from the saccharide, NaCl and phosphate blend solution. Although not determined in our study, perhaps the muscles from the RC carcasses also retained some of the rinse solution resulting in an elevated moisture content that contributed to the slight increase in purge and cooking losses.

3.3. Sarcomere length and Warner-Bratzler shear force

Although RC did not affect ($P > .05$) sarcomere length, shorter sarcomeres would have less space to hold water and therefore decrease water holding capacity. RC Bison LL steaks had a significant ($P < .05$) shear force reduction (24%) compared to C. Yancey et al. (2002) using a saccharide, NaCl and phosphate blend solution did not find any difference in the tenderness of the LL from Charolais cattle carcasses. In contrast, Dikeman et al. (2003) reported the LL infused with the saccharide, NaCl and phosphate blend solution from Hereford x Angus steers were less tender than the control but conversely then they found an increase in tenderness in the semitendinosus muscle. More recently, Fowler et al. (2017) reported there was an 11-newton reduction (34%) reduction in toughness (lower shear force) of the lamb LL due to the RC. However, as with our bison sarcomere findings, they also did not find any differences between RC and C lamb. Upon infusion, it has been observed in commercial packing plants that during application of Rinse & Chill that unrestrained appendages exhibit significant visible movement, which appeared to be a contractile response. Perhaps the infusion stimulates the release of calcium from the sarcoplasmic reticulum early postmortem and at a time in which the pH is still relatively high. This early release of calcium would create more favorable conditions for calpain activity and therefore increased tenderization (Koohmaraie et al., 1990).

3.4. Color measurements

For PVC wrapped steaks, RC resulted in lighter (CIE L*) color than C but did not affect CIE a*, b*, estimator of oxymyoglobin, or estimator of metmyoglobin (Table 2). There was an interaction ($P < .05$) with treatment and display for deoxymyoglobin. PVC wrapped RC steaks had a higher estimate of deoxymyoglobin than C on day 1, but no other differences were found on day 4 and 7. Farouk and Price (1994) and Fowler et al. (2017) reported that vascular infused lamb was more yellow and lighter in color than controls. Our results support those of Fowler et al. (2017) in that infusion of carcasses did not affect CIE a* or reflectance estimate of oxymyoglobin or metmyoglobin during display in the LL.

RC vacuum packaged steaks were lighter (CIE L*), redder (CIE a*), had greater oxymyoglobin and deoxymyoglobin content and less metmyoglobin content than C (Table 2). CIE b* results were not significantly different in vacuum packaged bison steaks. Our results also support those of Hunt et al. (2003) who found that RC vacuum packaged beef LL was lighter in color. They also reported that infused beef carcasses (MPSC Inc.) had a lighter red initial appearance.

In PVC and vacuum packaged ground bison (Table 3), RC resulted in lighter ($P < .05$; CIE *L**) and redder (CIE *a**) product than C. RC PVC ground bison had a treatment by day interaction with RC being more yellow on day 4 of display. In addition, RC was more yellow (CIE b*) than C in vacuum packaged ground bison. In contrast, no significant differences were found for PVC ground bison in regards to

Table 2
Least Square Means of carcass chilling treatment[1] effects on CIE values and reflectance estimators of the chemical states of myoglobin[2] on refrigerated packaged bison *M. Longissimus Lumborum* steaks under continuous lighting display (PVC overwrapped) and non-displayed (vacuum packaged, VAC) conditions[3].

Day	CIE values				Chemical states of myoglobin			
	PVC		VAC		PVC		VAC	
	C	RC	C	RC	C	RC	C	RC
	CIE L* (lightness)				Estimator of oxymyoglobin (R610nm/R525nm)			
1	36.48	37.84	35.35	36.55	2.27	2.37	1.51	1.52
4	37.04	38.50	35.72	36.97	2.01	1.82	1.54	1.58
7	37.61	39.75	35.47	37.28	1.69	1.52	1.52	1.61
Overall Trt	37.04^{b}	38.70^{a}	35.51^{b}	36.93^{a}	1.99^{a}	1.90^{a}	1.52^{b}	1.57^{a}
S.E.	0.570		0.350		0.064		0.021	
	CIE a* (redness)				Estimator of deoxymyoglobin (R474nm/R525nm)			
1	19.37	19.47	14.92	15.34	1.12^{b}	1.13^{a}	1.47	1.49
4	16.42	15.84	15.60	16.02	1.10^{a}	1.09^{a}	1.50	1.53
7	13.63	11.39	16.00	16.43	1.09^{a}	1.08^{a}	1.49	1.56
Overall Trt	16.47^{a}	15.57^{a}	15.50^{b}	15.93^{a}	1.10	1.10	1.49^{b}	1.53^{a}
S.E.	0.539		0.194		0.004		0.017	
	CIE b* (yellowness)				Estimator of metmyoglobin (R572nm/R525nm)			
1	7.66	7.70	0.10	0.08	0.81	0.79	0.85	0.84
4	6.84	7.15	0.27	0.23	0.86	0.90	0.82	0.79
7	6.75	6.95	0.41	0.41	0.95	1.03	0.83	0.79
Overall Trt	7.08^{a}	7.27^{a}	0.26^{a}	0.24^{a}	0.87^{a}	0.91^{a}	0.83^{a}	0.81^{b}
S.E.	0.221		0.063		0.018		0.006	

S.E. = Standard error of the difference for overall carcass chilling treatment mean within an individual packaging system and dependent variable.
[a-b]Means within an individual independent measurement system (CIE values or chemical states of myoglobin and individual packaging system) and within a row with unlike superscript letters are different ($P < .05$); Treatment by day interaction ($P < .05$, S.E. = 0.007) for deoxymyoglobin in PVC overwrapped steaks.
[1] Carcass Chilling Treatment: C = Control, RC = Rinse & Chill®.
[2] CIE values and reflectance estimators of myoglobin: higher L*, a* and b* indicate lighter, redder, and yellower, respectively. Estimators of the chemical states of myoglobin determined by the reflectance (R) at the specified wavelengths (474, 572, 610 nm) divided by the reflectance at 525 nm. Greater the ratio value relates to more of that particular chemical state of myoglobin.
[3] Continuous lighting display: Day = 1, 4, 7 days displayed with polyvinyl chloride packaging; Dark storage non-displayed: Day 1, 4, 7 with vacuum packaging.

oxymyoglobin, deoxymyoglobin and metmyoglobin. However, RC vacuum packaged ground bison resulted in greater ($P < .05$) deoxymyoglobin and decreased ($P < .05$) metmyoglobin than C with no differences ($P > .05$) in oxymyoglobin. Butler, Bratzler, and Mallmann (1953) observed that the changes in meats accelerated by bacterial growth included discoloration due to increased rate of metmyoglobin formation, production of off-odors, and slime formation. Phosphates are used in meat products for several reasons such a changing or stabilizing pH, increasing water holding capacity, increasing shelf life, and improving texture and sensory properties (tenderness, juiciness, color, and flavor; Aberle et al., 2012). The Rinse & Chill® solution includes polyphosphates so the possibility exists that this ingredient can account for anti-microbial activity and improved color found in the RC bison product. Feirtag and Pullen (2003) discovered that data collected from two separate commercial beef slaughtering facilities demonstrated reductions of 40.3% ($n = 180$ carcasses) and 41.2% ($n = 100$ carcasses) for aerobic microorganisms on RC carcasses compared to controls. Results from a commercial facility (Feirtag & Pullen, 2003) also demonstrated a

Table 3
Least Square Means of carcass chilling treatment[1] effects on CIE values and reflectance estimators of the chemical states of myoglobin[2] on refrigerated packaged ground bison *M. Triceps brachii* under continuous lighting display (PVC) and non-displayed (vacuum packaged, VAC) conditions[3].

Day	CIE values				Chemical states of myoglobin			
	PVC		VAC		PVC		VAC	
	C	RC	C	RC	C	RC	C	RC
	CIE L* (lightness)				Estimator of oxymyoglobin (R610nm/R525nm)			
1	40.69	41.63	36.14	37.58	1.93	1.95	1.51	1.58
4	39.40	41.30	36.60	38.56	1.48	1.53	1.68	1.67
7	na	na	36.73	37.79	na	na	1.59	1.64
Overall Trt	40.04^{b}	41.46^{a}	36.49^{b}	37.98^{a}	1.71^{a}	1.74^{a}	1.59^{a}	1.63^{a}
S.E.	0.418		0.214		0.046		0.022	
	CIE a* (redness)				Estimator of deoxymyoglobin (R474nm/R525nm)			
1	15.41	15.97	15.40	16.85	1.11	1.11	1.46	1.52
4	9.54	10.34	16.15	17.02	1.08	1.08	1.57	1.59
7	na	na	16.19	17.56	na	na	1.53	1.57
Overall Trt	12.48^{b}	13.15^{a}	15.91^{b}	17.15^{a}	1.10^{a}	1.09^{a}	1.52^{b}	1.56^{a}
S.E.	0.254		0.118		0.004		0.008	
	CIE b* (yellowness)				Estimator of metmyoglobin (R572nm/R525nm)			
1	7.42^{a}	7.51^{a}	0.51	0.69	0.92	0.91	0.85	0.83
4	6.87^{b}	7.68^{a}	0.49	0.68	1.17	1.16	0.80	0.79
7	na	na	0.56	0.82	na	na	0.82	0.80
Overall Trt	7.15	7.60	0.52^{b}	0.73^{a}	1.05^{a}	1.04^{a}	0.82^{a}	0.81^{b}
S.E.	0.154		0.047		0.013		0.003	

S.E. = Standard error of the difference for overall carcass chilling treatment mean on individual packaging system.
[a-b] Means within an individual independent measurement system (CIE values or chemical states of myoglobin and individual packaging system) and within a row with unlike superscript letters are different ($P < .05$); Treatment by day interaction ($P < .05$; S.E. = 0.081) for CIE b* in overwrapped ground bison.
[1] Carcass Chilling Treatment: C = Control, RC = Rinse & Chill®.
[2] CIE values and reflectance estimators of myoglobin: Higher L*, a* and b* indicate lighter, redder, and yellower, respectively. Estimators of the chemical states of myoglobin determined by the reflectance (R) at the specified wavelengths (474, 572, 610 nm) divided by the reflectance at 525 nm. Greater the ratio value relates to more of that particular chemical state of myoglobin.
[3] Continuous lighting display: Day = 1, 4 days displayed with polyvinyl chloride (PVC) packaging; Dark storage non-displayed: Day 1, 4, 7 with vacuum packaging.

67.8% reduction in coliforms on the RC carcasses compared to controls. Recently, Moreira, Connolly, and Claus (2018) found that RC resulted in lower aerobic plate counts on the surface of lean cows compared to the controls.

4. Conclusions

Although the application of Rinse & Chill® may increase cooking loss, this technology has the potential to improve bison meat tenderness. Some other mechanism besides sarcomere length must be involved in the tenderization response. Vascularly rinsing bison carcasses was found to influence the color of meat. Increasing lightness was the most consistent result. Rinse & Chill® has the potential to lighten the color of dark bison and increase redness.

Declaration of Competing Interest

None.

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