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The influence of elevated temperature conditioning on bison (*Bison bison bison*) meat quality

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Abstract

Elevated temperature conditioning (ETC: 10°C until 10 h post mortem) was effectively employed as a means of cooling bison carcasses in order to avoid the cold-induced meat quality defects that are a risk with conventional bison carcass chilling (0–2°C for 24 h). The ETC treatment maintained internal *M. Longissimus lumborum* and *M. Semimembranosus* temperature above 10°C within the first 10 h post mortem. The time/temperature combination did not result in significant evaporative loss, although loss of weight during carcass cooling can represent a practical economic loss. ETC accelerated post-mortem glycolysis and pH decline, and resulted in samples of lighter, more intense red colour than those conventionally chilled. Significant improvement in both initial tenderness and tenderization during ageing was realized with the use of ETC.

Keywords: Bison; Meat quality; Elevated temperature conditioning

1. Introduction

Carcass cooling rate in the early post-mortem period is a major determinant of meat quality due to its effects on biochemical and biophysical processes. Inherent carcass characteristics (size, thickness of lean and fat) are as influential as ambient conditions (Lochner, Kauffman & Marsh, 1980), and affect heat exchange and postmortem carcass temperature decline (Aalhus, 1995). Carcass cooling rate influences glycolytic rate, the resulting rate of pH decline, and proteolytic enzyme activity (O'Halloran, Troy, & Buckley, 1997; Smulders, Marsh, Swartz, Russell, & Hoenecke, 1990). Too early exposure to cold may have negative effects on tenderness (Locker, Davey, Nottingham, Haughey & Law, 1975) due to the effects of cold shortening in the early pre-rigor period (Smulders et al.).

A general rule of thumb for cold shortening prevention states that muscle temperature should be maintained above 10°C within the first 10 h post-mortem. An obvious means of achieving this condition would be to employ elevated temperature conditioning (ETC) by holding dressed carcasses above normal chilling temperature for an appropriate period of time prior to subsequent cooling (West, 1979).

ETC is a means of hastening rigor onset (Chrystall & Devine, 1985) such that development of rigor is near completion at the time of cold exposure, therefore, lowering the risk of sarcomere shortening resulting in toughness. Early studies using ETC attributed tenderizing effects solely to this mechanism (Locker, 1985; Parrish, Rust, Popenhagen & Miner, 1969; Smith, Arango & Carpenter, 1971). More recently, temperature enhanced activity of proteolytic enzymes has been implicated (Dutson & Pearson, 1985; Moeller, Fields, Dutson, Landmann & Carpenter, 1976; Yates, Dutson, Caldwell & Carpenter, 1983).

Overall leanness and uneven subcutaneous fat distribution are characteristic of bison (*Bison bison bison*) carcasses (Hawley, 1986; Koch, Jung, Crouse, Varel & Cundiff, 1995). Since a bison specific carcass processing system has not yet been developed in Canada, commercial carcass cooling conditions are geared towards beef carcasses that are thicker with a more uniform fat cover, introducing the risk of "overchill" as defined by Lochner et al. (1980). West (1979) reported that carcasses with thinner muscling and less fat had the greatest potential for successful ETC application because they typically display a more favourable response to ETC treatment than thicker carcasses.

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The objective of this study was to examine the efficacy of a chilling treatment designed to inhibit potential cold-induced meat quality defects in bison carcasses.

2. Materials and methods

2.1. Slaughter and post-mortem carcass treatment

For the duration of this study, all animals were handled and slaughtered according to the guidelines of the Canadian Council on Animal Care (1993). Twenty bison bulls, averaging 31–32 months of age and with mean liveweight 496.6±5.57 (S.E.M.) kg were recruited from three Alberta feedlot operations, transported by truck to the Agriculture and Agri-Food Canada Lacombe Research Centre (AAFC LRC) in Lacombe, AB, and slaughtered and dressed under simulated commercial conditions. Immediately after carcasses were split and weighed, thermocouples (Hewlett Packard 34970A Data Acquisition Switch Unit, Loveland, CO) were inserted into the *M. Longissimus lumborum* (LL) and *M. Semimembranosus* (SM) of each of four paired sides for continuous monitoring of internal muscle temperature during carcass cooling treatments. Temperature was recorded for 9 h chilling time (to 10 h post-mortem) and 23 h chilling time (to 24 h post-mortem) for LL and SM, respectively. Another thermocouple recorded ambient cooler temperature. Alternate left and right sides were moved to conventional (CONV) cooler conditions (0–2°C until 24 h post-mortem) while the opposite side was exposed to elevated temperature conditioning (ETC) (10–12°C) for the first 9 h of chilling. At 10 h post mortem ETC treated sides were railed into the conventional cooler for the remainder of the chilling time (to 24 h post-mortem).

2.2. Carcass and meat quality measurement

At several times post-mortem [0 time (during exsanguination), 1, 3, 10, and 24 h] small (~50 g) muscle samples were removed from the 13th rib region of the LL using a stainless steel corer. Cores were trimmed of subcutaneous fat and obvious connective tissue and immediately flash frozen in liquid nitrogen to halt metabolic activity. Once frozen, cores were bagged (Whirl-Pak), labeled, and stored at −80°C for later assay of lactate content. Temperature and pH at the sampling site were also measured at these times using an Accumet 1002 pH meter with temperature probe (Fisher Scientific, Edmonton, AB) and Orion Ingold Electrode (Udorf, Switzerland).

At 24 h post-mortem, sides were weighed for cooler shrink loss determination, and ribbed at the 11/12th rib interface. Following a 20 min bloom period, colour of the lean tissue was objectively evaluated (CromaMeter II, Minolta Camera Company, Japan) at three separate locations across the exposed surface with care to avoid areas of clearly visible connective and adipose tissues. CIE L^*, a^*, and b^* (Commision Internationale de l'Éclairage, 1978) values for each side were averaged and the colour ($hue_{ab} = \arctan[b^*/a^*]$) and colour saturation ($chroma_{ab} = [a^{*2} + b^{*2}]^{0.5}$) were calculated.

Also at 24 h, small (~100 g) LL samples were removed from the 12th rib area and immediately prepared for sarcomere length and fibre diameter measurement according to methods reported by Aalhus, Best, Costello, and Jeremiah (1999). Under 400× (fibre diameter) and 1000× oil immersion (sarcomere length) phase contrast magnification (Zeiss Axioskop, Germany), images were captured using Image Pro® Plus (Version 3.0, Media Cybernetics, Silver Springs, MD). For each of these two measurements, images of 10 different myofibres from each sample were captured. Fibre diameter measurements were made using the mouse driven length measurement function. Sarcomere lengths were measured using the fast fourier transformation function that analyzed the repeating striated pattern.

At 48 h post-mortem, entire LL sections were removed from all sides, vacuum packed in oxygen impermeable bags, and stored at 2°C. At 6 days, LL samples were removed from bags and ultimate pH (pH_u) was measured. Serial steaks were cut (2.54 cm thickness) and objective colour measurements were repeated. One steak was placed on a polystyrene tray lined with a dry-lock pad, overwrapped with oxygen permeable film (8000 ml m^{-2} 24 h^{-1}; Vitafilm Choice Wrap, Goodyear Canada Inc., Toronto, ON) and stored for 4 days at 2°C to determine driploss. Three steaks from each LL were removed for shear force determination; one prepared immediately and two vacuum packaged, and stored at 4°C. At 6, 13, and 20 days post mortem, a stainless steel temperature probe (Hewlett Packard 34970A Data Acquisition Switch Unit, Loveland, CO) was inserted into the geometric centre of LL steak samples in order to continually monitor internal temperature during cooking. Steaks were placed on a preheated (200°C) electric grill (Garland ED-30B, Garland Commercial Ranges Ltd., Mississauga, ON), cooked to an internal temperature of 40°C, turned, and cooked to a final internal temperature of 72°C. When the final cooking temperature was reached, temperature probes were removed, steaks were removed from the grill and placed in individual zipper lock bags. Cooked samples were immediately cooled in an ice bath to arrest cooking, then refrigerated (4°C) overnight. The following morning, four to six 19 mm diameter cylindrical cores were removed from each steak with a stainless steel corer oriented parallel to the axis of the grain of the meat so as to allow shearing perpendicular to the fibres. Cores were placed in a Warner–Bratzler shear cell attached to an Instron Model 4301 Materials Testing System (Burlington, ON) with crosshead speed set at 200 mm min^{-1}. Peak shearing force (kg) was recorded.

2.3. Lactate assay

Samples for lactate assay were prepared in duplicate following methods previously described by Dalrymple and Hamm (1973) and Yambayamba, Aalhus, Price and Jones (1996) with the exception that lactate content of samples were read using a YSI 2300 Stat Plus glucose/lactate analyzer (YSI Incorporated, Yellow Springs, OH).

2.4. Statistical analyses

Carcass and meat quality data were analyzed according to a split-plot design using the GLM procedure of SAS (1990) with carcass chilling (ETC or CONV) in the sub plot in order to ensure a within animal control for the treatment. Mean separation ($P < 0.05$) was achieved using linear contrasts with a single degree of freedom.

To determine the effect of ageing time on objective tenderness measures, time (6, 13, or 20 days ageing) was included in the model for the analysis of shear values. In order to further assess shifts in tenderness over the ageing period and within chilling treatments, count frequencies within tenderness categories were determined. Since bison have a similar range in tenderness as beef, tenderness categories were based on extensive beef data within the following boundaries: tender: < 5.6 kg; probably tender: 5.6–< 7.85 kg; probably tough: 7.85–9.6 kg; tough: > 9.6 kg. Frequencies were analyzed by treatment and within time period (6, 13, 20 days) using the chi-square option of SAS (1990).

3. Results and discussion

3.1. Temperature decline

There was a significant ($P < 0.05$) chill treatment effect on LL temperature (Fig. 1) at 3 and 10 h post-mortem.

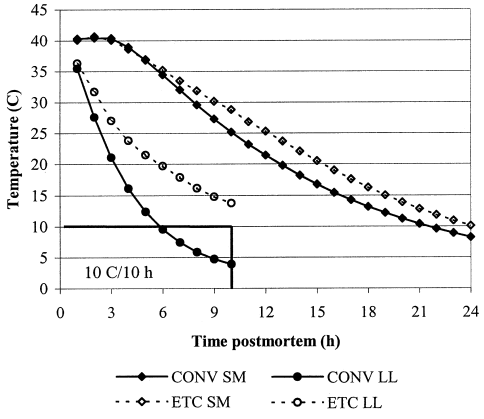

Fig. 1. Post-mortem temperature decline of bison *Semimembranosus* (SM) and *Longissimus lumborum* (LL).

A more gradual decline in temperature of both LL and SM was noted with the use of ETC compared to CONV chilling. ETC was sufficient to maintain internal muscle temperature above 10°C for the first 10 h post-mortem. Only CONV LL dropped below 10°C where cold shortening is a risk (Fig. 1).

During carcass fabrication, an off odour was detected in at least one SM, by an experienced meat technician. Although not quantified in this study, similar cases have been reported in the literature where slow-chilled beef carcasses subsequently developed a sour odour (Jeremiah, Martin & Achtymichuk, 1984; Joseph & Connolly, 1977). Lawrie (1998) described this type of undesirable odour as bone taint and attributed its presence to microbial growth exacerbated by insufficient cooling of deep-seated locations.

3.2. Cooler shrink

The present time/temperature conditions did not result in a statistically significant treatment effect (Table 1; $P > 0.05$) on cooler shrink, but the loss of any carcass weight is a practical concern and represents a loss of saleable product weight. Carcasses exposed to ETC versus CONV chilling have a greater evaporative rate (Newbold & Harris, 1972), and this is a primary argument against widespread implementation of ETC.

3.3. Fibre diameter

No significant chilling treatment effect ($P > 0.05$) on fibre diameter was noted (Table 1). Since maintenance of fibre diameter is a matter of maintaining intracellular hydration, fibres that lost only a marginal amount of moisture during chilling would be expected to display only a marginal loss in fibre diameter, as was the present situation.

3.4. Driploss

No significant chilling treatment effect ($P > 0.05$) on driploss was observed (Table 1). Jeremiah et al. (1984) measured expressible juice following centrifugation of *M. Longissimus* samples from carcasses treated with various degrees of ETC and also found no significant treatment effect. Penny (1977) stated that increased protein denaturation resulting from increased rate of pH decline during elevated temperature conditioning may be partly responsible for an enhanced loss of water holding capacity. According to Lawrie (1998), some loss of water holding capacity is inevitable as pH_u nears the isoelectric point of myofibrillar proteins. The present lack of significant chilling effect on drip loss is, therefore, not surprising considering the similarity of pH_u values between the chilling treatments (Table 1).

3.5. Biochemical traits

ETC resulted in a significantly greater lactate concentration in the LL at 3, 10, and 24 h post mortem ($P < 0.01$; Table 1). Given that enzymes of glycolysis function optimally at or near physiological temperatures, it is not surprising that ETC samples exhibited significantly faster glycolytic activity. The post-mortem muscle pH decline followed a similar pattern as would be expected since the lowering of pH post-mortem is directly related to the concentration of H^+ liberated from lactic acid during post-mortem anaerobic metabolism. At 3, 10, and 24 h post-mortem, pH in ETC samples was significantly lower than in CONV samples ($P < 0.01$; Table 1).

3.6. Colour

Any treatment designed to promote rapid post-mortem decline of muscle pH has potential to cause the development of lighter, redder meat because of the preferential binding of oxygen to myoglobin as opposed to its consumption by mitochondria in low pH conditions (Renerre, 1990). As such, a significant ($P < 0.01$) chill treatment effect was noted (Table 1) for all objective measures of colour at both 24 h and 6 days post-mortem, except hue_{ab} at 24 h ($P > 0.05$). Meat from ETC treated carcasses can be described as being lighter (higher L^*) and of a more intense (higher $chroma_{ab}$) cherry-red (higher hue_{ab}) colour than meat from CONV treated carcasses.

Fields, Carpenter and Smith (1976) observed that ETC enhanced visual appearance and consumer acceptance of beef by promoting a brighter colour in treated samples, a reflection of a small but significant difference in pH. West (1979) noted a reduction in beef colour variability with the use of ETC, but stated that the overall treatment effect was minimal when the elevated temperature employed was less than 30°C. At the time of carcass grading, 24 h post-mortem, the colour objectively assessed in ETC carcasses was preferable (brighter red) to that of CONV carcasses. Because lean colour is a component of the current Canadian bison grading system, the ETC treatment could result in different grade assignment. This significant colour difference persisted to 6 days post-mortem. It is reasonable to assume that some product may be marketed at this time and, because consumers prefer lean meat to appear bright red, the effect of the ETC treatment on colour development may be of commercial importance.

Table 1
The effects of chill treatment on Bison *Longissimus lumborum* quality and biochemical traits

	CONV[a] ($N=20$)	ETC[b] ($N=20$)	S.E.M.	P
Cooler shrink (g kg^{-1})	20.58	21.01	0.42	0.47
Fibre diameter (μm)	84.74	82.88	1.35	0.34
Drip loss ($mg.g^{-1}$)	20.48	21.66	1.07	0.45
Lactate ($\mu molg^{-1}$)				
0 h	15.26	15.26	0.00	0.28
1 h	28.08	28.60	1.17	0.76
3 h	59.80	67.70	1.91	< 0.01
10 h	79.76	92.32	1.80	< 0.01
24 h	89.70	95.80	1.10	< 0.01
pH				
0 h	6.88	6.88	0.00	0.65
1 h	6.61	6.62	0.02	0.89
3 h	6.32	6.16	0.03	< 0.01
10 h	5.90	5.67	0.04	< 0.01
24 h	5.59	5.54	0.01	< 0.01
6 days	5.52	5.54	0.01	0.26
Colour				
L^* 24 h	30.35	31.83	0.17	< 0.01
Hue 24 h	23.36	23.42	0.24	0.87
Chroma 24 h	22.06	25.26	0.28	< 0.01
L^* 6 days	31.72	32.99	0.15	< 0.01
Hue 6 days	22.23	22.97	0.15	< 0.01
Chroma 6 days	23.11	24.74	0.20	< 0.01
Shear (kg)				
6 days	8.22	7.04	0.32	0.02
13 days	7.28	5.68	0.35	< 0.01
20 d	5.90	5.13	0.37	0.16
Sarcomere length (μm)	1.63	1.72	0.04	0.15

[a] Conventional chilling treatment.
[b] Elevated temperature conditioning treatment.

3.7. Tenderness frequency, sarcomere length, shear force

Plotting tenderness frequency counts by treatment (Fig. 2) clearly illustrates the shift towards improved tenderness with increasing ageing time. This improvement in tenderness is accelerated by ETC and demonstrates the practical importance of the treatment for reducing postmortem ageing time while maintaining product tenderness. While treatment effect on frequency counts within shear value categories was not statistically significant in any given time period in this analysis, the overall effect of ageing time on tenderization was highly

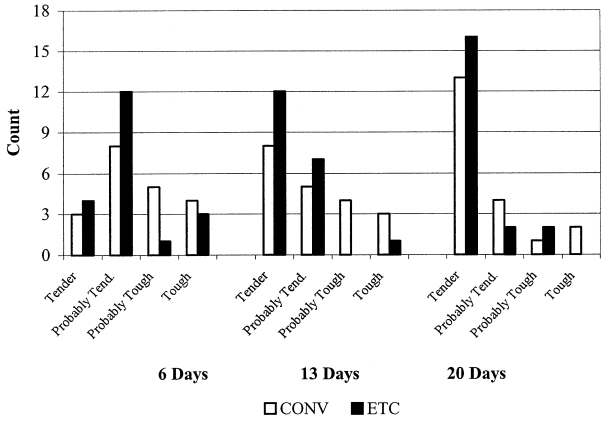

Fig. 2. Tenderness frequency counts of bison *Longissimus lumborum* (LL) steaks during ageing.

significant ($P < 0.01$). For both CONV and ETC chilling treatments there was a shift towards a greater number of "tender" samples over time, however, a greater number of "tender" and "probably tender" samples were found within the ETC treatment group.

Koohmararie, Babiker, Merkel, and Dutson (1988) hypothesized that both lysosomal enzymes and calcium-dependent proteases (calpains) were likely candidates as the factor resulting in increase in tenderness observed with postmortem ageing. It has been suggested (Moeller et al., 1976; Yates et al., 1983) that lysosomal enzyme systems are released and function optimally at relatively higher cooling temperatures, and that the application of ETC exploits this process producing an enhanced ageing effect. Following investigation, Koohmaraie et al. concluded that the activity of the calpains, not lysosomal cathepsins, was the primary determinant of tenderness development during ageing (Koohmaraie et al.). With ETC treatment it is possible that the high temperature conditions prevailing while pH remains relatively high in the early postmortem period permit a "head start" effect on the proteolytic tenderization of ETC samples.

While mean sarcomere length did not differ significantly between chilling treatments (Table 1), a beneficial effect of ETC versus CONV in terms of a significantly decreased shear force requirement was observed (Table 1), and has been noted in the literature (Hostetler, Carpenter, Smith & Dutson, 1975; Parrish, Young, Miner, & Anderson, 1973; Smith, Kastner, Hunt, Kropf & Allen, 1979). There was improvement in shear ($P < 0.05$) of 14 and 22% at 6 and 13 days, respectively, with the use of ETC as compared to CONV carcass chilling. Upon examination of minimum and maximum shear values, it was observed that ETC samples had a lower shear value than CONV samples at all measurement times. The application of CONV carcass chilling produced an initial minimum shear value of 10.44 kg, well within the "tough" category (> 9.6 kg), while the maximum shear value reached was 18.47 kg at 13 days. The maximum value encountered in the ETC treatment was 13.81 kg (at 6 days) while the minimum values in all time periods were well within the "tender" category (< 5.6 kg). The gap between minimum and maximum values within the ETC treatment was reduced as ageing proceeded (9.49, 8.58, 6.04 kg), while the gap between minimum and maximum fluctuated over time after CONV treatment (7.55, 13.02, 8.56 kg). Using this observation as an indicator of consistency of product response to chilling treatment, ETC could be recommended for improving the uniformity of tenderness with ageing.

4. Conclusions

Loss of weight during carcass cooling can represent a practical economic loss, but the moderate ETC time/temperature combination discussed was not sufficient to result in a statistically significant evaporative loss. Another practical concern with the ETC technique is the possibility of off odours developing in deep carcass locations, and the unpredictable nature of this type of defect. Significant improvement in both initial tenderness and tenderization during postmortem ageing was realized with the use of this treatment when compared to CONV carcass chilling. Based on tenderness frequency data, ageing beyond two weeks is not necessary when ETC is used in the immediate postmortem period. Beyond this point, improvement in shear force is minimal while still incurring refrigerated storage costs. Elevated temperature was effectively employed as a means of conditioning bison carcasses while avoiding serious cold-induced meat quality defects.

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