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EFFECT OF HOT BONING AND ELEVATED BRINE TEMPERATURE ON THE PROCESSING, STORAGE AND EATING QUALITY OF CURED BEEF HINDQUARTER (M. *BICEPS FEMORIS*) AND FOREQUARTER (M. *PECTORALIS PROFUNDUS*) MUSCLES

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ABSTRACT

Eating quality, processing and storage attributes were examined in hot- and cold-boned beef (90 min and 24 h postmortem, respectively) post from two muscles (M. *biceps femoris* [BF] and M. *pectoralis profundus* [PP]) injected with curing brines at conventionally chilled (2–4C) and elevated temperature (15–17C) curing brines, stored over 21 days (4C). The pH/temperature profiles showed all hot-boned experimental treatments were outside of the reported ranges for the occurrence of cold or heat shortening. Hot-boned beef did not exhibit any significant added or reduced functionality compared to conventionally-boned beef i.e., cook loss and final yield unaffected in BF and PP muscles. Cold-boned BF products were harder ($P < 0.05$) than hot-boned; however, this was not supported by sensory analysis. Samples prepared with elevated brine temperatures had a detrimental effect on the sensory characteristics of PP hams. Principal component and hierarchical cluster analyses (PCA and HCA, respectively) were used to better visualize the underlying structure between the quality measurements and samples, showing gradual product deterioration over storage. Although the combination of hot boning and higher brine temperature led to expected higher bacterial numbers, microbial stability of the product was maintained after 21 days.

PRACTICAL APPLICATIONS

Commercial demands for reduced energy usage and chill requirements were the primary factors for the development of hot boning. Hot-boned meat also has the advantage of being in a pre-rigor state which is known for its improved functional qualities. While it is practiced in some countries, predominantly Australia and New Zealand, it still remains underdeveloped in some territories, such as Ireland. Concerns over its widespread adoption center on: (1) training costs; (2) improved hygiene standards; and (3) increased risk of toughness due to the contraction of some muscles when they are removed from skeletal restraint. However, it is estimated that a reduction in chill space requirements could be as much as 50%, resulting in cumulative savings in refrigeration energy, capital costs and quicker plant turnover. The outcomes of this work were to develop products using techniques that would be a huge economic benefit to the meat industry.

INTRODUCTION

Despite offering potential advantages in production costs and in functional properties of the meat, hot boning i.e., the removal of muscles before the onset of *rigor mortis* (pH > 6.0), has not been widely adopted by meat plants in Ireland. One of the main post-slaughter reasons for the variability in meat tenderness is the result of how muscles

are treated before the onset of rigor (Narayan *et al.* 2013). Concerns center on reports of less tender meat associated with accelerated boning are well documented (Seidemen and Cross 1982) and are usually attributed to cold shortening. Locker and Hagyard (1963) first observed cold shortening in the unrestrained muscle, noting pre-rigor muscles could shorten by as much as 50% when exposed to temperatures around 0C. Later work (Bendall 1972) described how cold shortening is most common in muscles held at temperatures <10C. Therefore, careful management of pH and temperature is required during pre-rigor period (White *et al.* 2006a).

The type of processing strategy adopted will also influence the quality of the final product when utilizing pre-rigor meat. For example, when a hot-boned muscle is conventionally wet injection cured, chilled aqueous brine (2–4C) would be introduced. This could dramatically reduce the temperature of the muscle over a very short period of time, depending on the rate of injection and thermal transfer rate of individual muscles (Keenan *et al.* 2010). Furthermore, longer tumbling times or curing processes (e.g., immersion curing) could lead to sufficient temperature decline to induce cold shortening. Injecting brine at elevated or ambient temperatures may slow the decline and also cut down on additional refrigeration costs of the brine. Therefore, the use of pre-rigor meat and warm brine could act as a form of temperature conditioning that may offset any potential deleterious effects associated with hot boning, such as cold shortening. Combinations of hot boning and temperature conditioning have been previously reported by Seidemen *et al.* (1989) who reported an increase in tenderness in some muscles.

The justification for this works comes from the limited publications involving processing with warm or heated brines. Furthermore, a major concern centers on the microbiological safety of the product over time when combining hot-boned meat with ambient or elevated brine temperatures. The objective in this study was to determine the effects using elevated brine and hot boning on the appearance, eating quality, storage and safety of cured beef.

MATERIALS AND METHODS

Preparation of Cured Beef Hams

Heifers ($n = 8$) were slaughtered at Teagasc's pilot abattoir in Ashtown. Carcasses were centrally split into left- ($n = 8$) and right-hand sides ($n = 8$). Two muscles, M. *biceps femoris* (BF) and M. *pectoralis profundus* (PP), were excised and randomized. The BF hams weighed in the range 5.3–7.4 kg and the PP hams 2.4–3.5 kg. Four treatments were assigned i.e., control (cold-boned muscles cured with conventional brine [2–4C]), cold-boned muscles cured with elevated temperature brine (15–17C), hot-boned muscles cured with conventional brine and hot-boned muscles cured with heated brine, employing a balanced incomplete block design. Each treatment occurred in four repetitions and in eight blocks and every treatment occurred in a block with every other treatment, to give balance to the design.

Hot-boned muscles were removed 90 min postmortem and processed directly. Muscles were pumped to 115% of their green weight with a brine solution, using a Dorit Injecto-mat 20-needle brine injector (Dorit Food Processing Equipment Ltd., Killwangen Switzerland). Brine solutions were designed to give the following concentration of ingredients, % by weight, in the injected meat: sodium chloride 2.0, phosphate 0.3, dextrose 0.2, sodium ascorbate 0.05 and sodium nitrite 0.015. The temperature of the elevated temperature brines (15–17C) was maintained by water-bath heating element (Grant Instruments, 119551001, Cambridge, UK.). Conventional brines were prepared 24 h post injection and chilled to 2–4C. Injected hot-boned muscles were continuously tumbled with a Dorit VVT-50 vacuum tumbler (Dorit Food Processing Equipment Ltd.) under vacuum for 1 h at ambient temperature. For cold boning, the carcasses were chilled at 0–2C before excision of the muscles at 24 h postmortem. These muscles were injected as previously described and tumbled under chill (2–4C). All treatments were packaged in elasticated netting, vacuum packed, heat shrink wrapped and steam cooked in an Jugema Aditec MIC 2500 oven (Jugema, Sroda Wlkp, Poland) at 85C to a (ham) core temperature of 72C. Hams were subsequently chilled (2–4C) for 24 h.

pH and Temperature Measurement

pH (Thermo Orion Multimeter 250A, Orion Research Inc., Duisburg, Germany) and temperature (Minitherm HI8751, Hanna Instruments, Cluj-Napoca, Romania) measurements were performed on muscles immediately after boning, injection and tumbling. Hot-boned muscles were measured 90 min postmortem, while cold-boned muscles were measured 24 h postmortem.

Final Yield and Cook Loss

The final yield was calculated as differential weight between the green weight and the final chilled weight. Cook loss was calculated as the differential weight between the cured beef hams after cooking and the final chill weight.

Measurement of Chemical Composition

Chemical analyses were carried out on cooked samples. Two 20-mm-thick slices of each ham weighing ca. 300 g were blended (Robot Coupe Blixer 4 3000 mono, Bourgogne,

France). Moisture/fat (Smart Trac 5 Model 907875, CEM Corporation, Matthews, NC), salt (Mohr titration) and protein contents (LECO Nitrogen Determinator, St. Joseph, MI) were determined as described by Keenan *et al.* (2010). Nitrite content was determined by a purple azo dye colorimetric titration using a Foss FIAstar 5000 (Foss UK, Warrington, UK) flow-rate injection analyzer. The azo dye was measured at 540 nm (Ruzicka and Hansen 1981) and expressed as mg/kg.

Sensory Analysis

An eight-member panel experienced in sensory analysis of meat products was employed to evaluate the cooked, cured beef hams using the protocol of the American Meat Science Association (AMSA 1995). Three preliminary training sessions were conducted to familiarize the panelists with the procedure. For the test sessions proper, four samples, comprising a 2-mm-thick slice for each of the treatments in the trial, were presented in random order in each session. Samples were rated on 6-point descriptive scales for cured color, tenderness, juiciness, saltiness, overall flavor, overall texture and overall acceptability (6 = Very pale / tender / juicy / extremely salty / good / good / acceptable; 1 = Very dark / tender / dry / not salty / very poor / poor / not acceptable). Samples were tested on day 1 (results reported as sensory analysis), and days 7, 14 and 21 (reported as sensory analysis for storage period).

Instrumental Measurement of Texture and Color

Texture profile analysis (TPA) and Warner–Bratzler Shear Force (WBSF) measurements were carried out using an Instron Universal Testing Machine (Models 5543 and 4464, respectively, Instron Ltd., High Wycombe, UK). For TPA (Keenan *et al.* 2010), two slices of 20 mm thickness were taken. Five beef cores (diameter 25 × height 20 mm) per slice, representing the whole slice, were compressed to 50% of the original height using a 25-mm circular flat disk attached to a 500 N load cell with a crosshead speed of 50 mm/min. For WBSF values (White *et al.* 2006a), one meat slice of 25 mm thickness was taken from each cooked ham. Eight representative cores (12.5 mm in diameter) were removed from the slice and sheared, using a 500 N load cell and a crosshair speed of 200–250 mm/min. Shear values were reported in newtons (N) as the mean of value for six cores.

Color measurements were carried out on cooked samples. Color was measured on a dual beam xenon flash spectrophotometer (Ultrascan XE, Hunterlab, Reston, VA) and the International Commission on Illumination L^*, a^*, b^* system. Sample slices were placed against the instrument aperture with a 25-mm porthole, D_{65} illuminant, 10° observer angle and Universal Software version 4.1 (Hunter Associates Laboratory, Inc., Reston, VA). Six measurements representing the whole slice were taken on each of the two 20-mm-thick slices. Color measurements were taken on days 7, 14 and 21.

Storage and Microbiological Evaluation

Subsamples from the original hams were carved for sensory (10 slices, 2 mm thick; ca. 5 g each) and texture (2 slices, 20 mm thick; ca. 50 g each). Samples were modified atmosphere packaged in laminated retail polystyrene trays (155 × 110 × 37 mm) (Linpac 2–37 EPS; Linpac plastics, West Yorkshire, UK) and double gas flushed using an Ilpra food pack 400 V/G packaging machine (Ilpra s.p.a., Vigevano, Italy) Packs were flushed with an atmosphere of 80% CO_2: 20% N_2 and sealed with a barrier film (8 cc cm^3/m^2 / 24 hr/atm at 23C, 75% relative humidity; Versatile Packaging, Monaghan, Ireland). All packs were placed in random order in a chilled front display cabinet (Cronos fan assisted cabinet, Criosbanc, Padova, Italy) for 21 days display. Average display cabinet temperature was 3.2C. Lighting (58W delux cool white bulbs, color temperature: 4200K, Philips, Eastern Electric, Dublin, Ireland) was provided in the retail display cabinet to reflect retail display conditions. Lighting remained consistent for the entire storage period with an insulating blind used to ensure a uniform temperature was maintained in the cabinet. Microbiological analysis was carried out on days 14 and 21 using variations of accredited methodologies i.e., Total Viable Counts (ICMSF 1987), *Escherichia coli* (ISO 4832 1999), *Staphylococcus aureus* (BS 5763: Part 7 1983), *Listeria monocytogenes* (Lovett 1987) and *Salmonella* species (ISO 6579 1990). Confirmation of microbiological stability was followed by sensory analysis and instrumental measurements of texture and color.

Statistical Analysis

Analysis of variance of the effect of boning method and brine temperature as well as their interactions on processing and sensory properties were performed using SAS software (SAS for Windows version 8.1, SAS Institute Inc., Cary, NC) to analyze the experimental data. Sources of variation were identified by a probability of 0.05 or less and significant differences between the means were identified using the standard error of the means. Principal component (PCA) and hierarchical cluster analyses (HCA) were also applied to the storage data using XLStat software (version 2011, Paris, France) as described by Keenan *et al.* (2012).

RESULTS AND DISCUSSION

Compositional Analyses

Compositional analyses for cooked beef hams prepared from two muscles are presented (Table 1). Boning method had no effect on nitrite content (after tumbling), protein and salt content (after cooking) of both muscle products. Hot-boned PP products had higher ($P < 0.05$) fat content whereas hot-boned BF products had lower ($P < 0.05$) moisture content than cold-boned products. However, the differences were small in practical terms. Salt content was lower ($P < 0.001$) after tumbling in hot-boned in BF samples than cold-boned but not significant after cooking. This implies that salt penetrated the sample by diffusion over the cooking period as it is a linear progression in the dry and wet curing of meat (Tyskiewicz *et al.* 1998). Hot-boned BF beef was shown to have higher ($P < 0.05$) nitrite content after tumbling than cold-boned beef. This is supported by Arnau *et al.* (1998), who observed at lower pH, nitrite is more easily transformed into nitrous oxide, which in turn reacts with the meat components in color formation. In the higher pH hams, the nitrite is less reactive and could migrate to the center of the product.

Brine temperature had no effect on composition of BF samples. For the PP hams, fat content was higher ($P < 0.01$) in hams injected with conventional brine compared to those using elevated temperature brine. This could be attributed to natural variation in seam and intramuscular fat content of the muscles. PP hams also had higher ($P < 0.01$) nitrite content after tumbling in samples using elevated temperature brine compared to their conventional counterparts. Overall, the nitrite content of beef was higher after tumbling than after cooking for both muscles which merely reflects its reduction and subsequent formation of the stable cured color pigment nitrosyl myochromogen (Honikel 2010). There was an interactive effect on moisture content between boning method and brine temperature in that the combination of conventional brine and cold boning resulted in lower moisture in BF products. This is an unexpected result as combinations of hot boning and conventional brine temperature should result in a faster rate of temperature decline. This would retard lactic acid build up, resulting in slower pH decline and therefore, lead to higher water-holding capacity in the meat (Hamm 1981).

pH, Temperature and Yield Analyses

Results for pH/temperature profiles during cured beef processing in BF and PP hams are presented in Fig. 1a,b. Prerigor meat is in a biochemically dynamic state and is very dependent on the interactions of pH, time and temperature (White *et al.* 2004). As expected, temperature values were highest ($P < 0.001$) for hot-boned meat compared to cold-boned, ranging between 35 and 36C in the former (Fig. 1a)

TABLE 1. EFFECT OF BONING METHOD AND BRINE TEMPERATURE ON CHEMICAL COMPOSITION OF CURED BEEF (M. *BICEPS FEMORIS* BF AND M. *PECTORALIS PROFUNDUS* PP)

	Moisture (%)		Fat (%)		Protein (%)		Salt (%)				Nitrite (mg/kg)			
							After tumbling		After cooking		After tumbling		After Cooking	
Treatment	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP
A: Boning Method														
HB	69.6	69.1	1.2	1.7	24.9	24.2	1.3	2.6	2.2	2.6	65.4	63.0	27.3	16.8
CB	70.7	69.8	1.3	1.2	24.6	24.5	2.1	2.8	2.0	2.5	47.7	72.0	13.6	12.9
SL	*	ns	ns	*	ns	ns	***	ns	ns	ns	ns	ns	*	ns
B: Brine Temperature														
2–4C	70.3	69.5	1.4	1.8	24.5	24.5	1.6	2.7	2.0	2.4	46.8	36.0	15.1	19.0
15–17C	69.8	69.4	1.2	1.1	25.0	24.2	1.8	2.6	2.1	2.7	66.2	98.0	25.8	10.6
SL	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	**	ns	ns
Interactions A × B														
SL	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Samples														
HB 2–4C	69.5	69.0	1.3	2.2	24.7	24.4	1.4	2.6	2.0	2.2	48.4	35.4	16.4	16.3
HB 15–17C	69.7	69.2	1.1	1.2	25.1	24.0	1.2	2.5	2.3	2.9	82.5	90.3	38.3	17.3
CB 2–4C	71.1	69.9	1.5	1.3	24.3	24.6	1.7	2.8	2.1	2.5	45.3	36.9	13.9	21.7
CB 15–17C	69.8	69.7	1.2	1.0	24.8	24.5	2.4	2.8	1.9	2.5	50.1	106.3	13.3	4.0
SEM	0.20	0.21	0.14	0.14	0.18	0.28	0.13	0.13	0.10	0.10	7.77	11.8	3.51	3.69

*, **, ***, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

CB, cold boning; HB, hot boning; ns, not significant; SEM, standard error of means; SL, significance level;

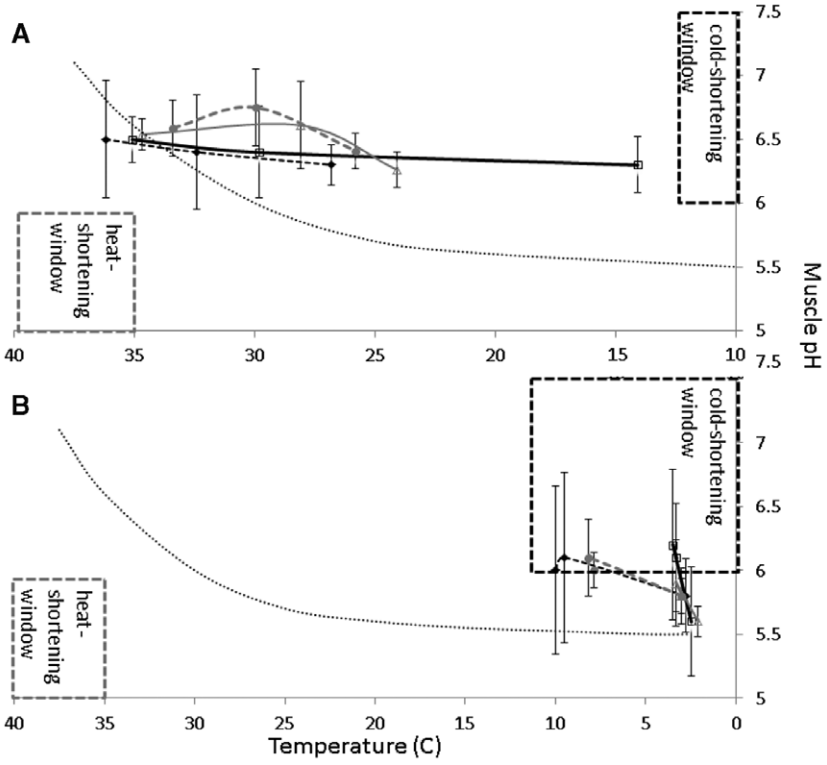

FIG. 1. pH/TEMPERATURE PROFILES FOR (A) HOT- AND (B) COLD-BONED CURED BEEF FROM M. *PECTORALIS PROFUNDUS* (PP)
Beef injected with conventional (2–4C) (—▫—) and elevated (15–17C) (-·▪·-) brine temperatures and from M. *biceps femoris* (BF) injected with conventional (2–4C) (——) and elevated (15–17C) (-·-) brine temperatures, with cold/heat shortening windows and optimum temperature decline (·····) taken from Thompson (2002).

and 3–4C in the latter (Fig. 1b). The temperature of the brine affected the decline in muscle temperature after injection ($P < 0.05$) and after tumbling ($P < 0.05$) with combinations of elevated temperature brine and hot boning retarded temperature decline to a greater extent than all other treatments. The same trends for temperature were observed for PP muscles. However, temperature decline when combined with conventional brine injections was more pronounced in these hams, which is most likely due to the larger surface area to volume ratio, compared to the BF muscles, allowing for more rapid heat loss. Final pH was higher ($P < 0.001$) for hot-boned BF and PP ($P < 0.01$) samples compared with cold-boned, as expected. Higher pH values in hot-boned meat are expected as the production of lactic acid causes the pH of muscles to decrease to 5.4–5.7 and this occurs gradually over the 24-h chilling period that muscles conventionally-boned are subjected (Varnam and Sutherland 1995). The higher muscle temperature coupled with its increased pH (pH >6.2) during the pre-rigor phase has a large impact on the extent of cold shortening (White *et al.* 2006b), and is recommended that muscle temperature does not fall below 10–15C while pH is >6 (Honikel *et al.* 1986; Thompson 2002). This is in agreement with the data in the present study. Some increased pH was observed in cold-boned muscles which placed them within the reported (Thompson 2002) cold-shortening window (Fig. 1b). However, as these muscles had already entered *rigor mortis*, this would not induce a cold-shortening effect. No interactive effects were observed between boning method and brine temperature with respect to pH/temperature in both BF and PP beef.

Brine uptake, cook loss and yields were not affected by boning or brine temperature treatment in both BF and PP products with no interactive effects observed between the two treatments (Table 2). In general, this study did not show any significant improvement in water-holding in pre-rigor meat. These findings are contrary the majority of literature evidence, which suggest claim improved functionality rather than reduced or none at all. However, the findings in these publications are often related to products such as beef steaks or hams that did not undergo further processing such as curing. West (1983) suggested that the advantages of reduced moisture loss for hot-boned meat may be seen in the early stages of processing but these advantages are often offset in latter processing. Boles and Swan (1997) investigated combinations of temperature-modified brines and pre-rigor meat and reported no effect of brine temperature on cook yield in injected pre-rigor roast beef hams which is in agreement with the findings of the present study. These authors surmised that combinations of pre-rigor meat and cold or conventional temperature (4C at 10% injection level) brine would be insufficient

TABLE 2. EFFECT OF BONING METHOD AND BRINE TEMPERATURE ON BRINE UPTAKE, COOK LOSS AND YIELD (%) OF CURED BEEF (M. *BICEPS FEMORIS* BF AND M. *PECTORALIS PROFUNDUS* PP)

	Brine uptake (%)		Cook loss (%)		Yield (%)	
Treatment	BF	PP	BF	PP	BF	PP
A: Boning Method						
HB	15.7	15.4	21.5	27.0	85.0	80.5
CB	16.0	15.9	23.2	28.5	87.1	81.6
SL	ns	ns	ns	ns	ns	ns
B: Brine Temperature						
2–4C	16.1	15.9	21.5	26.4	86.5	82.0
15–17C	15.6	15.5	23.2	29.0	85.7	80.1
SL	ns	ns	ns	ns	ns	ns
Interactions $A \times B$						
SL	ns	ns	ns	ns	ns	ns
Samples						
HB 2–4C	15.6	15.5	20.9	25.5	84.2	81.2
HB 15–17C	15.9	15.4	22.2	28.4	85.9	79.7
CB 2–4C	16.7	16.2	22.2	27.4	88.8	82.8
CB 15–17C	15.4	15.6	24.1	29.7	85.5	80.4
SEM	0.28	0.42	0.57	0.74	0.70	0.82

CB, cold boning; HB, hot boning; ns, not significant; SEM, standard error of mean; SL, significance level.

to induce cold shortening in the muscle i.e., reducing subsequent muscle temperature by only 5C. This result confirms temperature data observed in this work (Fig. 1a,b) in which the product pH/temperature profiles avoid the cold and hot shortening windows described by Thompson (2002).

Sensory Analysis

Table 3 shows sensory data of BF and PP hams. In general, no effects of boning and brine temperature were observed for the sensory attributes i.e., tenderness, saltiness, overall flavor, texture and acceptability for either muscle. This is in

TABLE 3. EFFECT OF BONING METHOD AND BRINE TEMPERATURE ON SENSORY† QUALITY OF CURED BEEF (M. *BICEPS FEMORIS* BF AND M. *PECTORALIS PROFUNDUS* PP)

	Cured color		Tenderness		Juiciness		Saltiness		Overall flavor		Overall texture		Overall acceptability	
Treatment	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP
A: Boning Method														
HB	2.3	3.2	4.2	3.8	3.9	3.9	3.8	3.7	3.2	3.4	3.6	3.7	3.3	3.4
CB	2.7	3.0	3.9	3.5	4.1	3.3	4.0	3.3	3.1	3.4	3.6	3.6	3.1	3.3
SL	**	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns
B: Brine Temperature														
2–4C	2.6	2.8	4.1	4.2	4.3	4.3	3.7	3.9	3.3	3.6	3.6	4.0	3.3	3.7
15–17C	2.5	3.4	4.0	3.1	3.8	2.9	4.0	3.2	3.1	3.2	3.5	3.3	3.1	3.1
SL	ns	***	ns	***	**	***	ns	***	ns	*	ns	***	ns	**
Interactions A × B														
SL	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
Samples														
HB 2–4C	2.3	3.0	4.4	4.4	4.0	4.5	3.4	3.9	3.3	3.7	3.5	4.0	3.3	3.8
HB 15–17C	2.3	3.3	4.0	3.3	3.8	3.2	4.2	3.6	3.1	3.1	3.6	3.3	3.2	3.0
CB 2–4C	2.8	2.6	3.8	4.0	4.5	4.1	4.0	3.8	3.2	3.5	3.7	3.9	3.2	3.6
CB 15–17C	2.7	3.4	3.9	2.9	3.8	2.6	3.9	2.8	3.0	3.3	3.4	3.3	3.0	3.1
SEM	0.08	0.09	0.10	0.12	0.09	0.12	0.11	0.12	0.10	0.09	0.10	0.09	0.10	0.10

*, **, ***, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

† Cured color, tenderness, juiciness, saltiness, overall flavor, overall texture and overall acceptability were evaluated by means of 6-point scales (6 = Very pale / tender / juicy / extremely salty / good / good / acceptable; 1 = Very dark / tender / dry / not salty / very poor / poor / not acceptable).
CB, cold boning; HB, hot boning; ns, not significant; SEM, standard error of means; SL, significance level.

TABLE 4. EFFECT OF BONING METHOD AND BRINE TEMPERATURE ON INSTRUMENTAL TEXTURE OF CURED BEEF (M. *BICEPS FEMORIS* BF AND M. *PECTORALIS PROFUNDUS* PP)

	Hardness (N)		Springiness (mm)		Cohesiveness		Gumminess (N)		Chewiness (J)		*L**		*a**		*b**	
Treatment	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP
A: Boning Method																
HB	89.8	139.6	5.2	5.4	0.45	0.43	40.2	60.5	189.0	341.0	47.5	50.8	11.9	11.6	9.3	8.9
CB	103.0	129.7	4.6	5.5	0.50	0.47	50.6	61.7	268.0	348.0	49.5	50.1	10.5	10.4	10.0	10.0
SL	*	ns	***	ns	***	**	***	ns	***	ns	*	ns	ns	ns	ns	ns
B: Brine Temperature																
2–4C	101.8	160.1	5.0	5.6	0.48	0.44	48.6	71.5	250.0	411.0	48.8	51.2	10.8	11.3	9.6	9.6
15–17C	91.0	109.2	4.8	5.3	0.47	0.46	42.1	50.7	270.0	278.0	48.2	49.6	11.6	10.7	9.6	9.4
SL	ns	***	*	**	ns	ns	*	***	**	***	ns	ns	ns	ns	ns	ns
Interactions A × B																
SL	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Samples																
HB 2–4C	94.8	169.9	4.6	5.6	0.45	0.44	42.6	74.4	20.1	425.8	49.0	50.2	8.8	11.8	9.0	9.1
HB 15–17C	84.8	109.3	4.5	5.2	0.45	0.43	37.8	46.6	176.3	259.5	46.5	49.0	13.2	11.5	8.7	8.9
CB 2–4C	108.9	150.4	5.5	5.6	0.51	0.45	54.7	68.5	299.0	396.8	49.1	49.9	11.0	10.9	9.4	10.3
CB 15–17C	97.2	109.1	5.0	5.4	0.49	0.49	46.5	54.8	237.4	300.1	49.8	50.3	10.0	9.9	10.5	9.8
SEM	2.83	4.64	0.06	0.05	0.01	0.01	1.44	2.39	8.74	15.0	0.49	0.54	0.64	0.54	0.42	0.31

*, **, ***, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

CB, cold boning; HB, hot boning; J, joules; mm, millimeters; N, newtons; ns, not significant; SEM, standard error of means; SL, significance level.

agreement with other studies that have shown no effects of boning on sensory parameters. Williams *et al.* (1994) found no differences in sensory parameters between hot- and cold-boned ground beef, Al-Joher and Clarke (1993) reported no differences in sensory hardness in cooked restructured steaks, while Bentley *et al.* (1988) reported no significant differences for luncheon loaves prepared with hot- and cold-boned pork fat on sensory evaluations of firmness, flavor and overall desirability. Hot-boned BF hams were rated as darker ($P < 0.01$) than their cold-boned counterparts by panelists which is in agreement with a previous study (Rees *et al.* 2002b) and by instrumental color measurements carried out in the present study. Similarly, boning method only presented limited significance in PP hams, with hot-boned PP samples rated juicier ($P < 0.01$) than cold-boned samples by panelists. This could be attributed to the superior functionality of pre-rigor meat which has been well documented i.e., the added extractability of myofibrils leading to better binding and water-holding capacity (Pisula and Tyburcy 1996; Claus and Sørheim 2006). However, this observation is not supported by yield or moisture data in the present study. In general, PP beef hams prepared were affected to a much greater extent than BF beef by brine temperature. Hams prepared with warm brine perceived lighter or pink color ($P < 0.001$). Work carried out by Rees *et al.* (2002a), Moller and Vestergaard (1988) and Miller *et al.* (1984) on pork observed lighter color with temperature conditioned hot-boned meat. Unfortunately, sensory analysis results for hams prepared with elevated temperature brines were lower than expectations, with panelists scoring them as less salty ($P < 0.001$) and inferior in juiciness ($P < 0.01$), overall flavor ($P < 0.05$), overall texture ($P < 0.001$) and overall acceptability ($P < 0.01$) compared to hams prepared with conventional brine. It is unclear why brine temperature affected sensory perception of the PP hams substantially more than BF hams. Significant data with respect to lower juiciness and overall texture may be evidence that cold shortening may have occurred, which has been shown to induce a greater proportion of free water loss from meat due to the shrinkage of the myofibrils (Marsh *et al.* 1972), leading to tougher meat. However, the pH/temperature findings in this study give evidence that cold shortening did not occur and that sensory findings are not supported by physical or instrumental measurements i.e., no effects of brine temperature were shown in yield or moisture content and TPA hardness values were contradictory, showing hams prepared with conventional brines were harder. Any perceived lack of juiciness and tenderness could have had an accumulative detrimental effect on determining overall acceptability, which also scored significantly inferior.

Instrumental Texture and Color

Instrumental texture measurements for BF and PP samples are presented in Table 4. Hot boning decreased ($P < 0.05$) TPA hardness in BF hams by >10% compared to conventional cold boning. Literary evidence tends to express opposite views to the findings in the present study. Previous work by this research group (Keenan *et al.* 2010) found higher TPA hardness values in hot-boned cured beef (PP muscles)

compared to conventional cold boning. Similarly, Jeremiah *et al.* (1985) found consistently lower degrees of tenderness after hot boning various different muscles, which is consistent with the theory of cold shortening (Locker and Hagyard 1963). However, Al-Joher and Clarke (1993) reported that both compressive and penetrative force measurements in cooked hot-boned restructured steaks were lower than their cold-boned counterparts. The lack of apparent toughening associated with hot boning in this study could be attributed to stricter controls over pH/temperature for the muscles as proposed by Lochner *et al.* (1980) Therefore, the onset of toughness by cold shortening may have been avoided thus yielding a comparably tender meat to cold-boned. Hot-boned BF samples were more springy ($P < 0.001$), more gummy ($P < 0.001$), less chewy ($P < 0.001$) and less cohesive ($P < 0.001$) than cold-boned samples. In contrast, boning method had no effect on TPA hardness, springiness, gumminess and chewiness values of PP hams. Cohesiveness was the only texture variable in the PP to be affected, with hot-boned samples shown to be less cohesive ($P < 0.01$). An interactive effect ($P < 0.05$) was observed between boning method and brine temperature for cohesiveness in PP samples.

Brine temperature had no effect on TPA hardness values for BF samples. This is in agreement with the work of Boles and Swan (1997) that found no significant effect of brine temperature in WBSF measurements on injected hot-boned roast beef. Despite these data, some of the secondary texture attributes were affected (with the exception of cohesiveness), with springiness ($P < 0.05$), gumminess ($P < 0.05$) and chewiness ($P < 0.01$) differing significantly between beef hams prepared with elevated and conventional brines. Furthermore, brine temperature seemed to have a more pronounced effect on the texture attributes of PP beef. TPA hardness was affected ($P < 0.001$) by brine temperature with PP hams prepared with elevated brine temperature shown to be more tender than conventional brines. The differences in tenderness between the muscles may be attributed to their individual pre-rigor behavior which is a critically important determinant of meat tenderness (White *et al.* 2006a). Overall, the decreased hardness had a concomitant effect on other texture attributes that were less springy ($P < 0.01$), gummy ($P < 0.001$) and chewy ($P < 0.001$) than their conventionally injected counterparts.

Table 4 also shows instrumental color measurements for BF and PP samples. L^* values for hot-boned BF hams were lower ($P < 0.01$) i.e., darker, than their cold-boned counterparts, which is supported by sensory scores in the present study for cured color. This could be attributed to the lower met-myoglobin content (dark brown pigment) resulting from higher muscle respiratory action at the time of boning (Sadler and Swan 1997). No boning effect was observed for a^* and b^* values. Furthermore, no effect of brine temperature was observed for any of the instrumental color parameters in both muscles. This is in agreement with work carried out by Feldhusen *et al.* (1986) who showed no significant differences in color or its stability between different temperature curing brines (5, 20 and 30C) in immersion cured pork.

Storage Evaluation

A storage trial was undertaken to investigate the implications for quality and microbiological stability due to the potential risks of combining hot boned meat with heated brines. Table 5 presents instrumental texture and color values for BF and PP samples over the storage period. Boning method affected WBSF values with hot-boned BF hams shown to have lower shears on days 7 ($P < 0.001$), 14 ($P < 0.001$) and 21 ($P < 0.05$) than cold-boned hams. Brine temperature also affected WBSF values with hams prepared with warm brine resulting in lower values on days 7 ($P < 0.01$) and 14 ($P < 0.001$). However, no effect was observed between the days of storage. In PP samples, boning method affected WBSF values with hot-boned hams shown to have higher shears on day 21 ($P < 0.05$) than cold-boned hams. Brine temperature also affected WBSF values with hams prepared with warm brine resulting in higher values on day 7 ($P < 0.05$). No differences were observed between days 21 and 14 but these samples were significantly higher ($P < 0.05$) than day 7 for WBSF values. Color analysis for BF and PP samples during the storage period showed b^* values were not affected by either boning method or brine temperature for either BF or PP hams (Table 5). Brine temperature had no effects on L^* and a^* values. L^* values were lower ($P < 0.05$) in hot-boned hams compared to cold-boned hams on day 7. Hot-boned samples were also shown to be more red (a^*) on days 14 ($P < 0.001$) and 21 ($P < 0.05$) than their cold-boned counterparts. In PP hams, brine temperature had no effects on L^* or a^* values. Similarly, L^* values were unaffected by boning. Hot-boned samples were shown to be more red (a^*) on days 14 ($P < 0.001$) and 21 ($P < 0.05$) than their cold-boned counterparts. Storage trends for cured beef produced with either BF or PP beef were similar i.e., L^*, a^* and b^* values degraded over the storage period as expected with no differences between days 7 and 14 but both were significantly higher ($P < 0.05$) than day 21.

Of the sensory characteristics (Fig. 2a–h), no differences for cured color, tenderness, saltiness, overall texture, overall flavor or acceptability scores of BF samples were observed; while in PP samples saltiness did not change through days 7, 14 or 21. BF products were perceived as less juicy ($P < 0.05$) on day 14 than days 7 or 21. PP products showed more degradation and were rated darker ($P < 0.05$),

TABLE 5. INSTRUMENTAL TEXTURE (WARNER–BRATZLER SHEAR FORCE – WBSF) AND COLOR (*L**, *A**, *B**) PARAMETERS OVER STORAGE FOR CURED BEEF FROM M. *BICEPS FEMORIS* (BF) AND M. *PECTORALIS PROFUNDUS* (PP)

	WBSF (N)						*L**						*a**						*b**					
	D7		D14		D21		D7		D14		D21		D7		D14		D21		D7		D14		D21	
Treatment	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP
A: Boning Method																								
HB	23.0	27.2	25.5	29.2	27.5	33.3	47.5	50.8	48.3	49.9	43.7	47.7	11.9	11.6	12.7	12.6	10.0	7.8	9.3	8.9	9.4	9.5	8.4	8.0
CB	31.9	26.7	33.5	28.6	31.8	28.1	49.5	50.1	49.3	51.7	45.8	47.5	10.5	10.4	9.4	7.5	6.8	5.7	10.0	10.0	9.1	9.5	7.6	7.9
SL	***	ns	***	ns	*	*	*	ns	ns	ns	ns	ns	ns	ns	***	***	*	*	ns	ns	ns	ns	ns	ns
B: Brine Temperature																								
2–4C	30.2	25.4	32.8	27.2	29.5	30.3	48.8	51.2	49.2	50.3	44.9	48.0	10.8	11.3	11.2	9.1	8.4	6.9	9.6	9.6	9.2	9.4	8.1	8.1
15–17C	24.7	28.6	26.2	30.6	29.7	31.1	48.2	49.6	48.4	51.3	44.6	47.2	11.6	10.7	10.9	11.0	8.4	6.6	9.6	9.4	9.3	9.6	7.8	7.8
SL	**	*	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Interactions A × B																								
SL	ns	*	*	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Samples																								
HB 2–4C	24.8	27.2	26.6	26.4	28.1	35.8	49.0	52.0	49.3	48.9	44.0	48.2	8.8	11.8	12.1	11.6	9.3	7.2	9.0	9.1	9.8	9.3	9.0	8.3
HB 15–17C	21.3	27.3	24.4	32.0	26.8	30.8	46.5	49.0	47.3	50.8	43.4	47.1	13.2	11.5	13.4	13.5	10.6	8.4	8.7	8.9	9.1	9.7	7.8	7.8
CB 2–4C	25.7	23.5	39.0	28.0	31.0	24.7	49.1	49.9	49.2	51.8	45.7	47.7	11.0	10.9	10.3	6.5	7.5	6.6	9.4	10.3	8.7	9.4	7.3	8.0
CB 15–17C	28.1	29.9	28.0	29.2	32.6	31.5	49.8	50.3	49.4	51.7	45.8	47.3	10.0	9.9	8.4	8.5	6.1	4.8	10.5	9.8	9.5	9.6	7.9	7.8
SEM	1.10	0.91	0.68	0.90	1.12	1.13	0.49	0.54	0.63	0.72	1.31	1.29	0.64	0.54	0.58	0.80	0.78	0.51	0.42	0.31	0.25	0.18	0.55	0.41

*, **, ***, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

CB, cold boning; HB, hot boning; N, newtons; ns, not significant; SEM, standard error of means; SL, significance level.

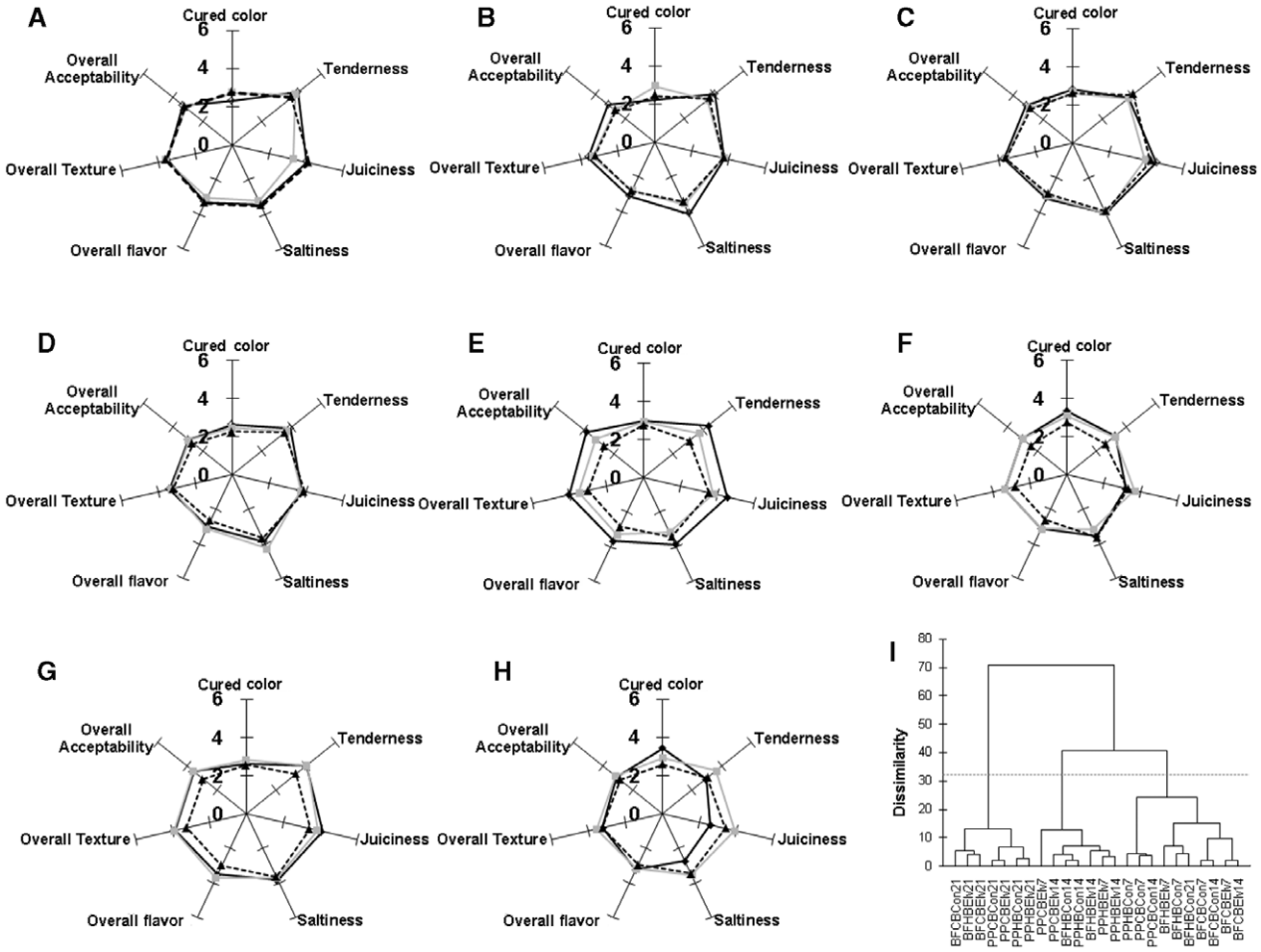

FIG. 2. SENSORY ANALYSIS OVER STORAGE [DAYS 7 (—); 14 (—) AND 21 (- -)] FOR CURED BEEF FROM M. *BICEPS FEMORIS* (BF) (A) hot-boned with conventional brine (2–4C); (B) hot-boned with elevated temperature brine (15–17C); (C) control – cold-boned with conventional brine (2–4C); and (D) cold-boned with elevated temperature brine (15–17C) and M. *pectoralis profundus* (PP) (E–H) for the aforementioned treatments; (I) dendogram of hierarchical cluster analysis of all treatments over storage.

tougher, less juicy and lower in overall flavor texture acceptability on day 21 compared to days 7 or 14.

Visualization of the underlying structure in the collective (BF and PP hams) storage data (excluding microbiological analysis) and the relationships between the samples was made easier using pattern recognition methods, i.e., principle component and hierarchical cluster analyses (PCA and HCA). The resultant information from the HCA is presented in the dendrogram (Fig. 2i). HCA identified three distinct groups. The first group contained only samples from day 21 of the storage period; the second group contained predominantly hams prepared with elevated temperature brines while the third group contained a large proportion of samples prepared with conventional temperature brine. HCA visualizations were then compared to PCA of the same dataset (Fig. 3a–d). The PCA score plot generated for the first two dimensions is shown in Fig. 3a. PC1 explained 41% of the total variance in the data set and PC2 explained 24%. Similar to HCA, samples at the end of the shelf life (day 21) were identified by PCA, which were colocated in the bottom-hand quadrant of the PC space. Fig. 3b illustrates the relationship between the physicochemical and sensory parameters studied. The positioning of the samples is diametrically opposed to sensory attributes of overall acceptability and flavor (which is strongly correlated to positive extreme of PC1). This shows that overall product quality degraded over the storage period as expected. Furthermore, other important sensory quality attributes, such as tenderness and overall texture, are correlated with this principle component. Typically, samples occupying this PC space are more common from the beginning of the storage life (i.e., day 7). Decreasing product acceptability could be attributed to gradual lipid oxidation as the product aged (Thomas *et al.* 2008). Cured color as

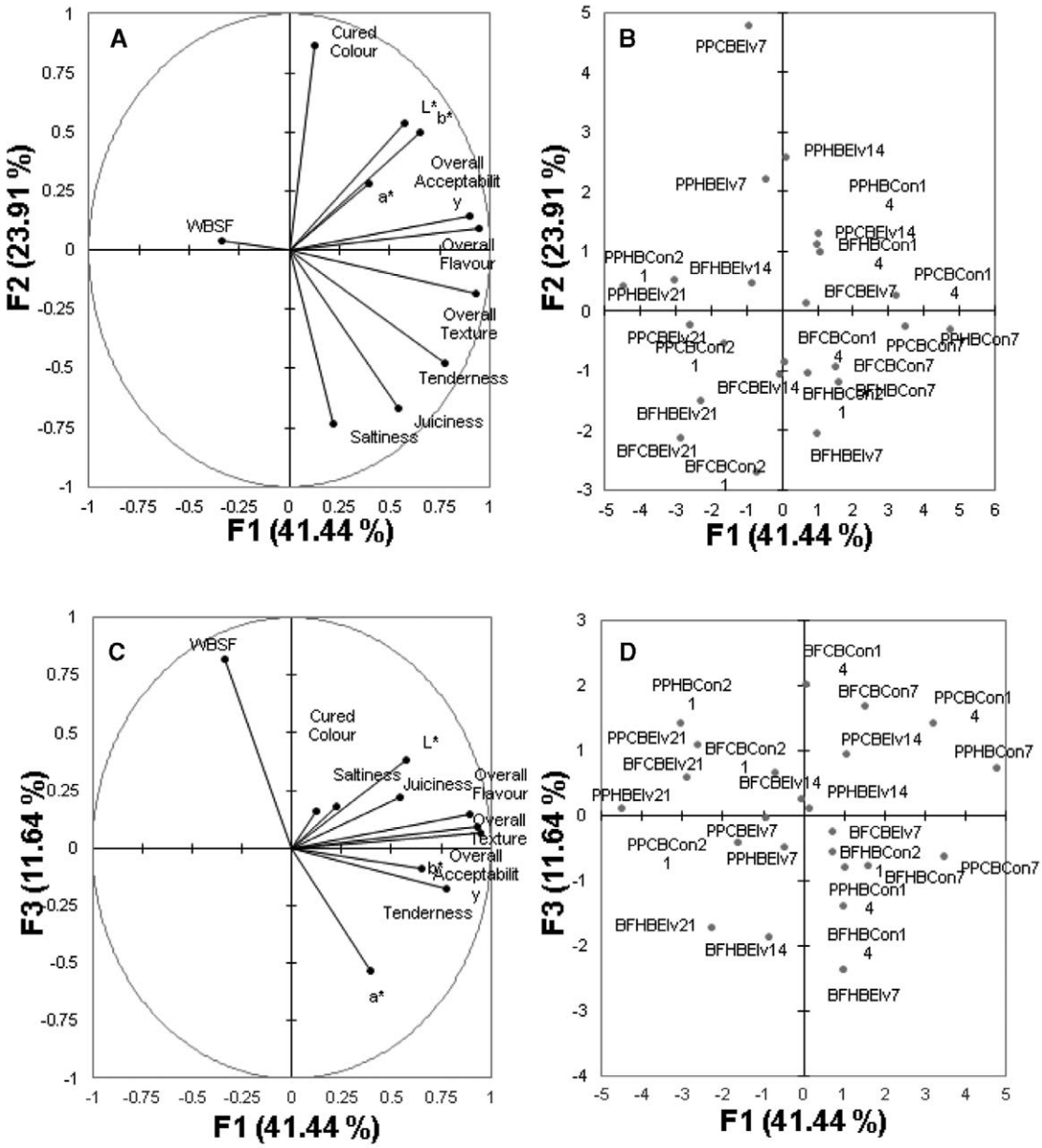

FIG. 3. PRINCIPAL COMPONENT ANALYSIS (PCA) PLOTS
(A) PCA score plot for cured beef processed from different muscles over storage; and (B) loading plot for different variables on PC1 and PC2; (C-D) score and loading plots (respectively) for cured beef from different muscles over storage on PC1 and PC3.

perceived by sensory panelists was highly correlated to PC2. Again, samples at the end of the storage life (day 21) were at the negative extreme of this PC space e.g., cold-boned BF hams prepared with conventional brine. Color also decreased over time, likely due to the storage cabinet lights. As ultraviolet light causes protein denaturation, this causes brown pigments to form in the longer term. If rancidity was a factor, this may have liberated strong oxidizing agents i.e., peroxides, that also promoted brown pigment formation (Honikel 2010). From the results, it would appear that BF beef was more resistant to the effects of storage. This could be attributed to the muscle's lower fat content and possible lower rancidity compared to the PP muscle. To further understand the relationships between the different variables and the sample groups, other PC solutions were considered i.e., PC1 to PC3. PC3 accounted for 12% of the total data variance. Score and loading plots for PC1 and PC3 are presented in Fig. 3c,d. This solution shows that Warner–

TABLE 6. EFFECT OF SHELF-LIFE ON MICROBIOLOGY OF CURED BEEF (M. *BICEPS FEMORIS* BF AND M. *PECTORALIS PROFUNDUS* P)

	TVC				Enterobacteriaceae		*Staphylococcus aureus*		*Salmonella*		*Listeria monocytogenes*	
	D14		D21									
Samples	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP	BF	PP
HB 2–4C	1.9[b]	5.0[b]	4.7[c]	3.7[c]	<10	<10	<100	<100	N/D	N/D	N/D	N/D
HB 15–17C	1.1[c]	2.1[b]	1.4[c]	7.0[b]	<10	<10	<100	<100	N/D	N/D	N/D	N/D
CB 2–4C	5.6[a]	3.7[a]	2.9[b]	1.2[b]	<10	<10	<100	<100	N/D	N/D	N/D	N/D
CB 15–17C	1.4[b]	2.0[b]	4.1[b]	7.7[b]	<10	<10	<100	<100	N/D	N/D	N/D	N/D

Superscripts: a, 10^4 cfu/mg; b, 10^5 cfu/mg; c, 10^6 cfu/mg; d, 10^7 cfu/mg.
CB, cold boning; HB, hot boning; N/D, not detected.

Bratzler shear force data are better resolved. There was an increased tendency for day 21 samples from the different muscle types and treatments to be located in the top left-hand quadrant, which corresponded to high shear force measurements. This is an unexpected finding as meat typically becomes more tender as a function of time and is supported by the majority of the literature (Goll *et al.* 1991; Koohmaraie 1994, 1996, Ouali 1990). While the differences were small in practical terms, the phenomenon could be attributed to moisture losses (samples were perceived as less juicy by sensory panelists as the shelf life progressed) in the samples during storage leading to small increases in shear force.

Microbiological analyses for days 14 and 21 are presented (Table 6). Mean values for total viable counts (TVC) ranged from 4.7 to 6.0 (D14) and 5.5 to 6.7 (D21) $\log_{10}$ cfu/g. Predictably, hot-boned beef resulted in higher counts than cold-boned beef, as expected (combined means: 6.0 versus $\log_{10}$ 5.2 cfu/g, respectively). Similarly, hams prepared with warm brine had higher counts than those prepared with conventional brine (combined means: 5.7 versus $\log_{10}$ 5.4 cfu/g, respectively). Of the other microbiological analyses, all samples were below the recommended detection limits for *E. coli* (<10), *S. aureus* (<100), *L. monocytogenes* (not isolated) and *Salmonella* species (not isolated). In general, trends for TVC in PP beef hams were similar to BF beef, with counts increasing over days 14 to 21. As expected, combinations of hot boning and warm brine resulted in higher counts, while all samples were below the recommended detection limits for *E. coli* (<10), *S. aureus* (<100), *L. monocytogenes* (not isolated) and *Salmonella* species (not isolated). Combinations of hot boning and higher brine temperatures led to higher bacterial counts, as expected. However, the retail shelf life of similar cured, cooked products, which is estimated as time to $\log_{10}$ 7 cfu bacteria/g, was maintained (Food Safety Authority of Ireland 2001). Both *L. monocytogenes* and *Salmonella* sp. were not isolated in any of the four treatments on days 14 or 21 in either muscle due to the modified atmospheres used (CO_2 : N_2 in 20:80% concentration), which restricts the growth of Enterobacteriaceae (Adams and Moss 1997).

CONCLUSIONS

Different boning methods and brine temperature regimes were used in the processing of cured hams from two beef muscles. Careful management of the critical time/temperature window during the pre-rigor phase appeared to overcome some of the potential adverse effects that can arise from hot-boned meat, such as toughness brought about by cold shortening. However, no evidence for the expected increases in functionality was observed by hot boning i.e., yield and water-holding were unaffected. Hot-boned BF hams were less hard than their conventionally-boned counterparts, but this was not supported by sensory assessment. Multivariate analyses helped visualize some storage-related reductions in sensory quality as perceived by taste panelists with juiciness, overall texture and overall acceptability rated as inferior, particularly in the case of PP beef. Overall, combinations of hot boning and warm brine did not exceed microbial guidelines for similar products. This indicates processing at higher temperatures can be achieved without compromising consumer safety. It may also help offset the effects of cold shortening in hot-boned meat and save costs for the processor i.e., cost of refrigeration associated with conventionally chilling brine.

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