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Effect of carcass suspension and cooking method on the palatability of three beef muscles as assessed by Korean and Australian consumers

B. Y. Park[A], *I. H. Hwang*[B], *S. H. Cho*[A], *Y. M. Yoo*[A], *J. H. Kim*[A], *J. M. Lee*[A], *R. Polkinghorne*[C] *and J. M. Thompson*[D,E]

[A]National Livestock Research Institute, Rural Development Administration, Suwon, 441-350, Korea.
[B]Department of Animal Resources and Biotechnology, Chonbuk National University, 664-14 Duckjin-dong, Jeonju City, 561-756, Korea.
[C]Marrinya, Agricultural Enterprises, 70 Vigilantis Road, Wuk Wuk, Vic. 3875, Australia.
[D]Cooperative Research Centre for Beef Genetic Technologies, School of Environmental and Rural Sciences, University of New England, NSW 2351, Australia.
[E]Corresponding author. Email: jthompso@une.edu.au

Abstract. A total of 36 steer carcasses (18 slaughtered in Australia and 18 slaughtered in Korea), where one side had been suspended by the hip (tenderstretch) and the other by the Achilles tendon were used to provide sensory and shear force samples from the *Mm. triceps brachii*, *longissimus lumborum* and *semimembranosus.* Sensory samples were cooked using grill (25 mm thick) and barbeque (BBQ, 4 mm thick) methods and served to 360 untrained Australian and 720 untrained Korean consumers. Australian consumers sensory tested grill and BBQ samples from Australian carcasses (216 samples), while Korean consumers sensory tested grill and BBQ samples from both Australian and Korean carcasses (a total of 432 samples). The three-way interaction between carcass suspension, cooking method and muscle was significant ($P < 0.05$) for tenderness, overall liking and a composite palatability score (MQ4), where the combination of BBQ cooking and hip suspension resulted in large increases in sensory scores for the *M. semimembranosus*. Variation in sensory scores and shear force are discussed in the context of possible interactions with cooking temperature. There was a significant ($P < 0.05$) first order interaction between consumer group and muscle for juiciness score. Consumer effects were significant ($P < 0.05$) for all sensory scores, being largest for juiciness (~8 sensory units), like flavour and overall liking (both ~6 sensory units) and MQ4 (~5 sensory units) scores, with the smallest effect on tenderness (~2 sensory units).

Additional keywords: consumer sensory scores, cooking effect, muscle effects, tenderstretch.

Introduction

Meat Standards Australia (MSA) is a beef grading system that predicts the palatability of individual muscles in the carcass (Thompson 2002; Polkinghorne *et al*. 2008). The development of the prediction model used by MSA has been underpinned by extensive consumer testing of beef samples from a range of production, processing and value adding scenarios (Watson *et al*. 2008). The consumers used in these taste panels have largely been sampled from urban Australian populations. The accuracy of these prediction equations when applied to other consumer groups of different cultural background is not known. In particular, there was interest in assessing the accuracy of the MSA prediction equations for both Australian and Korean consumers.

There is little information on the relative meat quality preferences for Korean and Australian consumers. A study by Baghurst (1997) suggested that Korean consumers placed less importance on tenderness, in contrast to results from studies of western consumers, whilst Cho *et al*. (1999) documented the preference of Korean consumers for highly marbled meat. More recently, Kim and Lee (2003) reported that consumer panelists preferred more marbled meat due to higher flavour intensity, while tenderness and juiciness got the same degree of preference. In contrast, Australian consumers discriminate against high levels of marbling (Chappell 2001), with the highest preference for tenderness. Whilst the above studies suggest some differences between Korean and western consumers, the authors were not aware of studies that directly compared palatability scores from these two groups.

Several studies have identified that hip suspension (tenderstretch) has a large effect on the palatability of hind limb and loin muscles in the carcass, with little effect on forequarter muscles (Hostetler *et al*. 1973; Maher *et al*. 2004). The tenderstretch effect is generally largest in those carcasses that are at risk of cold-shortening (Sorheim *et al*. 2001; Thompson *et al*. 2006). However, Ferguson *et al*. (1999) concluded that hip suspension and electrical stimulation were, to a degree, additive in their impact on palatability of hindquarter muscles. In this study, the tenderstretch treatment was applied to create variation in eating quality of some muscles within a carcass.

Grilling is a common form of cooking beef in many western countries and was the main cooking method used in the MSA consumer taste panels (Thompson 2002; Watson *et al*. 2008). Beef is not traditionally cooked this way in Korea; rather, it is

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often prepared as thin strips of beef cooked quickly at high temperatures on a barbeque plate. There appears to be little information as to whether these two cooking techniques impact differently on beef palatability, as assessed by consumers from western or Korean backgrounds.

The current study was conducted to evaluate Korean and Australian consumer responses to samples prepared using different cooking methods (BBQ and grill) from carcasses where sides had been either suspended by the hip or the Achilles tendon. Thompson *et al*. (2008) used the sensory data from this experiment to examine whether there are differences in the way Australian and Korean consumers grade cooked beef samples and the boundaries between the grades. The importance of demographic factors on the sensory scores given by Korean and Australian consumers was examined by Hwang *et al*. (2008). This paper examined the effects of tenderstretch, muscle and cooking techniques on palatability scores and whether these differed between consumer groups that are culturally very different.

Material and methods

Experimental design

The experimental design, preparation and sensory testing of grill and BBQ samples was described in detail by Thompson *et al*. (2008) and Hwang *et al*. (2008). Briefly, the experiment sensory tested samples from carcasses of 18 Hanwoo steers slaughtered in Korea and 18 Angus steers slaughtered in Australia. At each location, alternate sides were tenderstretched (by suspension from the obturator foramen) or hung by the Achilles tendon. At boning, 24 h after slaughter, three primals (blade, striploin and topside) were removed from each side and stored in vacuum packs. After storing for 7 days at 1°C, the *Mm. triceps brachii*, *longissimus lumborum*, *semimembranosus* were dissected from the blade, striploin and topside primals, respectively, before the preparation of sensory samples for the grill and BBQ cooking methods.

The preparation of sensory samples was according to the protocol described by Watson *et al*. (2008). Samples from Australian carcasses were sensory tested using untrained Australian consumers, whilst samples from both Australian and Korean carcasses were sensory tested by untrained Korean consumers.

Carcass measurements

Animals were stunned using a captive bolt and individual stunning times were recorded. A Jenco pH meter, with a polypropylene spear-type gel electrode (Ionode IJ 44), was used to measure pH. In the first 8 h post-mortem, a total of six pH, temperature and time measurements plus an ultimate measurement at 24 h post-mortem were recorded at the 12th rib junction in the *M. longissimus dorsi*. For each measurement, the pH probe was inserted into fresh muscle tissue in the vicinity of the 12th rib. At grading, an MSA grader subjectively scored the carcasses for marbling at the 12/13th rib junction, and ossification on calcification of the sacral, lumbar and thoracic vertebrae (Romans *et al*. 1994).

Sensory measurements

The sensory testing protocol has been described in detail by Watson *et al*. (2008). For the grill panels, five 25-mm thick steaks were prepared from each sample. For the BBQ strips, ten 4-mm thick samples were prepared. The three muscles were first portioned into anterior or posterior portions for the *M. longissimus lumborum* and proximal and distal portions for the *Mm. triceps brachii* and *semimembranosus*. Sample blocks for steaks and BBQ strips were randomised across portions for samples from the different consumer–cattle subgroups. Grilling comprised cooking on a clam bake grill (Silex) to achieve a medium degree of 'doneness'. After cooking for a set time, steaks were rested and halved before serving to 10 consumers. The strips were cooked using a gas-heated tin plate (~225°C) with a water jacket. BBQ strips were individually cooked by placing them on the tin plate and turning at the first pooling of liquid on the surface of the sample, before serving to consumers. In both the grill and BBQ taste panels, each consumer tested one starter sample followed by six experimental samples. In total, 360 Australian consumers tested the grills, while 180 consumers tested the BBQ samples. For taste panels run in Korea, 360 Korean consumers tested the grill samples and 360 tested the BBQ samples.

Objective quality measurements

At the same time the sensory samples were prepared, a 25-mm-thick steak was taken at the same position from the three muscles from each side for objective meat quality analysis. Shear force was measured on cooked steaks according to the method described by Wheeler *et al*. (2000). Cooking loss was calculated as a percentage of weight change of the objective block during cooking. Mean sarcomere length at 24 h was determined on at least six slices from each sample, using a Helium-Neon laser diffraction technique according to the method described by Cross *et al*. (1981). Intramuscular fat percentage (%) was determined on 100-g samples from each of the three muscles from each side by the microwave-solvent extraction method (AOAC 2000). There was no difference between sides in intramuscular fat % and, because there were several missing samples, intramuscular fat % was averaged for muscles from the tenderstretched and Achilles hung sides.

Statistical analyses

Changes in both pH and temperature as functions of time were modelled in individual carcasses using the exponential function:

$$y_t = a_\mathrm{u} + (a_\mathrm{i} - a_\mathrm{u})\mathrm{e}^{-k.t}$$

where y_t is pH or temperature at time t, a_u is ultimate pH or temperature, a_i is initial pH or temperature, k is the exponential rate of pH or temperature decline and t is time post-mortem. Parameters from the pH/time equation were estimated using nonlinear procedures (PROC NLIN, SAS 1997). The parameters were used to predict the time to achieve pH 6.0, which was then used to predict temperature at pH 6.0 (temp@pH6).

Objective meat quality measurements (shear force, sarcomere length and percentage cooking loss) were analysed using a mixed model (PROC MIXED, SAS 1997) which included fixed effects for country of origin of the cattle, muscle, tenderstretch and covariates for intramuscular fat (%), ossification score and temp@pH6. A random term for animal nested within country of origin was included in the model. Relevant first order interactions were tested and, where significant ($P < 0.05$), were included in the model along with significant covariates ($P < 0.05$).

A composite palatability score (MQ4) was formed by summing the four sensory scores after weighting for 0.4, 0.1, 0.2 and 0.3 for tenderness, juiciness, like flavour and overall liking scores, respectively (Polkinghorne *et al*. 1999; Watson *et al*. 2008). The 10 sensory scores for each sample were ranked and the two highest and two lowest scores clipped to reduce the variance of the mean score (Polkinghorne *et al*. 1999; Watson *et al*. 2008). Hwang *et al*. (2008) showed that, using the current dataset, clipping reduced the standard error of the mean sample score by ~30%.

The clipped sensory scores were analysed in a mixed model (PROC MIXED, SAS 1997) which contained fixed effects for country of origin of the cattle, tenderstretch, muscle, position (muscle), cook and consumer effects, plus relevant covariates, with a random term for animal nested within origin of the cattle. Model building was undertaken using a multivariate procedure where the four sensory variables (tenderness, juiciness, like flavour and overall liking scores) were simultaneously examined in a model containing fixed effects, covariates and relevant first and second order interactions. The model building process involved testing various interactions between fixed effects and covariates, and including significant ($P < 0.05$) terms in the final model.

The final model for the four sensory and MQ4 scores contained terms for country of origin of the cattle, tenderstretch, muscle, position (muscle), cook, carcass suspension × muscle, carcass suspension × cook, muscle × cook, carcass suspension × muscle × cook, consumer group, consumer group × muscle, and covariates for intramuscular fat % and ossification score, along with a random term for animal nested within country of origin. The covariate for temp@pH6 was not significant ($P > 0.05$) and was not included in the final sensory models.

Results

Objective meat quality

Table 1 summarised the carcass traits for the Korean Hanwoo and Australian Angus carcasses. It is important to emphasis that this experiment focussed on the differences in consumer response to the processing and cooking treatments, not a comparison between the cattle groups. However, as carcass traits were used as covariates to account for between-group differences in both analysis of sensory and objective meat quality traits, the distribution of carcass traits between the two groups was important. Table 1 showed that the two groups of cattle were similar in carcass weight, temp@pH6 and ultimate pH, but different in fatness traits and ossification scores, with the Korean Hanwoo carcasses having lower fat depth and ossification scores and higher intramuscular fat (both as marble scores of the *M. longissimus lumborum* and intramuscular fat % of the three muscles) than the Australian Angus carcasses. However, despite differences between the means, there was sufficient overlap between the groups to support the use of these measurements as covariates.

Table 2 shows the significance of treatment effects and relevant covariates on shear force, sarcomere length and percentage cooking loss. The tenderstretch × muscle interaction was significant ($P < 0.001$) for both shear force and sarcomere length. Table 3 showed the tenderstretch effect on shear force was restricted to the *M. longissimus dorsi*, with a reduction in

Table 1. Mean carcass traits, variance and range for the 18 Korean Hanwoo and 18 Australian Angus carcasses

Marble and ossification scores were (subjectively) assigned using the scales defined by Romans *et al*. (1994)

Carcass traits	Korean Hanwoo		Australian Angus	
	Mean ± s.d.	Range	Mean ± s.d.	Range
Cold carcass weight (kg)	366 ± 36	313–443	386 ± 25	342–423
12/13th rib fat depth (mm)	8.8 ± 3.1	4–16	15.5 ± 4.8	9–29
Marble score	593 ± 115	390–820	372 ± 63	260–480
Ossification score	206 ± 22	170–250	160 ± 17	140–190
Intramuscular fat (%)				
M. biceps brachii	7.4 ± 2.3	3.3–13.2	4.2 ± 1.9	2.3–9.3
M. longissimus dorsi	11.6 ± 4.0	6.5–21.2	5.5 ± 2.5	2.8–10.8
M. semimembranosus	5.5 ± 2.3	2.9–12.6	3.9 ± 2.1	1.5–8.9
Temperature at pH 6 (°C)	34.7 ± 2.5	27.6–37.7	34.1 ± 1.8	30.5–37.2
Ultimate pH	5.5 ± 0.03	5.4–5.5	5.5 ± 0.07	5.4–5.6

Table 2. *F*-ratios for the effects of origin of the cattle, muscle, tenderstretch, tenderstretch × muscle, along with relevant covariates for intramuscular fat (IMFAT%) and temperature at pH 6.0 (temp@pH6) on objective laboratory measurements (shear force, sarcomere length and cooking loss %)

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$, n.s., not significant

Independent variables	Shear force		Sarcomere length		Cooking loss %	
	NDF, DDF	*F*-ratio	NDF, DDF	*F*-ratio	NDF, DDF	*F*-ratio
Cattle origin	1, 34	20.73***	1, 33	0.01n.s.	1, 34	2.59n.s.
Muscle	2, 157	12.93**	2, 158	68.14***	2, 159	5.75**
Tenderstretch	1, 157	3.83***	1, 158	329.61***	11, 159	0.39n.s.
Tenderstretch × muscle	2, 157	5.94***	1, 158	137.37***		
Intramuscular fat %	1, 157	13.49***			1, 159	7.73**
Temp@pH6			1, 158	3.05^{A}		
Regression coefficient (s.e.)						
IMFAT%	–0.684	(0.187)			–0.231	(0.083)
Temp@pH6			–0.012	(0.006)		

$^{A}P = 0.08$.

Table 3. Predicted shear force (N) and sarcomere length (μm) means for the interaction between carcass suspension (Achilles tendon or tenderstretch) and muscle (*Mm. triceps brachii*, *longissimus lumborum* or *semimembranosus*)
Within rows, means followed by the same letter are not significantly different ($P = 0.05$)

Objective meat quality	Achilles tendon			Tenderstretch			Maximum s.e.
	M. biceps brachii	*M. longissimus lumborum*	*M. semimembranosus*	*M. biceps brachii*	*M. longissimus lumborum*	*M. semimembranosus*	
Shear force	33.8b	31.1c	39.9a	35.3b	26.7d	38.8a	1.1
Sarcomere length	2.41b	1.83d	1.81d	2.40b	2.24c	2.84a	0.03

shear force, compared with Achilles hung sides. This decrease in shear force of the *M. longissimus lumborum* was accompanied by an increase in sarcomere length. Whilst tenderstretch also resulted in a large increase in sarcomere length of the *M. semimembranosus*, this was not accompanied by any change in shear force. As expected, tenderstretch had little effect on shear force or sarcomere length of the *M. triceps brachii* (Table 3).

Regression coefficients in Table 2 showed that as intramuscular fat % increased, shear force decreased. For shear force there was no interaction between intramuscular fat %, muscle and tenderstretch ($P > 0.05$), indicating a similar relationship between intramuscular fat % and shear force for the three muscles. There was a trend ($P = 0.08$) for increased temp@pH6 to result in shorter sarcomeres within carcass suspension and muscle subclasses, although the magnitude of the regression coefficient was very small (i.e. a 1°C increase in temperature@pH6 resulted in a 0.012 decrease in sarcomere length, Table 2). Percentage cooking loss was affected by muscle and intramuscular fat content ($P < 0.05$, Table 2), with the *Mm. longissimus lumborum* and *semimembranosus* having a cooking loss of ~25.0%, compared with 26.6% in the *M. triceps brachii* (average standard error of 0.3). As intramuscular fat % increased, percentage cooking loss decreased at a similar rate for the three muscles (Table 2).

Consumer sensory scores

Table 4 showed the treatment effects on sensory scores (tenderness, juiciness, like flavour, overall liking and MQ4 scores) for samples tasted by Australian and Korean consumers, cooked by both grill and BBQ methods. The effect of cattle origin was significant ($P < 0.05$) for tenderness and MQ4 scores.

Position within muscle was significant ($P < 0.05$) for all sensory scores, except like flavour. With the exception of the *M. triceps brachii*, there was a consistent trend for the anterior (or proximal) portions of the *Mm. longissimus lumborum* and *semimembranosus* to have sensory scores that were 2–4 taste panel units higher than the posterior (or distal) portions.

There was a significant ($P < 0.01$) three-way interaction between cook, tenderstretch and muscle treatments for all sensory scores, with the exception of juiciness. *F*-ratios in Table 4 indicated that the largest effects were for tenderness and MQ4 scores. As expected, tenderstretch had little effect on the sensory scores of the *M. triceps brachii*, whereas it did result in an increase in sensory scores of the *M. longissimus lumborum*, whether it was cooked using grill or BBQ methods ($P < 0.05$, Table 5). The magnitude of the tenderstretch response for the *M. longissimus lumborum* for both cooking methods was greatest for tenderness score (~9 sensory units) and smallest for juiciness and like flavour scores (~3 sensory units). For the

Table 4. *F*-ratios for the effects of cattle origin, tenderstretch, muscle, position (muscle), cook, consumer and covariates (IMFAT% and ossification score) on sensory scores (tenderness, juiciness, like flavour, overall liking and MQ4 scores)
*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$, n.s., not significant

Independent variables	NDF, DDF	Sensory scores				
		Tenderness	Juiciness	Like flavour	Overall liking	MQ4
Cattle origin	1, 33	5.64*	0.15n.s.	0.27n.s.	2.37n.s.	3.22**
Tenderstretch	1, 586	99.19***	26.34***	23.79***	82.48***	94.89***
Muscle	2, 586	74.93***	52.80***	28.22***	56.93***	71.46***
Position (muscle)	3, 586	6.81**	7.16***	2.71n.s.	8.27***	5.76**
Cook	1, 586	91.37***	68.55***	55.89***	55.17***	89.71***
Tenderstretch × muscle	1, 586	37.43***	6.71***	5.82**	25.71***	30.38***
Muscle × cook	2, 586	7.23***	20.91***	3.59**	9.48***	10.74***
Tenderstretch × cook	1, 586	3.30n.s.	3.62n.s.	0.91n.s.	1.09n.s.	1.75n.s.
Tenderstretch × cook × muscle	1, 186	9.36***	0.91n.s.	3.67**	6.37**	8.51***
Consumer	1, 586	5.12*	118.93***	69.00***	64.23***	40.72***
Consumer × muscle	2, 586	0.57n.s.	2.34n.s.	12.87***	1.49n.s.	2.41n.s.
Intramuscular fat %	1, 586	25.13***	37.34***	11.37***	32.05***	30.96***
Ossification score	1, 586	3.41*	0.98n.s.	3.34n.s.	4.06*	4.07*
Regression coefficient (s.e.)						
IMFAT%		1.183 (0.236)	1.033 (0.169)	0.505 (0.150)	1.006 (0.178)	0.959 (0.172)
Ossification score		–0.072 (0.039)	–0.026 (0.026)	–0.043 (0.024)	–0.056 (0.028)	–0.056 (0.028)

Table 5. Predicted sensory score (tenderness, juiciness, like flavour, overall liking and MQ4 scores) means for the interaction between cooking method (grill and BBQ), carcass suspension (Achilles tendon and tenderstretch) and muscle (*Mm. triceps brachii*, *longissimus lumborum* and *semimembranosus*)

Within rows, means followed by the same letter are not significantly different ($P = 0.05$)

Sensory scores	Grill						BBQ						Maximum s.e.
	Achilles tendon			Tenderstretch			Achilles tendon			Tenderstretch			
	M. triceps brachii	*M. longissimus*	*M. semimem branosus*	*M. triceps brachii*	*M. longissimus*	*M. semimem branosus*	*M. triceps brachii*	*M. longissimus*	*M. semimem branosus*	*M. triceps brachii*	*M. longissimus*	*M. semimem branosus*	
Tenderness	53.5a	62.4bc	43.5d	54.2a	71.5ef	53.2a	64.2bc	66.2c	47.6g	61.7b	74.6f	70.0e	1.6
Juiciness	62.0a	65.0ab	49.9c	64.5ab	69.0d	56.6e	68.6df	66.0bf	61.4a	66.5bdf	69.6d	66.0d	1.2
Like flavour	59.9a	63.8b	56.3c	61.0a	66.8d	58.5ac	64.5be	66.4bd	59.6a	64.0be	68.9d	67.0d	1.1
Overall	58.2a	63.9bc	49.9d	59.5a	70.7e	57.2a	63.7bc	65.6c	53.8f	63.5bc	71.2e	68.9e	1.2
MQ4	57.0ab	63.0c	48.6d	58.1b	69.9e	55.6af	64.5c	65.5c	53.1f	63.0c	71.4e	68.4e	1.2

Table 6. Predicted sensory score (tenderness, juiciness, like flavour, overall liking and MQ4 scores)

Means are for the interaction between consumer group (Korean or Australian) and muscle (*Mm. triceps brachii*, *longissimus lumborum* or *semimembranosus*); other adjustments used in the model are described in Table 4. Within rows, means followed by the same letter are not significantly different ($P = 0.05$)

Sensory scores	Korean			Australian			Maximum s.e.
	M. biceps brachii	*M. longissimus lumborum*	*M. semimembranosus*	*M. biceps brachii*	*M. longissimus lumborum*	*M. semimembranosus*	
Tenderness	57.0a	67.3b	53.1c	59.9a	70.1b	54.1c	1.4
Juiciness	61.2a	62.3a	55.2b	69.5c	72.5d	61.8a	1.1
Like flavour	59.3a	62.1b	59.5a	65.5c	70.8d	61.2b	1.0
Overall liking	58.1a	64.1b	55.1c	64.8b	71.6d	59.8a	1.1
MQ4	58.0a	64.4b	55.1c	63.3b	70.5d	57.8a	1.1

M. semimembranosus, the impact of the tenderstretch effect varied with cooking technique, with approximately a 10-unit increase in tenderness score when the tenderstretched samples were cooked as a grill, compared with a 22-unit increase when cooked using the BBQ protocol.

There was a significant ($P < 0.05$) interaction between consumer group and muscle for like flavour score. Table 6 showed like flavour scores given by Korean consumers were lower than those given by Australian consumers, by ~5, 8 and 2 sensory units for *Mm. biceps brachii*, *longissimus lumborum* and *semimembranosus*, respectively. When averaged over all muscles, consumer had a significant ($P < 0.05$, Table 4) effect on all sensory scores, although the relative importance (ranked using the *F*-ratios) varied between sensory scores. The consumer effect had the largest effect on juiciness, followed by like flavour, overall liking and MQ4 scores, with the lowest *F*-ratios for tenderness. Australian consumers gave scores that were on average 8, 5, 6, 4 and 2 sensory units higher than the Korean consumers for juiciness, like flavour, overall liking, MQ4 and tenderness scores, respectively.

Intramuscular fat % had a significant ($P < 0.01$) effect on all sensory scores and reduced the cattle origin effect. As intramuscular fat % increased, so too did sensory scores, with an increase of ~1 sensory score for every 1% increase in intramuscular fat % (Table 4). The exception was the like flavour score, where the regression coefficient was approximately half this. Further inclusion of a curvilinear term for intramuscular fat in the model was not significant ($P > 0.05$). Also, the interactions between intramuscular fat % with muscle or tenderstretch terms were not significant ($P > 0.05$), indicating that the relationships between intramuscular fat % and sensory score were similar within the three muscles and different carcass suspension treatments.

Table 4 also showed the coefficients for the change in sensory scores relative to ossification score. The effect of ossification score was significant ($P < 0.05$) for tenderness, overall liking and MQ4 scores. As ossification score increased, these sensory scores decreased at approximately –0.06 sensory units/ossification score.

Discussion

Tenderstretch, cook and muscle effects on sensory and objective meat quality traits

The response to tenderstretch, in terms of sensory scores and shear force, varied according to muscle and cooking technique. For the *M. semimembranosus* the tenderstretch effects were much greater for the BBQ than grill cooking technique. This was in contrast to the *M. longissimus lumborum*, where no interaction between tenderstretch and cooking method was evident. As expected, the *M. triceps brachii* showed no effect of tenderstretch, but there were large cooking effects on its sensory scores. Further, there was a tenderstretch effect for shear force of the *M. longissimus lumborum*, but not for the *Mm. triceps brachii* or *semimembranosus*.

These apparently contradictory results for tenderstretch and cooking effects, whereby some muscles showed differences in sensory scores whilst there were no differences in shear force, align well with those reported by Bouton *et al*. (1975) and Eikelenboom *et al*. (1998). Those authors reported that the magnitude of the tenderstretch effect varied according to muscle and the temperature at which the samples were cooked. Both workers reported that raw *M. semimembranosus* samples (or samples cooked to a low temperature) from tenderstretch sides were tougher than those from Achilles hung sides. For the high connective tissue cuts, such as the *M. semimembranosus*, Eikelenboom *et al*. (1998) showed that cooking temperatures of greater than 80°C were required before tenderstretch samples had a lower shear force (i.e. were more tender) than Achilles hung samples. A similar crossover effect was evident for the low connective tissue *M. longissimus lumborum*, although the critical temperature appeared to be lower than for the high connective tissue *M. semimembranosus*.

In this study, the 6- to 7-point increase in MQ4 score for grilled *Mm. semimembranosus* and *longissimus lumborum* samples from tenderstretched sides was similar to Ferguson *et al*. (1999). Similarly, Hwang *et al*. (2002) reported that stir-fry samples tested by a consumer panel showed an improvement due to tenderstretch of 2–7 MQ4 units for the *M. longissimus lumborum* and *semimembranosus*, respectively. In both these experiments, the grill and stir-fry samples were cooked to a medium degree of doneness (which although not measured would presumably have equated to internal cooking temperatures of 70 to 75°C). In this study, *M. semimembranosus* samples cooked in a water bath to 70°C showed no tenderstretch effect on shear force but there was a clear tenderstretch advantage for the *M. longissimus lumborum*. In contrast, Bouton *et al*. (1978) studied cattle and Moller *et al*. (1987) studied pigs, and showed a clear tenderstretch advantage for shear force of *M. semimembranosus* cooked at 80°C.

Tornberg (1996) proposed a model to explain the interaction between stretched muscle and cooking temperature on tenderness, whereby stretched muscle in the raw state was tougher than unstretched muscle in the raw state, due to a smaller viscous component in the muscle structure. Upon heating to 60°C or above, connective tissue began to contract and reversed this effect. This is because the smaller extracellular space in cooked stretched muscle allows less room for connective tissue to contract without being restricted by the myofibrillar mass, resulting in a more tender muscle. Further, Tornberg (1996) proposed that the interaction between stretching and cooking temperature was likely to be greater in muscles with high connective tissue content.

This hypothesis provides a useful model to explain the interaction between muscle, tenderstretch and cooking treatments in the present study, where the high connective tissue *M. semimembranosus* showed a variable tenderstretch response, depending on cooking method/temperature. For objective *M. semimembranosus* samples cooked at 70°C, there was no tenderstretch response, whereas grill samples cooked to a medium degree of doneness (which would have most likely reached internal temperatures just above 70°C) showed a moderate response. In this study, the very large response to tenderstretch was obtained for the high connective tissue *M. semimembranosus* cooked using the BBQ method. Again, although no cooking temperatures were recorded in this study, the BBQ protocol which involved cooking a 4-mm thick strip of meat on a plate held at 220°C, would likely have reached high internal temperatures, even though samples were cooked for only a short time. By comparison, the low connective *M. longissimus lumborum* did not show any interaction between cooking method and tenderstretch treatment. The results of Eikelenboom *et al*. (1998) suggested that the crossover point for low connective tissue *M. longissimus lumborum* was of the order of 60°C, well below cooking temperatures used in this study. Whilst the hypothesis proposed by Tornberg (1996) was a convenient model to explain the objective and sensory results in this study, the cooking effect was confounded by slice thickness which may also have contributed to the large response due to the BBQ cooking effect.

In this study, higher intramuscular fat resulted in higher sensory scores in all muscles. Miller (1994) proposed several mechanisms by which increased intramuscular fat content could affect the different sensory scores and it was likely that several of these mechanisms were operating on the various sensory dimensions in this study. The intramuscular fat data in the current study were rather unique in that they were measured in all three muscles. The lack of any interaction between intramuscular fat with muscle and/or tenderstretch treatment suggested the same mechanism was probably operating within each of these muscles, regardless of the intramuscular fat % and the configuration of the myofibrillar and connective tissue proteins (i.e. whether stretched or not). This would support a simple mechanism for the effect of intramuscular fat on tenderness score, such as dilution of a more dense muscle matrix with less dense fat, as proposed by Miller (1994). It was interesting that, over the extended range in intramuscular fat % in this study, there was no evidence of the curvilinear relationship between intramuscular fat and juiciness and like flavour scores, reported by Thompson (2004) for grilled *M. longissimus lumborum*.

Ossification score is an index of skeletal maturity (Romans *et al*. 1994), scored as the visual calcification of cartilage in the spinous processes. In this study, ossification score had a negative effect on tenderness, overall liking and the MQ4 scores. This indicates that, as ossification score increased, sensory scores decreased. Other workers have examined the relationship between tenderness scores and skeletal maturity, with some studies showing a negative relationship between maturity scores and tenderness scores (Smith *et al*. 1982; Smith *et al*. 1988; Hilton *et al*. 1998), while others have failed to find any relationship (Romans *et al*. 1965; Field *et al*. 1997). In this study, the relationships between ossification score and tenderness, overall liking and MQ4 scores were only small, but consistently negative. This supports its use as a predictor of palatability in a beef grading scheme, such as MSA.

Consumer effects on sensory scores

This study used untrained consumers from different cultural backgrounds to evaluate cooked beef samples that differed widely in eating quality. Given that both consumer groups tested samples from the same muscles and cooking protocols, the consumer effects in this study were real and not simply confounded with processing or preparation effects. The interaction between consumer group and muscle was only evident for like flavour score, showing the largest effect for *M. longissimus dorsi* and the smallest effect for the *M. semimembranosus*. It is difficult to ascribe a reason to why Korean consumers scored the *M. longissimus dorsi* lower for like flavour than Australian consumers.

Differences in sensory scores between the consumer groups indicated that Korean and Australian consumers had a somewhat different perception for juiciness, like flavour, overall liking, MQ4 scores and, to a lesser extent, tenderness. After adjustment for the origin of the cattle, cooking, muscle, tenderstretch treatments, intramuscular fat % and ossification score, Australian consumers scored samples 8 units higher for juiciness and 5–6 units higher from overall liking, like flavour and the MQ4 score than did Korean consumers. Although still significant, the consumer effect on tenderness score was small, with Australian consumers scoring samples 2 sensory units higher than Korean consumers. Other workers have noted differences in overall liking scores between populations from different cities in the United States (e.g. Goodson *et al*. 2002), although it is difficult to be prescriptive about the reasons. The relatively small consumer effect for tenderness score suggests that it is more universal in its meaning than perhaps the other sensory traits.

Conclusions

This study showed that the effect of tenderstretch sensory scores varied due to muscle and cooking method. High connective tissue muscles from tenderstretched sides showed a large increase in tenderness when cooked as a thin BBQ strips. Results from previous studies suggest that cooking temperature may interact with the physical state of the muscle to result in this large increase in sensory tenderness scores.

Perhaps the most important conclusion from this study was that consumers from diverse cultural backgrounds showed only small differences in tenderness for samples over a wide range in palatability. Consumers did differ in their scores for juiciness, like flavour and overall liking, with Korean consumers scoring samples lower than Australian consumers. Whilst tenderness differences were still significant, the magnitude of the consumer effect was small at 2 taste panel units. This suggested that, regardless of cultural background, consumers generally had a similar view of tenderness of beef.

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