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Eating quality of conventionally chilled sheep meat

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Abstract. The meat and eating quality of the *M. longissimus et lumborum* (LL) from 80 adult sheep carcasses was examined. Half of the carcasses were subjected to the full range of electrical inputs that are routinely used at the abattoir: immobilisation, spinal discharge and high voltage stimulation (HVS), whereas the other half of the carcasses were subjected to all electrical inputs except HVS. HVS significantly decreased the first pH values and increased the average predicted temperature at pH 6.0. When the shear force of samples aged for 1 day was examined ($n = 77$), there was a significant effect of stimulation, such that non-stimulated meat was tougher. For a reduced sample ($n = 40$), the most influential effect on shear force was aging, with no significant effect of stimulation or interaction between stimulation and aging. This was such that aging reduced the percentage of samples with a shear force above 50 N from 75% after 1 day to 17.5% after 7 days of aging for the 40 LLs. When the LLs were aged for 7 days, there was no effect of stimulation on eating quality traits including tenderness, flavour, juiciness or overall liking. Based on the data for the LLs aged for 7 days, a relationship between overall liking and the overall ranking score was derived. Predicted overall liking scores at each rating score were derived, from which it was determined that to achieve a rating score of 3 (good every day), the overall liking score had to be 57. There was a significant interaction between category (less or greater than 57) and stimulation, such that for the less than 57 category, the mean overall liking score was lower for samples from non-stimulated carcasses (46.1) than those from stimulated carcasses (54.4). In the greater than 57 category, there was no difference between stimulated and non-stimulated samples with mean overall liking scores of 67.2 and 70.8, respectively. In total, 14% of samples had overall liking scores below 57. These results show that the proportion of very poor samples is reduced with stimulation even with aging and this is a very important outcome.

Additional keywords: consumer, electrical stimulation, quality, sheep meat.

Introduction

Electrical stimulation of muscle from slaughtered animals hastens the onset of rigor mortis. It does this by causing muscles to undergo work via anaerobic glycolysis, resulting in an initial fall in pH followed by a change in the rate of pH decline (Devine *et al*. 2004). Electrical stimulation technology was first used commercially in New Zealand to accelerate the onset of rigor mortis so that it occurred at higher temperatures than normal to prevent muscle shortening before the meat was frozen (Hwang *et al*. 2003). However, it has been reported by Geesink *et al*. (2001) that intense stimulation or over-stimulation can adversely affect meat quality. In work reported by Thompson *et al*. (2005*b*), this effect was evidenced as a reduction in the eating quality of meat when the temperature at pH 6.0 was $>30^{\circ}$C. At high muscle temperatures, some shortening can occur that, in some cases, leads to increased toughness in meat (Simmons *et al*. 1997; Unruh *et al*. 1986). This effect has been referred to as heat shortening and is considered to be due to the combination of high temperature and low pH in the muscle causing the early exhaustion of proteolytic activity (Hwang and Thompson 2001), increased toughening (Simmons *et al*. 1996) and drip loss (Denhertogmeischke *et al*. 1997).

The conditions required for heat shortening to occur in Australia are rare given the low adoption of electrical stimulation, however, the scenario does exist for Australia's largest sheep meat exporter. This exporter processes hot boned mutton and stimulation is used to avoid cold shortening (Toohey and Hopkins 2006). Given that tender meat is a major requirement for consumers, it is important to optimise the eating quality of meat according to the conditions of target markets. The aim of this experiment was to examine the impact of a combination of electrical inputs on the meat and eating quality of aged sheep meat destined for overseas markets.

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Materials and methods

Animals

There were 2 treatment groups, each containing 40 sheep: a control (non-stimulated) group that received electrical inputs without high voltage stimulation (HVS) and a group that received all electrical inputs including HVS. The sheep were Merinos sourced from 3 different farms by direct consignment: 1 farm located in the Western Division of New South Wales, group 1 ($n = 40$), and 2 farms located in the Central West slopes and plains of New South Wales, group 2 ($n = 20$) and group 3 ($n = 20$), respectively. The sheep were on similar quality pasture prior to slaughter but were of mixed age and were slaughtered over 2 days; on day 1, group 1 sheep were slaughtered and on day 2, groups 2 and 3 sheep were slaughtered.

Electrical inputs

The following electrical inputs were applied to every sheep carcass: head stunner (200 V at 1 A with a 50 Hz sine waveform) that preceded exsanguination; an immobiliser (15–17 V peak at 1.5–2.0 A with a 7 ms square waveform pulse width and 63 ms pulse space) applied for 40 s immediately after stunning; spinal discharge (588 V r.m.s., average current 3.8 A with a 50 Hz sinusoid waveform) applied for 3–4 s about 1 minute after death; and HVS (1130 V peak, the r.m.s. V is 800 V, peak current 1.1 A with a 14 Hz sinusoid waveform) applied for 100 s about 20 min after death. Each carcass was subjected to the immobiliser and spinal discharge, however, the HVS was switched on for 40 sheep carcasses and off for the remaining 40 (alternating 10 on and 10 off).

Measurements and sampling

Carcasses were trimmed according to the specifications of AUS-MEAT (AUS-MEAT 1992). Hot carcass weights were recorded and the GR measured (total tissue depth over the 12th rib, 110 mm from the midline) using a GR knife. Further background information was also collected on each group sampled including where they were sourced from and their transport time.

Carcass pH and temperature measurements were taken at regular intervals about 1, 2, 3, 5, 6 and 24 h after death and the carcasses were held in chillers at 4°C. The pH and temperature measurements were taken in the left portion of the *M. longissimus thoracis et lumborum* (LL) as previously described by Hopkins *et al*. (2006).

After chilling for 24 h, the pH of the LL was measured (pH_{24}) with calibration of the meter at chiller temperature. The left LL (from the lumbar/sacral junction to the 4th rib) was completely removed from each carcass and packed in double lined polystyrene boxes with ice packs then sealed and strapped for road transport to Co-Sign Pty Ltd, Coffs Harbour, NSW.

The right side LL was removed with a knife and divided into 2 portions (caudal and cranial) for shear force testing. This allocation was a predetermined stratified randomisation to ensure portion location was not confounded with aging period. Samples were prepared into 65 g blocks and the 1-day-aged samples were frozen (−20°C) at 1500–1600 hours on the day of preparation. Sections of LL aged for 7 days were vacuum-packed and held chilled (2–4°C) until freezing. Unfortunately, the 7-day-aged samples that were taken from kill 1 were accidentally frozen on day 1, hence these samples could not be tested, reducing the sample size. Samples were subsequently tested for peak shear force as described by Thompson *et al*. (2005*a*).

A 1 g sample of LL was also taken for determination of pH after 7 days of aging (for 40 of the 80 samples) using an iodoacetate method adapted from that described by Dransfield *et al*. (1992). Frozen muscle samples were homogenised using an Ultra Turrax at 19 000 rpm in 6 mL of cold buffer. The buffer contained 5 mmol/L iodoacetate and 150 mmol/L KCl adjusted to pH 7.0 with KOH at 4–5°C. Samples were homogenised for 2 bursts of 15 s with breaks of 30 s on ice. The suspensions were then incubated in a water bath at 20°C and the pH measured using a meter (TPS, WP-80, PTS Pty Ltd) with a polypropylene spear-type gel electrode (Ionode IJ 44) that was calibrated at 20°C.

Consumer testing

At the meat preparation laboratory, the subcutaneous fat, connective tissue and the epimysium were removed from each loin. Each sample cut was individually packed and aged for 7 days from the date of slaughter at 0–4°C and then kept frozen (−22°C) until testing. Before testing, the steaks were microwaved to raise their temperature to about −4°C and 5 slices of 15 mm thickness were prepared. These slices (steaks) were restored at −22°C until thawing at ambient temperature for cooking.

Sample preparation for consumer testing has been outlined by Thompson *et al*. (2005*a*). Each untrained consumer was asked to assess each steak for tenderness, juiciness, liking of flavour and overall liking on a continuous 100 point scale from 0 to 100. The 10 tastings for each muscle sample ($n = 80$) were averaged to give the final eating quality scores for the muscle, so that 800 tests were completed in total with each consumer testing 6 samples. In addition, each person was asked to score (rate) each sample as awful (1 star), unsatisfactory (2 star), good every day (3 star), better than every day (4 star) or premium (5 star).

Statistical analyses

Carcass and meat quality traits were analysed using a REML procedure in Genstat (Genstat 2004), which contained fixed effects for stimulation (Yes or No) and aging (1 or 7 days; for the reduced sample of 40) including the interaction term stimulation × aging for shear force and cooking loss data. For muscle pH immediately post-stimulation, muscle temperature was used as a covariate, and for the predicted temperature at pH 6.0, GR was used as a covariate. Random terms in the model included slaughter day (1 or 2) and lot nested within day. The relationship between overall liking score and the rating score was derived using linear regression and a threshold overall liking score was determined. A chi-square test was performed to examine whether there was a difference in the proportion of samples with unacceptable overall liking scores between stimulation treatments. The rate of temperature decline relative to time from the first measurement post-mortem for each carcass was described using data for 5–6 different sample points using the non-linear equation as previously described by Hopkins and Thompson (2001).

The rate of pH decline relative to time could not be fitted using a non-linear procedure so a linear regression procedure was used to derive the relationship between post-stimulation pH and temperature. For 46 carcasses the model for pH against temperature predicted coefficients that were inflated and so rate of decline and predicted temperature at pH 6.0 were not determined for these carcasses. Data from all carcasses were used to generate Figure 1.

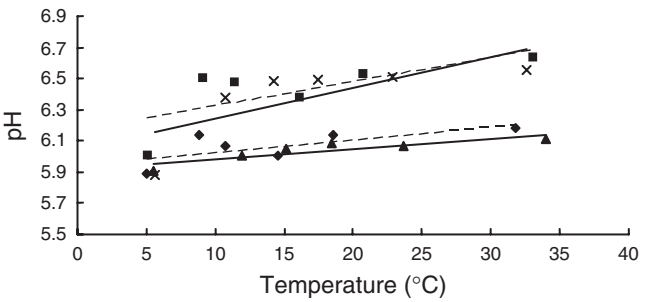

Fig. 1. The relationship between pH measurement and muscle temperature (°C) for non-stimulated carcasses slaughtered on day 1 (■), and day 2 (×) and stimulated carcasses slaughtered on day 1 (▲) and day 2 (◆).

Results

Carcass measures

The carcass and meat quality characteristics of the 80 mutton carcasses used in this experiment are shown in Table 1. There was considerable variation in the carcass weight, fat levels and in final pH levels.

pH levels and decline

High voltage stimulation significantly ($P<0.001$) decreased the first pH values as shown in Figure 1 and increased predicted temperature at pH 6.0 (Table 2). As GR increased, there was a significant ($P<0.05$) increase in the predicted temperature at pH 6.0 with a coefficient of 0.84 ($\pm$ 0.23) units. There was no effect ($P>0.05$) of stimulation on muscle pH as measured 24 h after death and this was further confirmed when the ultimate pH of half the samples was measured on samples aged for 7 days using the iodoacetate method. There was no difference in the proportion of samples with pH values above 5.8, 24 h after death for stimulated and non-stimulated carcasses, but 59% of samples had pH values above 5.8. This was compared with 54% when a subsample was tested after 7 days of aging.

Table 1. Mean, standard deviation (s.d.) and range of carcass and meat quality traits

Trait	Mean	s.d.	Range
Hot carcass weight (kg)	26.7	4.49	17.4–36.4
GR depth (mm)	12.9	5.93	2.0–24.0
Loin pH_{24}	5.92	0.28	5.53–6.70
Temperature at first pH measurement (°C)	32.8	2.16	27.2–36.1
Predicted temperature at pH 6.0 (°C)[A]	19.0	11.4	3.9–38.2

[A]Measured for 34 carcasses.

Shear force and cooking loss

A reduced sample size meant that there was only data for 40 samples aged for 7 days, with 77 samples aged for 1 day. For the reduced sample ($n=40$), the most influential effect on shear force was aging ($P<0.001$) with no significant effect ($P>0.05$) for stimulation or interaction between stimulation and aging. The aging effect was such that the percentage of samples with a shear force above 50 N dropped from 75% after 1 day to 17.5% after 7 days of aging. When the shear force of samples aged for 1 day was examined ($n=77$) there was a significant effect ($P<0.05$) for stimulation (Table 2), such that non-stimulated meat was tougher. There was variation in shear force according to lot, but not day. Cooking loss was unaffected ($P>0.05$) by stimulation or aging time (Table 2), however, there was variation in cooking loss according to day, but not lot.

Eating quality

When the loins were aged for 7 days there was no effect of stimulation ($P>0.05$) on the eating quality traits (Table 2). Based on data for loins aged for 7 days, a relationship for overall liking and the overall ranking score was derived, where overall liking score $= -4.83 + 20.8$ (overall rating score), $R^2 = 0.74$, r.s.d. $= 4.8$. Predicted overall liking scores at each rating score were derived, from which it was determined that to achieve a rating score of 3 (good every day) the overall liking score had to be 57. On the basis of this value, a chi-square test was performed to determine if there was a difference in the proportion of samples that had an overall liking score less than 57 for stimulated and

Table 2. Characteristics of meat from sheep according to treatment (stimulation *v.* no stimulation) and aging (1 day *v.* 7 days)

Values are the predicted means and the average standard error of the difference (av. s.e.d.). Means within each columns followed by the same letter are not significantly different at $P=0.05$

Traits	Stimulation			Aging ($n=40$)		
	Yes	No	Av. s.e.d.	1 day	7 days	Av. s.e.d.
Initial pH[A]	6.15a	6.59b	0.04	—	—	—
Loin pH_{24}	5.91a	5.96a	0.06	—	—	—
Loin pH (ultimate)[B]	5.92a	6.01a	0.10	—	—	—
Temp pH 6.0[C]	25.8a	6.8b	2.31	—	—	—
Shear force (N)	54.2a	61.9b	3.67	59.7a	38.7b	2.85
Cooking loss (%)	20.1a	19.8a	2.07	21.6a	22.0a	1.94
Tenderness	66.8a	68.6a	2.21	—	—	—
Juiciness	57.3a	59.4a	2.25	—	—	—
Flavour	64.6a	66.6a	2.01	—	—	—
Overall liking	65.2a	67.6a	2.07	—	—	—

[A]Adjusted to a muscle temperature of 32.8°C.
[B]For 39 carcasses.
[C]Adjusted to a GR of 12.9 mm and tested for 34 carcasses.

non-stimulated carcasses. There was no significant ($P>0.05$) difference between the overall liking score for stimulated and non-stimulated carcasses, but there was a significant interaction between category (less or greater than 57) and stimulation such that the mean overall liking score was lower for unstimulated samples (46.1) with values less than 57 than for stimulated samples (54.4) with values below 57. Above 57, there was no difference between stimulated and non-stimulated samples with means of 67.2 and 70.8, respectively. In total, 14% of samples had liking scores below 57.

Discussion

The level of muscle glycogen preslaughter influences the final muscle pH, and glycogen levels are affected by energy intake (Pethick *et al*. 2000). After 1 day and 7 days of aging, 59 and 54% of samples, respectively, had a pH >5.8. This indicated that the sheep slaughtered for this experiment were likely to have had depleted glycogen levels. It is probable that the bacteriological stability of this meat, if transported as a chilled vacuum-packed product, would have been low, given that bacteriological stability declines above a pH of 5.8 (Egan and Shay 1988). Additionally, Young *et al*. (1993) have shown that as the pH increases, the intensity of foreign flavours increases and this could lead to a detrimental effect on eating quality. Fortunately, this was not the case and may reflect the fact that the tested meat was devoid of external fat, which lessened the opportunity for foreign flavours to develop.

As expected, HVS in combination with the other electrical inputs resulted in a large initial decline in pH, which is called the delta pH (Devine *et al*. 2004), and as a consequence, these carcasses entered rigor at a much higher temperature than the non-stimulated carcasses. Based on the modelling conducted in this study, the stimulated carcasses achieved pH 6.0 at around 25°C, within the critical range suggested by Thompson *et al*. (2005*b*). However, it is of interest that without the use of HVS, carcasses exhibited a slow overall rate of decline and reached pH 6.0 below the optimal temperature (Thompson *et al*. 2005*b*). This would suggest the potential for cold-induced shortening through a prerigor contracture Hwang *et al*. (2003) and appears to indicate that the immobilisation and spinal discharge inputs did not elicit a significant response in pH decline. This confirms previous results at the same abattoir (Toohey and Hopkins 2004). In the experiment conducted by Shaw *et al*. (2005), a control (non-stimulated) group of lamb carcasses achieved a temperature of 7.6°C at pH 6.0, whereas stimulated groups achieved temperatures in the order of 25°C at pH 6.0, which was similar to the present experiment. Shaw *et al*. (2005) also found that the mean shear force value in the control group was 56.9 N, which was significantly greater than the mean of 34.2 N for the stimulated group after 1 day of aging, representing a larger differential between treatment groups than those found in the present study. As a shear force value of about 50 N is suggested as the tenderness–toughness threshold based on the work of Shorthose *et al*. (1986), at least for lambs, the mean value of 62 N for the non-stimulated samples after 1 day of aging in the present study indicates that a percentage of samples would have an unacceptable degree of toughness and that there was some shortening. The magnitude of this effect could even be greater as recent evidence has emerged that current Australian consumers of sheep meat may have an even lower tolerance for tough meat, with a revised level suggested at 25–30 N (Hopkins *et al*. 2006). The use of HVS stimulation reduced the variation in shear force, as evidenced by a reduction in the difference between the mean and median values. This reduction in variability in shear force by reducing the number of tough samples has been reported previously. Hopkins and Ferrier (2000) reported that 44% of samples from a control (non-stimulated) group had shear force values above 81.4 N, whereas no samples subjected to low voltage stimulation exceeded this 81.4 N. Both Shaw *et al*. (1996) and Hanrahan *et al*. (1998) have reported a similar response.

It is well known that aging improves tenderness, with a reduction in shear force (e.g. Pearson and Young 1989). The aging period in the present study was chosen to simulate the time taken for the product to reach overseas markets and provide the company with a benchmark of how their product performed.

From the eating quality results, it was derived that the overall liking score needed to be above 57 to achieve an overall rating of good to every day. This overall liking score was similar to that previously reported by Toohey and Hopkins (2006) for hot boned, frozen sheep meat (55). In this present study, it was determined that only 14% of the product aged for 7 days had a score below 57. Thus, of the product sampled, a relatively high consumer compliance was achieved when an aging period of 7 days was applied, and there was no difference between the mean scores of stimulated and non-stimulated the meat. Previous work with lamb and sheep meat indicated that the mean value for overall liking of 66 found in this study was very good, with lower levels expected (Pethick *et al*. 2005; Thompson *et al*. 2005*b*). In the study reported by Shaw *et al*. (2005), an experiment is described that compared the eating quality of mutton loins subjected to HVS and aged for 10 days (mean overall liking 65) with those that were not stimulated and aged for 10 days (mean overall liking 63) illustrating that with sufficient aging, the non-stimulated mutton loins will attain similar levels of liking to the stimulated mutton loins. As with shear force, however, the eating quality results of the present experiment show that the proportion of very poor samples is reduced with stimulation and this is the most important outcome.

Conclusions

There was no apparent detrimental effect on the eating quality of loins from mutton carcasses when subjected to electrical inputs to generate a temperature at pH 6.0 of about 25°C. By contrast, carcasses that achieved a temperature at pH 6.0

of about 7°C produced a proportion of tough loins when tested for shear force at 1 day of aging. Even though the eating quality of these loins was not different on average from those that had entered rigor at the higher temperature when compared after 7 days of aging, the proportion of unacceptable samples was higher. A low value product such as a mutton loin can, with postmortem intervention, be turned into a very acceptable cooked table meat. The incidence of high pH meat does illustrate the potential limitations though of mutton meat with an expected reduction in shelf life.

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