Meat technology update

3/11 – May 2011

Heat toughening—Part 2:
Strategies for reducing the incidence of heat toughening in beef carcases

Heat toughening can have detrimental effects on meat quality, and the incidence can be reduced by:

- **rapidly cooling the affected muscles;**
- **minimising electrical inputs during dressing;**
- **not stressing the live animal prior to slaughter.**

Heat toughening in beef carcases is caused by rapid pH fall in the pre-rigor period, while muscle temperatures are still high. This was discussed in the previous Meat Technology Update titled 'Heat toughening—Part 1: Effects of heat toughening on quality of beef, and the incidence in Australia'. This MTU discusses the effects of on-farm, pre-slaughter and post-slaughter factors which contribute to heat toughening in beef carcases. It also presents strategies to reduce the incidence of heat toughening.

Contribution of muscle temperature

Temperature affects the rate of enzyme reactions, with an exponential increase in the rate of enzyme reactions at higher temperatures. Glycolysis is an important enzymic process in post-mortem muscle. It involves the formation of lactic acid from the anaerobic breakdown of glycogen, and results in a pH fall. At higher muscle temperatures, the rate of glycolysis, and thus the rate of pH fall, is exponentially increased. For example, lamb loin muscles held at 35°C had an average pH of 6.0 at 2 hours after slaughter. In contrast, muscles chilled to 2°C, had an average pH of 6.5 at 2 hours after slaughter. The difference in muscle pH was smaller if the carcases had been electrically stimulated, but was still 0.2 pH units lower in the muscles held at 35°C.

If beef carcases are held on the slaughter floor during breaks, or if there is a delay on the slaughter floor, the result will be that the temperature at pH 6 will be higher and the incidence of heat toughening is likely to be higher. Also, if beef carcases are over-stimulated, they will have a higher temperature at pH 6.

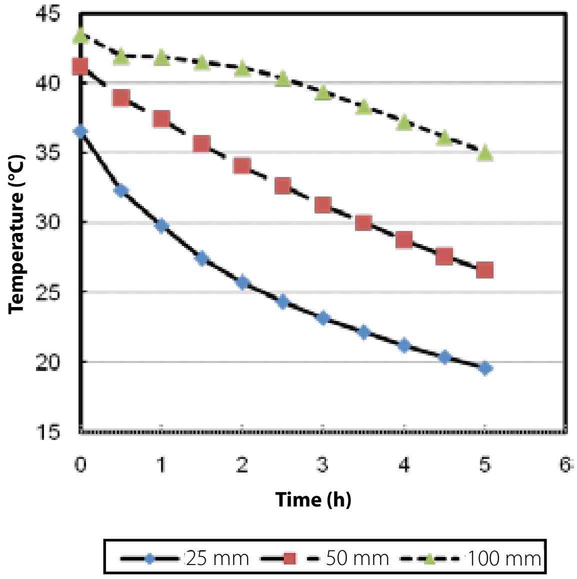

Figure 1: The muscle temperature (°C) at depths of 25, 50 and 100 mm measured every 30 minutes for 5 h post-slaughter (values are means)

Variation between muscles in temperature decline

Muscles in beef carcases vary substantially in their cooling rates. Muscles that are close to the surface of the carcase and have little depth, such as the loin, chill quickly. Deep muscles, such as the muscles in the butt, cool much more slowly, particularly in the centre of the muscle (see Figure 1). The MSA window is based on measuring the rate of pH and temperature fall in the loin muscle (*longissimus lumborum*). Primals (and muscles) such as the rump (especially *gluteus medius*), topside (especially *semimembranosus*) and outside (*biceps femoris*), are deep muscles and are very likely to have a higher temperature at pH 6 than the loin muscle. When measurements in the loin indicate that a beef carcase is heat toughened, the leg muscles are therefore likely to have more extensive quality problems such as pale colour, weep and inconsistent eating quality. In addition, the centre of a deep muscle declines in temperature more slowly and can have a faster pH fall. The outcome of this is that zones of heat toughening can occur in a muscle such as the *semimembranosus*, with darker, less weepy surface towards the outside, and a paler, more weepy surface towards the inside of the muscle/carcase. This can cause inconsistent and variable eating quality across a muscle.

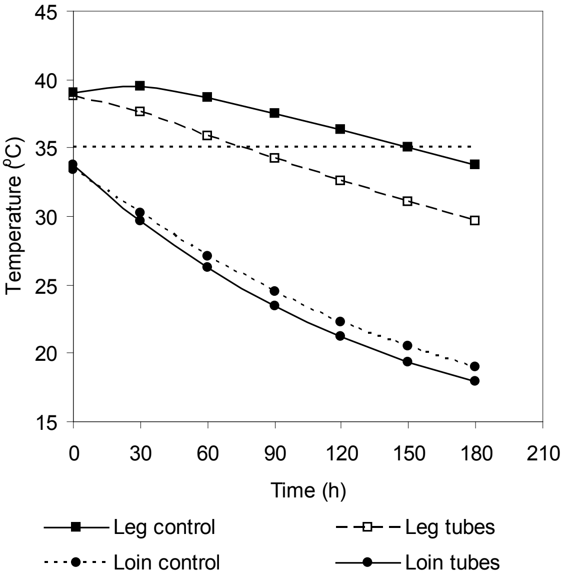

Figure 2: The effect of muscle (leg vs. loin) and heat tubes (control vs. tube) on the temperature time plot (values are means)

Effect of grain feeding, carcase weight and fat depth on muscle temperature

Heavy carcases cool more slowly. Generally, grain-fed carcases are often heavier, which partially explains why grain-fed carcases are known to have a high incidence of heat toughening. At the same carcase weight, increasing fat depth in grass-fed carcases results in slower chilling rates and an increase in the incidence in heat toughening (see Figure 9 in MTU 2/11). Thus a potential solution for heat toughening in carcases from grass-fed beef is to undertake hot-fat trimming after the scales, in order to increase the rate of muscle cooling.

In contrast, at the same carcase weight, fat depth has little influence on the incidence of heat toughening in grain-fed carcases (see Figure 9 in MTU 2/11). This appears to be because carcases from grain-fed cattle have an inherently fast metabolism. There is now mounting evidence that grain-fed cattle may be in a state of insulin resistance which can compromise the ability of an individual to thermoregulate and that this can be exacerbated by stressors. The only solution for the high incidence of heat toughening in grain-fed carcases appears to be animal intervention through dietary supplements. The most promising dietary supplements are betaine, chromium, tryptophan and magnesium—either alone, or in combination. Further research on this topic is warranted.

Effects of pre-slaughter stress or exercise on muscle temperature

The muscles in the carcases of animals undergoing stress or exertion pre-slaughter can be 2–3°C higher compared to animals slaughtered with minimal stress or no exertion pre-slaughter. This has been proven across a number of studies which demonstrate that stress and exertion pre-slaughter result in activation of adrenergic pathways and muscle metabolism in the live animal. There is then accelerated metabolism post-slaughter with associated faster rates of pH fall. To reduce the incidence of heat toughening in practice, stress and exertion pre-slaughter should be minimised. This includes consideration of the effect of using electric prodders/goads pre-slaughter on animal stress. Information on minimising stress pre-slaughter and recommendations for handling cattle, are available from the MSA website (www.mla.com.au/msa) or from Temple Grandin's website (www.grandin.com).

Effect of 'heat tubes' on muscle temperature

The rate of chilling of muscle tissue is limited by its poor thermal conductivity. Providing a high thermal conductivity path to the centre of the meat is a potential method of overcoming this problem. 'Heat tubes' are sealed metal tubes containing a refrigerant, which transfers heat to the cooler end of the tube if there is a small temperature difference between its ends. If one end of the tube is placed in contact with a warm medium, such as muscle, heat will be extracted from the medium and transferred to the cooler end of the tube, such as the chiller air. In the trial pictured in Figures 2 and 3, a high surface area was used at the cold medium end in order to increase the rate of heat transfer. Figure 3 shows the insertion of the heat tubes into the leg and rump of a beef carcase, and the sites for insertion of the thermocouples for temperature measurement. The heat tubes had a small effect on the rate of temperature decline in the loin and a much larger effect in the leg (see Figure 2). The importance of the effect of the heat tubes in the leg was to decrease the time taken for the temperature to reach 35°C to within 80 minutes, and to reduce the temperature by 4°C at 3 h after commencement of chilling. A temperature of 35°C is the upper limit of the 'normal' region of the MSA

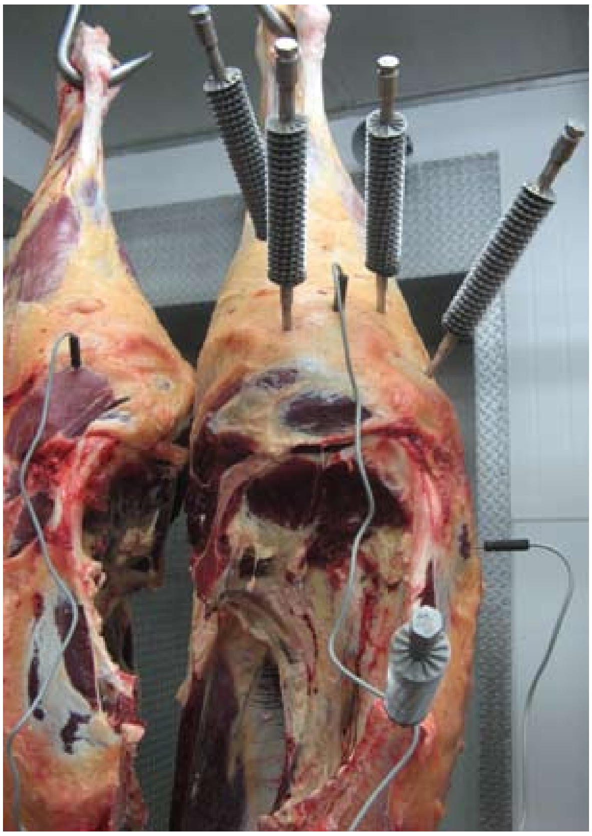

Figure 3: Location of heat pipes and thermocouples for the leg and loin for control and treatment sides. Note: The heat tubes must be placed at an angle above horizontal, in order to work.

pH-temperature window. Critically, from the point of view of reducing heat toughening, the heat tubes acted to reduce temperature early in the chill period. Heat tubes could be a way of increasing the rate of heat loss from beef legs for the purpose of preventing heat toughening; however, the practicalities of their use need to be considered.

Effect of vascular infusion on muscle temperature and metabolism

Vascular infusion is a process whereby water and, if required, a small quantity of some common substrates is pumped through the cardiovascular system of the intact carcase soon after slaughter. Vascular infusion is now applied commercially (MSPC, Inc., Eden Prairie, MN, USA). The vascular infusion of a cold solution to the beef carcase post-slaughter can reduce the muscle temperature of the loin by as much as 2–4°C.

Vascular infusion offers the potential to effectively administer solutions to carcases and thus manipulate the rate of pH fall. Solutions such as citrate, or sodium bicarbonate could be used in the infusion solution in order to slow down the rate of glycolysis and thus the rate of pH fall. Further, if very cold water could be used then this would reduce carcase temperature which, in itself, may be sufficient to alleviate the problems associated with pH decline in heavy beef carcases, without adding compounds to the water. Infusion of very cold water containing a citrate or bicarbonate compound, provides an avenue worthy of further study.

Electrical stimulation during immobilisation

At most beef slaughter plants, after an animal is stunned it falls out of the knocking box onto a table where an electrical current is applied to immobilise the animal during exsanguination and shackling of the hind leg. The immobilising current is applied for occupational health and safety reasons as it reduces the risk of worker injury due to carcases kicking during these operations. The older immobilisation units, which were set to deliver a higher current and lower frequency, increase the rate of pH fall in the loin muscle.

With the newer immobilisation units, when the settings are optimised, the effect of the electrical current applied during immobilisation on the pH fall, and % heat toughening, should be minimal. In a study of 60 beef carcases, when the immobiliser was set to 1.0 A and a frequency of 2,000 Hz, 100% of the carcases were within the pH-temperature window (see Table 1). When the current was increased to 1.6 A and the frequency reduced to 450 Hz, only 45% are in the pH-temperature window, with 55% heat toughened.

Electrical stimulation for bleeding or to prevent cold shortening

The application of electrical stimulation to a carcase was originally introduced in order to speed up the rate of pH fall, hasten rigor onset, and prevent cold shortening. More recently, it has also been applied to carcases to enhance the 'bleeding out' process, enabling more efficient blood collection. To reduce the incidence of heat toughening, it is recommended that all forms of electrical stimulation applied to the carcase are minimised. Electrical inputs used for immobilisation of the carcase immediately after exsanguination, or the use of a rigidity probe to stiffen the backbone during removal of hides may be unavoidable.

Table 1: Effect of current setting (1.0 vs 1.6 amps) and frequency of current (2,000 vs 450 Hz) applied during immobilisation on the average temperature at pH 6 and % of carcases in the pH-temperature window (i.e. temperature at pH 6 <35°C).

Group	n	Current (A)	Frequency (Hz)	Average temp. @ pH 6 (°C)	% of carcases in the MSA pH-temp. window
1	15	1.6	2000	30.9	87
2	15	1.0	2000	29.8	100
3	15	1.6	450	33.4	47
4	15	1.0	450	34.9	60

Notes: Temp @ pH 6 = group average temperature at pH 6.
% MSA = percentage of bodies grading within the MSA window.

Electrical stimulation during hide removal

In order to remove the hide from a beef carcase using a downward hide puller, a rigidity probe is applied to the back of the carcase, and a current is applied. This is in order to stiffen the backbone and prevent breakage in the spinal column. The application of the rigidity probe increases the rate of pH fall, and causes an increase in the temperature at pH 6. Figure 4 shows this relationship and the corresponding regression equation predicts that if the rigidity probe stimulation is reduced by 10 s, this would reduce the temperature at pH 6 by 2°C, potentially moving a borderline carcase away from being heat toughened. To reduce the influence of the rigidity probe on heat toughening, it is recommended that the rigidity probe stimulation time is as short as possible.

Most stiffening probes operate at 50 Hz at about 180 V through an isolating transformer, but newer equipment is available operating at 40 Hz pulsed DC, 4–5 A peak and reduces the effect on pH while providing effective stiffening.

Potential strategies which require further research

- Compounds such as sodium bicarbonate or citrate show potential to slow the rate of glycolysis if added to the carcase infusion solution.
- Feeding of magnesium, chromium, tryptophan or betaine as dietary supplements pre-slaughter have the potential to either reduce body temperature, or reduce the stress response pre-slaughter.

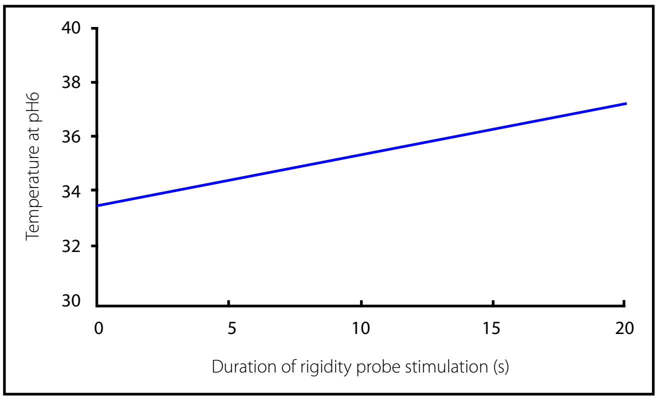

Figure 4: The predicted relationship between the temp. at pH 6 for the loin muscle and the duration of rigidity probe stimulation

Recommendations:

- Ensure the immobiliser is at optimum frequency and current (2,000 Hz and 1.0 A).
- Turn electrical stimulation/bleed units off for any carcases at risk of heat toughening, especially grain-fed or heavy carcases.
- Reduce the time the rigidity probe stimulation is applied at the hide puller to below 10 s.
- Consider hot-fat trimming carcases, particularly carcases from grass-fed cattle, to increase the rate of temperature fall.
- Run carcases off the slaughter floor at breaks.
- Consider strategies to reduce pre-slaughter stress and ensure animals are not being unduly exerted pre-slaughter. For example, walk them quietly from the pen to the knocking box, rather than galloping.
- Consider vascular infusion with cold water.
- Consider using heat tubes for susceptible carcases or susceptible muscles.

The contribution of MSA and DAFWA, particularly Janine Lau and Robin Jacob respectively, to the work reported here is acknowledged.

Strategies and recommendations for reducing the incidence of heat toughening in beef carcases

Site in chain	Strategy	Proposed mechanism	Comment
On-farm	Feeding betaine	Reduces body temperature	Experimental results show promise
	Feeding tryptophan (Trp) or magnesium (Mg) or chromium (Cr)	Reduces stress, therefore body temperature and muscle glycolytic metabolism	Successful in pigs (Mg, Trp) and sheep (Mg)
Pre-slaughter	Minimise electric prodding and improve handling of cattle	Reduces stress and therefore reduces carcase temperature and rate of glycolysis	
	Showering of cattle and providing shade	Reduces heat stress and thus reduces carcase temperature at slaughter	
	Don't excessively exercise or run cattle prior to slaughter	Reduces stress and muscle temperature	
Slaughter floor	Rinse-chill with solution of ice-cold water	Removes heat from carcase	Evidence for reductions in muscle temperatures of 2–3°C
	Rinse-chill with solution containing citrate or bicarbonate	Slows down rate of glycolysis	Proposed
	Expertly applied stunning	Minimal struggling and stress	
	Use high frequency current (2,000 Hz) set at 1 A during immobilisation	Reduces effect on glycolytic metabolism thus little effect on pH	Firm evidence
	Remove electrical stimulation for bleeding or cold shortening	Generally increases rate of pH fall and often increases muscle temperatures	Well proven
	Minimise time rigidity probe is on at hide puller	Rigidity probe current causes fall in muscle pH	Evidence that for every 10 s time reduction, temperature at pH 6 reduces by 2°C
Chillers	Hot-boning and very fast chilling	Reduces muscle temperatures and therefore glycolytic rate	
	Insertion of heat tubes	Reduces muscle temperature	Evidence that temperature in topside muscle is reduced by 6°C at 4 h post-slaughter

Contact us for additional information

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