Why is muscle metabolism important for red meat quality?
An industry perspective

Introduction
In the 1990s, the beef and sheep industry in Australia recognised that an eating quality assurance scheme was needed in order to describe and differentiate the eating qualities of different types of beef and sheep meat and to ensure the descriptions were credible (Meat Research Corporation 1996). This was in response to the falling per capita consumption of both beef and sheep meat in Australia (Williams and Droulez 2010) and evidence that the inconsistency in tenderness was causing major problems for both sheep (Safari et al. 2002) and beef (Meat Research Corporation 1996) meat. Furthermore, the recommendations for the proposed grading scheme were that it should encompass whole of chain, from genetics and animal age, through pre- and post-slaughter treatment of the carcass, to the consumer, where cooking technique based on cut and quality were recommended (Meat Research Corporation 1996). The development of the Meat Standards Australia (MSA) grading system, the consumer testing protocols, and the underpinning research for assuring quality to the consumer is summarised for beef by Polkinghorne et al. (2008) and Smith et al. (2008) and for sheep by (Thompson et al. 2005a) and Young et al. (2005).

Why is muscle metabolism important for eating quality assurance?
Importantly, although research had shown that muscle metabolism post-mortem, as measured by the rate of pH and temperature fall, influences eating quality (Marsh et al. 1987; see Kim et al. 2014), the grading schemes for assuring beef and lamb quality, from major meat producing countries such as Japan, USA and Canada, did not include this parameter (Webster et al. 1999; Polkinghorne and Thompson 2010). Early MSA trials showed reduced beef eating quality with inducement of rapid metabolism post-mortem using electrical stimulation (ES) (Polkinghorne et al. 2008) and this was confirmed in studies by Hwang and Thompson (2001b) and Hwang and Thompson (2001a) when ES was applied to specific types of carcasses. The negative effect of high pre-rigor temperature on the ageing potential of excised beef muscles under controlled conditions was demonstrated by Thomson et al. (2008). Although there has not generally been a detrimental effect of rapid metabolism induced by ES on tenderness in most experiments using sheep carcasses, there have been some instances where ES produced detrimental effects. Shaw et al. (2005) demonstrated that high voltage ES of sheep carcasses increased the percentage of 4-day-aged lamb loins rated as unsatisfactory. Warner et al. (2005) showed that low voltage ES of lamb carcasses resulted in lower consumer scores for smell, tenderness and overall liking, and attributed this to the ‘heat toughening’ (viz. higher rigor temperature). Finally, Thompson et al. (2005b) showed the curvilinear relationship between consumer scores for sheep meat for overall liking and rigor temperature, with the optimum rigor temperature being ~20°C.

In 1999, the Meat Standards Australia Pathways Committee recommended the inclusion of a ‘pH–temperature window’ in the Australian eating quality scheme for assuring quality to the consumer (Webster et al. 1999). The Meat Standards Pathways Team focussed on identifying an abattoir window which could avoid damage and reduce eating quality resulting from either hot- or cold-shortening (Webster et al. 1999). The prescribed pH–temperature window for beef carcasses stated that the muscle (striploin, longissimus lumbarum) should commence rigor (defined as pH < 6.0) between 12°C and 30°C to avoid cold-shortening (≤12°C) and ‘high rigor temperature’ (>30°C) respectively (Ferguson et al. 1999). This was later revised to between 10°C and 35°C (Thompson 2002) (see Fig. 1). The effect of high rigor temperature on the visual colour and water-holding capacity of beef striploin is shown in Fig. 2. For lamb carcasses, an optimal pH–temperature window for eating quality has been defined as 18–35°C for product aged for 5 days and 8–18°C for product aged for 10 days (Food Science Australia 2007).

As a consequence of the inclusion of the pH–temperature window in MSA grading, the registration of beef processing plants for accreditation for MSA includes an initial audit to establish the pH–temperature decline post-mortem of a typically slaughtered sample of carcasses (Meat Standards Australia 2013). If the beef carcasses are outside the window, the MSA graders assist the processing plant to achieve a pH–temperature decline to fit within the window. Furthermore, in order for a beef abattoir to maintain MSA accreditation, their procedures are audited within a QA system to ensure pH and temperature relationships are within the prescribed window to achieve optimal palatability (Thompson 2002). In the case of sheep carcasses, Meat Standards Australia requires sheep meat processors to measure and control systems to fall within the pH–temperature window (Food Science Australia 2007). Four times per year, processors are required to select four consignments of sheep per day and 25 carcasses per consignment to determine the number of carcasses ‘hitting’ the window. pH needs to be recorded 20–30 min post slaughter and again when the carcass is close to 18°C (Food Science Australia 2007).

Definition and explanation of high rigor temperature
As described above, a high rigor temperature carcass is defined as a carcass in which the longissimus lumbarum has a pH < 6.0 while the temperature is ≥35°C (Thompson 2002; Fig. 1). MSA has previously described this as ‘heat-shortening’ or ‘heat-toughening’. For reasons described in papers in this special issue (Jacob and Hopkins 2014; Kim et al. 2014; Warner et al. 2014), these terms are not recommended and the use of the term ‘high rigor temperature’ has been adopted in most of the papers in the special issue.
Why a project?

After MSA had been grading beef carcasses for 10 years in Australia, the processing industry reported that the incidence of ‘heat-shortening’ in beef carcasses was high, particularly in carcasses from grain-fed cattle. The processing industry requested the development of a ‘pH decline program’ to assist in controlling yield-, quality- and efficiency-related issues associated with fast pH decline. It was recognised by industry that these quality and yield problems had impacts on the acceptability of the product on domestic and export markets. Thus, it was proposed to undertake a series of case studies with beef supply chain companies experiencing associated quality and yield problems due to non-ideal pH and temperature declines. The proposed project was designed to focus on the development of industry guidelines, processing solutions and interventions and on a strategic research program to address the issues. The project involved collaboration between seven beef processing plants and seven research organisations and was supported by investment from all organisations and companies and funding from Meat and Livestock Australia.

Contents of the special issue and dissemination to industry

This special issue of Animal Production Science (‘Muscle metabolism in sheep & cattle in relation to meat quality’) provides the research outcomes and recommendations arising from a project which had the aim of addressing quality problems associated with high rigor temperature in beef and sheep carcasses. The first paper quantifies the occurrence of high rigor temperature in beef processing plants in Australia and identifies some of the causative factors. Section 1 contains a review and four research papers quantifying the influence of high rigor temperature on the visual, objective and sensory quality traits of muscles from beef and lamb carcasses. Section 2 has a review and three research papers which focus on the in vivo metabolic conditions that contribute to high rigor temperature post-slaughter and potential strategies to apply to the live animal to ameliorate or prevent the occurrence of high rigor temperature. Post-mortem muscle metabolism and potential industry solutions are presented in two reviews and two papers in Section 3. Finally, an overview is presented, in which the results are reviewed and summarised by overseas researchers external to the research and the project.

The research program also involved close collaboration with commercial meat processing companies. Outcomes were disseminated (and implemented) by site visits to each commercial processing plant involved in the project and the publication of industry fact sheets. The effects of heat-toughening on beef quality and the incidence in Australia is described in Meat and Livestock Australia (2011a) and the strategies for reducing the incidence in beef carcasses are described in Meat and Livestock Australia (2011b). Food Science Australia (2007) describes the procedures for managing electrical inputs in sheep carcasses in order to meet the pH–temperature window.

D. A. Gutzke
Meat and Livestock Australia

P. Franks
Meat and Livestock Australia

D. L. Hopkins
NSW Department of Primary Industries Centre for Red Meat and Sheep Development

R. D. Warner
CSIRO Animal, Food and Health Sciences

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**Fig. 1.** The pH–temperature window used by Meat Standards Australia to optimise the decline in pH relative to the temperature of the muscle in beef. The dotted line represents an optimal rate of decline, the solid line a cold shortening, and the dashed line, a high rigor temperature scenario. The regions to avoid for assurance of quality meat are the cold-shortening region and the high rigor temperature region.

**Fig. 2.** An exposed striploin (longissimus thoracis) at grading (quartered between 11th and 12th rib) showing the pale colour and beads of moisture exuding from the surface, both of which are associated with high rigor temperature beef carcasses. Credit: Robert Strachan, formerly Meat Standards Australia, Brisbane, Australia.
References


Hwang IH, Thompson JM (2001a) The effect of time and type of electrical stimulation on the calpain system and meat tenderness in beef longissimus dorsi muscle. Meat Science 58, 135–144. doi:10.1016/S0309-1740(00)00141-8


