final report

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Optimising the abattoir component of the supply chain for red meat to increase processing efficiency, yield and quality

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Abstract

Rapid pH fall in beef or lamb carcasses early post-mortem causes a condition called 'heat toughening'. Heat toughening is particularly prevalent in grain-fed carcasses and MLA was asked to assist the industry with reducing heat toughening. A survey of seven large beef-processing plants across Australia showed that the overall incidence of heat toughening was 74.6%. Animal and slaughter-floor factors which could be managed to reduce the incidence were identified.

Analysis of large data sets, including consumer data, identified that heat-toughened meat shows:

- a failure to tenderise in the vacuum bag;
- lower AUSMEAT colour scores; and
- higher water loss.

A review of literature and experiments conducted identified that minimising electrical inputs on the slaughter floor and novel techniques for muscle chilling have potential for reducing the incidence. Blood metabolite and temperature measurements indicated that grain-fed cattle have altered metabolism and higher core-body temperature, with betaine feeding showing potential for reducing body temperature. Heat toughening also occurs in lamb carcasses, but is far less prevalent. A filter-paper method used at grading showed promise for identifying heat toughened carcasses. Communications with Carnetech in New Zealand enabled incorporation of heat toughening into the QOP model for predicting quality. MSA is incorporating heat toughening into its model once identification of heat toughening at grading is possible.

Executive summary

Heat toughening is a phenomenon that is typically associated with conditions that occur during the immediate pre- and post-rigor period in beef. Typically this occurs when the post-slaughter pH fall is rapid while the carcass temperature is still high. This condition causes a level of denaturation to both the structural proteins and the proteolytic enzymes.

These conditions can be generated easily in any meat species where the level of electrical stimulation is high and the carcass cooling is relatively slow; however, for reasons that are currently unclear, grain-fed Australian beef carcasses can have a rapid pH fall during the early post-mortem period, even with minimal electrical inputs to the carcass. This problem is proving to be a commercial concern since beef that exhibit the so-called 'heat toughening' condition (muscle temperature at pH 6>35°C) are excluded from MSA grading.

The objectives of the project were to: (1) conduct a critical review, (2) engage with supply chain companies, (3) conduct case studies and economic analyses, (4) verify effects of heat-toughening on quality, (5) conduct targeted research to reduce the occurrence of heat-toughening, (6) enable incorporation of heat toughening into the MSA model, (7) assist in incorporation of Australian data into the QOP simulator, (8) evaluate importance of heat toughening in lamb carcasses and (9) enhance awareness of heat toughening in industry and scientific circles.

Seven beef processing plants were contacted and became collaborators in the case study conducted in the project. The aim of the case study was to quantify the occurrence of heat-toughening in beef carcasses around Australia, and to identify causative factors. The case study used data from 103 mobs of cattle and and 1,512 beef carcasses including data from grain-fed cattle, ranging in days on feed from 0 (grass-fed) to 350 days. A small proportion of vealers, ox, cow, yearling and MSA cattle were sampled but the majority of cattle were grain-fed. The occurrence of heat-toughening across all 7 abattoirs was 74.6% ranging between abattoirs from 56% to 94%. Analysis of the data identified that the temperature at pH 6, and therefore % heat-toughening, was increased by longer days on grain-feeding, longer times of contact for the rigidity probe at the hide puller and increasing carcass fat depth for grass-fed cattle, and also for male cattle. Overall, the carcasses of grain-fed cattle had >80% heat-toughening, MSA and grass-fed cattle had about 50-60% heat toughening and vealers and cull cows had about 24% heat toughening.

A critical review was conducted of the metabolic causes and post-mortem conditions that contribute to heat toughening. One of the main causes of heat toughening appears to be a combination of rapid glycolysis and relatively slow cooling which can lead to high rigor temperatures. Moreover, heat toughening may be exacerbated by loss in proteolytic potential due to inactivation of proteolytic enzymes. Factors which contribute to elevated body temperature pre-slaughter would potentially predispose animals to higher carcass temperature immediately post slaughter. There is now mounting evidence that a state of insulin resistance can compromise the ability of an individual to thermoregulate and that this can be exacerbated by stressors. There are a number of dietary treatments that might be investigated as means of reducing heat toughening. Most promising are dietary betaine, chromium and magnesium either alone, or in combination.

In order to reduce post-mortem carcass temperature, a number of strategies are recommended for consideration. (i) Double exponential equations such as those used for human cadavers could be useful for predicting the rate of temperature

decline of beef carcasses post mortem. (ii) An understanding of the relative contributions of heat production and heat inertia to the resistance of muscle temperature to change in the immediate post mortem period would be useful. This may assist in ascertaining the relative importance of animal metabolic factors versus post mortem cooling factors. (iii) Temperature benchmarks used in the AQIS refrigeration index model for hot boning could be expanded to include pH and temperature rates of decline for optimal meat quality. (iv) Prolactin plasma concentration at slaughter is a candidate for inclusion in blood panels to detect ergotism, where it may be contributing to high carcass temperatures at slaughter. (v) Vascular infusion offers potential and it is recommended that the administration of citrate in very cold water could be used to slow pH fall and reduce muscle temperature quickly.

High rigor temperature in muscle post-slaughter cause extensive protein denaturation to myofibrillar and sarcoplasmic proteins which results in detrimental changes to the colour, water-holding capacity, tenderness, flavour, oxidation (and rancidity onset), eating quality and protein functionality during processing. The critical pH, temperature and time combination is not clear from the literature and warrants further investigation.

Studies were conducted to investigate the feasibility of using “heat tubes” to increase the rate of heat loss from a beef carcase. Depth in the muscle was an important determinant of muscle temperature and the lateral distance of the temperature probe from the tube was also important. “Heat tubes” were successful for increasing the rate of cooling the legs of cow carcases when 4 heat tubes were placed in the leg. This effect was not found in the loin due presumably to the physical dimensions of the loins. “Heat tubes” placed in the leg decreased the time taken for temperature to reach the benchmark of 35°C by 80 min. Critically, from the point of view of reducing heat toughening, the heat tubes acted to reduce temperature early in the chill period. Further work is required, to find ways to overcome the potential for damage and the cost of multiple tubes per leg, for both research and commercial purposes.

A mob of 115 cattle, which had been grain-fed for 120 days, were used to investigate the effect of temperature at pH 6 on eating quality. Low voltage electrical stimulation (ES) was used to induce heat-toughening in one side of beef carcasses and the average temperature at pH 6 (Temp@pH6) was 39.5^{0}C, compared to a Temp@pH6 in the control sides (no ES) of 32.4^{0}C. There were trends for heat-toughened (+ES) M *longissimus lumborum* (striploin) to have higher purge and lower MQ4 score and tenderness scores. After 14 days of ageing, the consumers generally gave higher grade scores to the non heat-toughened (-ES) striploins. The heat-toughened M. *Longissimus thoracis* (cuberoll) subjected to simulated retail display showed more browning, and a shorter shelf-life, then the control cuberolls. Although there were no major differences in eating quality or water-holding capacity between the heat-toughened and non neat-toughened carcasses, it is probable that with a larger sample size, there would have been a significant difference. The differences in the Temp@pH6 between the two treatments was not large and the heat-toughening was not as severe as often seen in commercial plants.

A large data set was obtained from MSA in order to investigate the effects of high rigor temperatures on eating quality of different muscles in the beef carcass. The aim was to investigate the effect of high rigor temperature (Temp@pH6) on the consumer and quality traits of four beef muscles. A data set containing consumer eating-quality scores for 3,865 striploins (*longissimus lumborum*) 942 rumps (*gluteus medius*), 1023 topsides (*semimembranosus*) and 725 blades (*triceps brachii*) was analysed. Temp@pH6 was calculated for the striploin, and carcasses with a

Temp@pH6 > 35°C were classified as high-rigor-temperature (heat-toughened) carcasses. For short ageing periods (1-7 days), high rigor temperature striploins were assessed as more tender and more acceptable, than lower-rigor-temperature striploins. Beyond 14 days of ageing, the high-rigor-temperature striploins showed a failure to age. The consumer acceptability of the rump decreased with increasing rigor temperature, but this was not the case for the blade or topside. The eating quality of aged striploins and rumps was reduced by high rigor temperatures although this can potentially be overcome with tenderstretch.

The core body temperature of six Angus-cross steers was monitored continuously in order to observe if core body temperature increased due to a number of events. Events included long-term grain feeding, handling, yarding, transportation and slaughter. The effect of betaine supplementation on stressed cattle was additionally studied to observe if core body temperature would decrease. Grain feeding for 150 days and betaine supplementation did not influence core body temperature. Stress stimuli (handling, yarding, transportation and slaughter) significantly increased the core body temperature of the cattle with a maximum increase of 1.75°C. It is possible that differences in core body temperature may have been obtained if a larger sample size was sued. The results suggest that stress pre-slaughter may be a significant contributor to muscle temperature at slaughter.

As part of an LPI-MLA project, 128 *Bos Taurus* beef steers grain-fed for 150 days were used to investigate the effect of betaine feeding and access to shade. The treatments were supplementation with 0, 10, 20 or 40 g/hd/day of betaine and 'Shaded' or 'No Shade'. This section reports on the meat-quality parameters of the carcasses after slaughter. There were some slaughter-floor problems and only half the carcasses were measured for pH-temperature decline. In spite of the missing data. the cattle fed betaine at 10 and 20 g/hd/day, but not 40 g/hd/day, showed some evidence of slower metabolism (pH fall) post-mortem and better texture and firmness at grading, particularly from the Shaded treatment. Meat colour, ultimate pH and exudate of the loin surface did not differ between treatments. Betaine feeding to cattle in a feedlot shows promise for reducing heat toughening in grain-fed beef carcasses, and warrants further investigation.

For the incorporation of Australian beef data into QOP simulator, Carntech has submitted milestones to MLA which demonstrated their progress with incorporation of MSA beef data. They have tested the effect of freezing on tenderness, reporting on relationship between NZ tenderometer values and MSA MQ4 scores, developed a chilling simulator module and to a very limited extent incorporated the effects of rigor temperature (Temp@pH6) on tenderness into the model. Thus Carnetech has incorporated data from the MSA beef database into the QOP model, in order to make the model relevant to the Australian beef industry. The resulting changes to the model have not yet been viewed and so no comment can be made.

For incorporation of Australian SMEQ lamb data into the QOP model, Robyn Warner informed Carnetech that she had access to large data sets with both consumer and objective measurements. Clyde Daly reported in 2009 that they had included lamb data into the QOP model, in order to make the model relevant to the Australian lamb industry. The resulting changes to the model have not yet been viewed and so no comment can be made.

At the MSA meeting in April, 2009, the technical pathways scientific committee agreed it was important to incorporate the effects of heat toughening on beef eating quality into the MSA model. The only way to incorporate heat toughening into the MSA model is to have a method for measuring heat toughening on an individual beef carcass. The three options proposed for evaluation were; Smartstim, measure pH on-line or using filter paper. The evaluation of Smartstim for identifying heat-toughened beef carcasses is on hold until MLA sorts out the IP and experimental procedures with Carnetech, pending Carnetch modifying Smartstim algorithms. The pH on-line experiment has been conducted by Geert Geesink at UNE. The filter paper method showed promise for identifying heat toughening on an individual carcass basis.

Across five lamb processing plants in Australia, monitoring of pH-temperature conditions as a part of the sheep CRC has shown a wide range in conditions, even though all plants have electrical stimulation units installed. The results indicate some plants had very low average Temp@pH6 values and high incidence of cold shortening. Other abattoirs exhibited higher Temp@pH6 values, with even some carcasses in the heat-toughening region. These results demonstrate the importance of monitoring pH-temperature decline at abattoirs. Since this study, each abattoir has had assistance to optimise their electrical stimulation units, thus improving the pH-temperature decline post-mortem. Thus the occurrence of heat toughening in lamb carcasses in Australian abattoirs has been verified, but the extent of the occurrence needs quantification. This will be provided from the sheep CRC database on an ongoing basis. Importantly, an effect of Temp@pH6 on the shear force measurements has been shown, emphasising the need for monitoring of pH-temperature declines in lamb carcasses.

Fast pH fall and high muscle temperatures are known to cause quality problems in pig and beef meat, but this has not previously been reported in lamb. An experiment was designed to determine the effect of post-slaughter pH and temperature decline, and muscle stretching, on the quality of four muscles in the sheep carcass. 48 lambs were slaughtered and the carcasses randomly allocated to treatments of +/- medium voltage electrical stimulation, a holding temperature of 2°C or 37°C for 5 hrs post-slaughter and +/- stretch applied to one side of the carcass. The stretch treatment resulted in longer sarcomeres in the *gluteus medius (*GM), *semimembranosus (*SM) and *semitendinosus (*ST) and resulted in shortening in the *rectus femoris (*RF). The 37°C holding temperature resulted in tougher meat in the unstretched GM and SM muscles, relative to 37°C, but not in the stretched muscles. The muscles in carcasses held at 37°C had lower water-holding capacity (WHC) and higher purge then the muscles held at 2°C post-slaughter, which was reduced by the stretch treatment. The 37°C holding temperature resulted in extensive denaturation of myofibrillar and sarcoplasmic proteins, which would explain the reduced WHC and increased toughness. In conclusion, heat toughening occurred in the non-stretched lamb muscle subjected to a post-slaughter holding temperature of 37°C. The high holding temperature also resulted in excessive water loss and protein denaturation.

An experiment was conducted to investigate the effect of duration of time muscles are held at a high temperature (37°C), on lamb quality characteristics. The muscles of carcasses undergoing temperature conditioning at 37°C for 1.5, 3 or 4.5 hrs had a faster pH fall post-slaughter, increased protein denaturation more tender meat, lower water-holding capacity paler meat and reduced ageing of the muscle compared to carcasses held conventionally at 2°C undergoing no temperature conditioning. The effects of high temperature on the quality traits were overcome by muscle stretching.

Conclusions and recommendations are included in the report.

Contents

1. Project Background

Heat toughening is a phenomenon that is associated with conditions that occur during the immediate pre- and post-rigor period in beef. Typically this occurs when the post-slaughter pH fall is rapid while the carcass temperature is still high. This condition causes a level of denaturation to both the structural proteins and the proteolytic enzymes.

These conditions can be generated easily in any meat species where the level of electrical stimulation is high and the carcass cooling is relatively slow; however, for reasons that are currently unclear, grain-fed Australian beef carcasses can have a rapid pH fall during the early post-mortem period, even with minimal electrical inputs to the carcass. This problem is proving to be a commercial concern since beef that exhibit the so-called ‘heat toughening’ condition (muscle temperature at pH 6>35°C) are excluded from MSA grading.

Tenderness, juiciness and flavour of beef meat are important quality attributes for the consumer. Understanding the factors that contribute to variations in these quality traits assists in determining strategies to optimise the quality traits. The concept of a pH/temperature window was one of the initial specifications for the MSA grading scheme in Australia and was designed to minimise the detrimental effects of extremes in processing i.e. heat toughening and cold shortening (Ferguson, Thompson and Polkinghorne, 1999). The MSA scheme is aimed at predicting eating quality of individual cuts using a total quality management approach. The pH-temperature window was developed from the meat-science literature available from around the world which generally shows that minimal shortening in muscles occurs at about 15 - 20°C resulting in optimum tenderness (Locker and Hagyard, 1963; Tornberg, 1996, (Devine, Wahlgren and Tornberg, 1999).

The negative effects of fast pH fall at a high temperature on the water-holding capacity, colour and texture of pig muscle resulting in the pale, soft exudative (PSE) phenomenon have been well-documented (Warner, Kauffman and Greaser, 1997). Channon, Payne and Warner (2000) showed that PSE pork was initially more tender than normal pork although, after 5 days ageing this was reversed suggesting that PSE pork may not age as well as normal pork. This was supported in beef by Thomson, Gardner, Simmons and Thompson, (2008) who also showed the cross-over in shear force occurred at approximately 5 days ageing.

Electrical stimulation of beef carcasses was introduced in order to accelerate the rate of post-mortem pH fall, to allow more rapid rigor onset and prevent cold-shortening. Most of the standards set down for electrical stimulation in the 1970s were based on the assumption that electrical stimulation was the only electrical input on the slaughter floor (Petch, 2001; Chrystall and Devine, 1978) . While this assumption was generally true at the time, this no longer applies.

Tornberg, Wahlgren, Brondum and Engelsen, (2000) describe fast pH fall in beef carcasses as 5.6 at 4-5h post-mortem and found the meat to be tender when measured using WBSF on muscle at 24 h post-slaughter. Similarly, fast glycolysing beef muscle was defined by O'Halloran, Troy and Buckley, (1997) as about pH 6.6 at 1 h post-slaughter (estimated from graph in paper) and by O'Halloran, Troy, Buckley and Reville, (1997) as loin pH 5.9 to 6.2 at 3 h post-slaughter and in each case the loin was more tender (sensory panel and Warner-bratzler shear force) for fast-glycolysing muscle. In Australia, beef-processing plants often ecounter loin pH values of 5.5 at 1 h post-slaughter, while the muscle temperature can still be 40°C

(Janine Lau, unpublished results). Thus, the Australian meat industry reports much faster rates of pH fall than those historically reported for beef in different countries.

2 Project objectives

2.1 Project: Optimising the abattoir component of the supply chain

1. To conduct a critical review on the metabolic pathways associated with energy metabolism in vivo and post-mortem in ruminants with regard to the effects on yield and quality of red-meat carcasses.

2. To conduct initial discussions and measurements with between five (5) and ten (10) supply chain companies that are experiencing processing or quality problems associated with fast pH decline post-mortem.

3. To conduct case studies involving at least five (5) supply chains by measuring the pH and temperature fall in muscles in red-meat carcasses, and collect data and samples to identify factors contributing to the processing or quality problem.

4. Under controlled experimental conditions, to verify the effect of fast pH fall at high temperatures on colour, yield and consumer eating quality in at least two cuts of meat.

5. Conduct targeted research to identify the critical factors that determine the muscle metabolism post-slaughter, and how this can be manipulated to improve yield (i.e. drip and/or fluid accumulation in the vacuum bag), colour and quality.

6. Provide recommendations to the supply chains to reduce the rate of pH fall post-mortem, and assist in delivery of the recommendations.

7. Document the change in the extent of colour, yield and quality variation after an implementation period and provision of recommendations.

2.2 Extension of project

1. Uploading of SMEQ and MSA data into the MLA QOP simulator to extend it to Australian sheep and beef meat quality.

2. Evaluation of the QOP simulator model in the Australian beef and lamb processing environment.

3. Extension of the MSA model to incorporate effects of heat toughening on beef eating quality.

4. Extension of the heat-toughening principles into sheep meat allowing evaluation and testing of the present pH-temperature window recommendations for quality lamb and sheep meat, with the aim of developing accelerated tenderisation.

5. Enhanced awareness in industry and in scientific circles of heat toughening and effects on ageing of beef and lamb meat.

6. Upskilling people in Australia in the use of the MLA QOP simulator to enable its use as a tool to advise processors on producing quality meat.

3 Personnel involved in project

- Dean Gutzke, MLA, Brisbane office
- Janine Lau and Rob Strachan, MSA, Brisbane office
- Linden Cowper and staff, MSA, Wagga Wagga office
- Drewe Ferguson, CSIRO Livestock Industries
- David Hopkins, NSW DPI
- Julie Cassar, honours student, Sydney University
- Julie Slavik, Masters student, Danish University
- Vic Surridge, Honours student, Murdoch University
- Graham Gardner, Kelly Pearce, David Beatty and David Pethick, Murdoch University
- Robin Jacob, DAFWA
- Matthew Kerr, Athula Naththarampatha, Eric Ponnampalam and Wayne Brown, DPI-Vic, Werribee
- John Thompson, Geert Geesink, Xumei Han and Andrew Slack-Smith, UNE
- Frank Dunshea, Kristy DiGiacamo and Brian Leury, Melbourne University
- Clyde Daly and Nicky Simmons, Carnetech, New Zealand

4 Brief description of research and reviews undertaken in project

A number of experiments and a literature review were conducted within the project and the details are given in the Appendices. A brief summary of the Appendices are given below.

Appendices A, B and C - Seven beef processing plants were contacted and became collaborators in the case study conducted in the project. The aim of the case study was to quantify the occurrence of heat-toughening in beef carcasses around Australia, and to identify causative factors. The case study used data from 103 mobs of cattle and and 1,512 beef carcasses including data from grain-fed cattle, ranging in days on feed from 0 (grass-fed) to 350 days. A small proportion of vealers, ox, cow, yearling and MSA cattle were sampled but the majority of cattle were grain-fed. The occurrence of heat-toughening across all 7 abattoirs was 74.6% ranging between abattoirs from 56% to 94%. Analysis of the data identified that increasing days on feed caused an increase in the predicted temperature at pH 6 and in the % heat-toughening. The temperature at pH 6, and therefore % heat-toughening, was increased by longer days on grain-feeding, longer times of contact for the rigidity probe at the hide puller and increasing carcass fat depth for grass-fed cattle, and also for male cattle. Overall, the carcasses of grain-fed cattle had >80% heat-toughening, MSA and grass-fed cattle had about 50-60% heat toughening and vealers and cull cows had about 24% heat toughening.

Appendix D: Parts 1, 2 and 3 - A critical review was conducted of the metabolic causes and post-mortem conditions that contribute to heat toughening. One of the main causes of heat toughening appears to be a combination of rapid glycolysis and relatively slow cooling which can lead to high rigor temperatures. Moreover, heat toughening may be exacerbated by loss in proteolytic potential due to inactivation of proteolytic enzymes. Factors which contribute to elevated body temperature pre-slaughter would potentially predispose animals to higher carcass temperature immediately post slaughter. There is now mounting evidence that a state of insulin resistance can compromise the ability of an individual to thermoregulate and that this can be exacerbated by stressors. There are a number of dietary treatments that might be investigated as means of reducing heat toughening. Most promising are dietary betaine, chromium and magnesium either alone, or in combination.

Appendix D: Parts 4, 5 and 6 - In order to reduce post-mortem carcass temperature, a number of strategies are recommended for consideration. (i) Double exponential equations such as those used for human cadavers could be useful for predicting the rate of temperature decline of beef carcasses post mortem. (ii) An understanding of the relative contributions of heat production and heat inertia to the resistance of muscle temperature to change in the immediate post mortem period would be useful. This may assist in ascertaining the relative importance of animal metabolic factors versus post mortem cooling factors. (iii) Temperature benchmarks used in the AQIS refrigeration index model for hot boning could be expanded to include pH and temperature rates of decline for optimal meat quality. (iv) Prolactin plasma concentrations is a candidate for inclusion in blood panels to detect ergotism, where it may be contributing to high carcass temperatures at slaughter. (v) Vascular infusion offers potential and it is recommended that the administration of citrate in very cold water could be used to slow pH fall and reduce the temperature more quickly.

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Appendix R - For incorporation of Australian SMEQ lamb data into the QOP model, Robyn Warner informed Carnetech that she had access to large data sets with both consumer and objective measurements. Clyde Daly reported in 2009 that they had included lamb data into the QOP model, in order to make the model relevant to the Australian lamb industry. The resulting changes to the model have not yet been viewed and so no comment can be made.

Appendix S - Across five lamb processing plants in Australia, monitoring of pH-temperature conditions as a part of the sheep CRC has shown a wide range in conditions, even though all plants have electrical stimulation units installed. The results indicate some plants had very low average Temp@pH6 values and high incidence of cold shortening. Other abattoirs exhibited higher Temp@pH6 values, with even some carcasses in the heat-toughening region. These results demonstrate the importance of monitoring pH-temperature decline at abattoirs. Since this study, each abattoir has had assistance to optimise their electrical stimulation units, thus improving the pH-temperature decline post-mortem. Thus the occurrence of heat toughening in lamb carcasses in Australian abattoirs has been verified, but the extent of the occurrence needs quantification. This will be provided from the sheep CRC database on an ongoing basis. Importantly, an effect of Temp@pH6 on the shear force measurements has been shown, emphasising the need for monitoring of pH-temperature declines in lamb carcasses.

Appendix T - Fast pH fall and high muscle temperatures are known to cause quality problems in pig and beef meat, but this has not previously been reported in lamb. An experiment was designed to determine the effect of post-slaughter pH and temperature decline, and muscle stretching, on the quality of four muscles in the sheep carcass. 48 lambs were slaughtered and the carcasses randomly allocated to treatments of +/- medium voltage electrical stimulation, a holding temperature of 2°C or 37°C for 5 hrs post-slaughter and +/- stretch applied to one side of the carcass. The stretch treatment resulted in longer sarcomeres in the *gluteus medius (*GM), *semimembranosus (*SM) and *semitendinosus (*ST) and resulted in shortening in the *rectus femoris (*RF). The 37°C holding temperature resulted in tougher meat in the unstretched GM and SM muscles, relative to 37°C, but not in the stretched muscles. The muscles in carcasses held at 37°C had lower water-holding capacity (WHC) and higher purge then the muscles held at 2°C post-slaughter, which was reduced by the stretch treatment. The 37°C holding temperature resulted in extensive denaturation of myofibrillar and sarcoplasmic proteins, which would explain the reduced WHC and increased toughness. In conclusion, heat toughening occurred in the non-stretched lamb muscle subjected to a post-slaughter holding temperature of 37°C. The high holding temperature also resulted in excessive water loss and protein denaturation.

Appendix U - An experiment was conducted to investigate the effect of duration of time muscles are held at a high temperature (37^{o}C), on lamb quality characteristics. The muscles of carcasses undergoing temperature conditioning at 37^{o}C for 1.5, 3 or 4.5 hrs had a faster pH fall post-slaughter, increased protein denaturation more tender meat, lower water-holding capacity paler meat and reduced ageing of the muscle compared to carcasses held conventionally at 2^{o}C undergoing no temperature conditioning. The effects of high temperature on the quality traits were overcome by muscle stretching.

5 Bibliography

Channon, H. A., Payne, A., & Warner, R. D. (2000). Halothane genotype, pre-slaughter handling and stunning method all influence pork quality.

Chrystall, B. B. & Devine, C. E. (1978). Electrical stimulation muscle tension and glycolysis in bovine sternomandibularis.

Devine, C. E., Wahlgren, N. M., & Tornberg, E. (1999). Effect of rigor temperature on muscle shortening and tenderisation of restrained and unrestrained beef m. longissimus thoracicus et lumborum.

Ferguson, D. M., Thompson, J. M., & Polkinghorne, R. (1999). Meat Standards Australia. A 'PACCP' based beef grading scheme for consumers. 3) PACCP requirements which apply to carcass processing.

Locker, R. H. & Hagyard, C. J. (1963). A cold shortening effect in beef muscles.

O'Halloran, G. R., Troy, D. J., & Buckley, D. J. (1997). The relationship between early post-mortem pH and the tenderisation of beef muscles.

O'Halloran, G. R., Troy, D. J., Buckley, D. J., & Reville, W. J. (1997). The role of endogenous proteases in the tenderisation of fast glycolysing muscle.

Petch, P. (2001). Electrical inputs and meat processing. In: Meat Science and Applications.(Editors:Hui, Y. H., Nip, W-K., Rogers R.W., and Young, O. A.). CRC Press, Taipei City, Taiwan.

Thomson, K. L., Gardner, G. E., Simmons, N., & Thompson, J. M. (2008). Length of exposure to high post-rigor temperatures affects the tenderisation of the beef M. longissmus dorsi.

Tornberg, E. (1996). Biophysical aspects of meat tenderness.

Tornberg, E., Wahlgren, M., Brondum, J., & Engelsen, S. B. (2000). Pre-rigor conditions in beef under varying temperature- and pH-falls studied with rigometer, NMR and NIR.

Warner, R. D., Kauffman, R. G., & Greaser, M. L. (1997). Muscle protein changes *post-mortem* in relation to pork quality traits.

6 Publications and Conferences proceedings

Beatty, D. T., Gardner, G. E., and Jacob, R. H. (2009). The impact of long term grain feeding on the core body temperature of cattle. XIth International Symposium on Ruminant Physiology, Clermont-Ferrand, France, September 6-9, 2009.

Cassar, J.A. (2006). Identifying factors that cause the rapid rate of pH decline in heavy carcases from animals in long feeding programs. Honours Thesis (University of Sydney).

Hopkins, D.L., Cassar, J.A., Toohey, E.S. and P.C. Wynn (2007). Examination of pH in lot fed beef for Japan. Proceedings of the 67th New Zealand Society of Animal Production. 436-440.

Pearce, K. L., Williams, A., Hocking-Edwards, J. E., Jacob, R. H., Withers, R., Refshauge, G., Geesink, G. H., Warner, R. D., and Pethick, D. W. (2010). Assessment of electrical stimulation compliance at abattoirs using medium voltage electrical stimulation. Proceedings of the 55th International Congress of Meat Science and Technology, 15-20 August 2010, Jeju Island, South Korea.

Pighin, D.G., Warner, R.D., Brown, W., Ferguson, D.M. and Fisher, A.D. (2010). Predicting post-slaughter muscle glycogen content and dark-cutting through changes in pre-slaughter body temperature of lambs. Proceedings of the 55th International Congress of Meat Science and Technology, 15-20 August 2010, Jeju Island, South Korea.

Warner, R. D. & Kerr, M. G. (2009). High temperature conditioning of the lamb carcass causes heat toughening and high water loss. *International Congress of Meat Science and Technology, Copenhagen, Denmark*, 55, PE7.47

Warner, R. D., Kearney, G. A., Thompson, J. M. & Polkinghorne, R. (2009). Rigor temperature influences objective and consumer quality traits of beef striploin. *International Congress of Meat Science and Technology, Copenhagen, Denmark*, 55, PE7.44

Warner, R.D., Kearney, G., Thompson, J.H., Polkinghorne, R. and Gutzke, D. (2010-final). pH and temperature at rigor influence the eating quality and ageing potential of beef striploin and rump, but not blade or topside. To be submitted to *Meat Science,* has been reviewed by authors and now needs reviewing by DPI and MLA.

Warner, R.D., Kearney, G. (2010 – draft). Factors influencing the incidence of heat toughening in beef carcasses in Australia. To be submitted to *Animal Production Science,* after review by authors, DPI and MLA.

7 Presentations

Warner, R.D. Heat toughening in beef carcasses. Presentation to MINTRAC National /MI & QA Managers' Network meeting, September 23, 2010, Attwood.

Warner, R.D. Heat toughening in beef carcasses. W.H. Greenham and Sons, Pty., Ltd., Tongala, Vic. May 21, 2009.

Warner, R.D. (2008). Meat quality in beef and lamb carcasses- pH-decline program, DPI research and capabilities. Presentation to MLA, September 18, 2009.

Warner, R.D. Meat quality in beef carcasses- pH-decline program. Swifts, Brooklyn, November 23, 2009.

Warner, R.D. High Temperature abattoir window- results and recommendations for incorporation into MSA model. Meat Standards Australia, Research & Development - Pathways Team Meeting, June 30 to July 1, 2008.

Warner, R.D. (2008). Meat quality in beef carcasses- pH-decline program, update and progress. Coles Pty Ltd. and Swift, Brooklyn, May 23, 2008.

Warner, R.D. (Gutzke, D., Jacob. R. and North, M.). Fast pH fall in Beef Carcasses – Very Fast Chilling as a potential method to prevent heat toughening. December 8-9 2008.

a. Teys Bros., Beenleigh, Qld.
b. Argus-Realcold-Milmech, Qld.
c. Stanbroke Pastoral Company, Gatton, Qld.
d. Greenleaf Electrics, Freshwater, Qld.
e. MSA, Fortitude Valley, Brisbane, Qld.

Warner, R.D. Report on incidence of dark-cutting at Cargill Beef and methods for prevention, Wagga Wagga, NSW, May 19-20, 2008.

Warner, R.D. Incidence of heat toughening in beef carcasses and recommendations for Prevention. Cargill Beef Annual Wellness Meeting, Tamworth, NSW, April 10, 2008.

Warner, R.D., Gutzke, D. and Lau, J. (2006-2007). Update on Meat Quality Science and Technology Program – pH-decline program.

- Rockdale Beef Co., December 6, 2006.
- Stanbroke Pastoral Co., Gatton, Qld, February 8, 2007.
- AMH, Beef City, Feb 9, 2007.
- John Dee Abattoir, 8 February, 2007.
- Ranger Valley Beef, 8 February 2007.
- TGS, Belandra, Feburary 23, 2007.
- Coles Pty Ltd. February 23, 2007.
- Teys-Beenleigh 15 March, 2007
- Teys-Naracoorte, 19 March, 2007
- Harvey Beef, March 20, 2007 (including Robin Jacob)

- Harvey Beef, September 14, 2007 (including Robin Jacob, David Beattie, Brian McIntyre, Rafael Ramirez)

8 Success in achieving objectives

1. To conduct a critical review on the metabolic pathways associated with energy metabolism in vivo and post-mortem in ruminants with regard to the effects on yield and quality of red-meat carcasses.

Achieved – see Appendix D.

2. To conduct initial discussions and measurements with between five (5) and ten (10) supply chain companies that are experiencing processing or quality problems associated with fast pH decline post-mortem.

Achieved – see Appendix A.

3. To conduct case studies involving at least five (5) supply chains by measuring the pH and temperature fall in muscles in red-meat carcasses, and collect data and samples to identify factors contributing to the processing or quality problem.

Achieved – see Appendices A and C.

4. Under controlled experimental conditions, to verify the effect of fast pH fall at high temperatures on colour, yield and consumer eating quality in at least two cuts of meat.

Achieved – see Appendices C, J, K, T, U and V.

5. Conduct targeted research to identify the critical factors that determine the muscle metabolism post-slaughter, and how this can be manipulated to improve yield (i.e. drip and/or fluid accumulation in the vacuum bag), colour and quality.

Achieved – see Appendices C, F, G, H, I, L, M and N.

6. Provide recommendations to the supply chains to reduce the rate of pH fall post-mortem, and assist in delivery of the recommendations.

Achieved – see presentations list and Appendix A.

7. Document the change in the extent of colour, yield and quality variation after an implementation period and provision of recommendations.

<u>Extension of project</u>

1. Uploading of SMEQ and MSA data into the MLA QOP simulator to extend it to Australian sheep and beef meat quality.

Achieved – see Appendices N, O and R.

2. Evaluation of the QOP simulator model in the Australian beef and lamb processing environment.

Not achieved as the revised QOP simulator model was not made available. In its place, several experiments in lamb meat were conducted - see Appendices S and T.

3. Extension of the MSA model to incorporate effects of heat toughening on beef eating quality.

Achieved – see Appendices P and Q.

4. Extension of the heat-toughening principles into sheep meat allowing evaluation and testing of the present pH-temperature window recommendations for quality lamb and sheep meat, with the aim of developing accelerated tenderisation.

Achieved – see Appendices S, T and U.

5. Enhanced awareness in industry and in scientific circles of heat toughening and effects on ageing of beef and lamb meat.

Achieved through all work listed in Appendices, presentations and papers at conferences.

6. Upskilling people in Australia in the use of the MLA QOP simulator to enable its use as a tool to advise processors on producing quality meat.

Partially achieved but require input from Carnetech to complete this milestone.

9 Impact on meat and livestock industry–Now and in five years time

At the start of the project, there was some awareness of heat toughening in beef carcasses and no awareness of its impact or importance in lamb carcasses.

There was awareness of the occurrence of heat toughening in beef carcasses because MSA-accredited abattoirs were required to comply with the pH-temperature window and avoid heat toughening. The was no data on the levels of heat toughening in industry and the common understanding amongst scientists was that it was caused by heavy beef carcasses being slow to cool in temperature. The project quantified the high level of heat toughening across all classes and categories of beef carcasses, and a surprising >50% incidence in MSA beef and grass-fed carcasses destined for the domestic market. Research conducted in the project identified that grain-fed cattle have an inherently faster metabolism post-slaughter which needs to be controlled, in order to reduce the incidence of heat-toughening. The research also demonstrated other strategies for reducing the incidence of heat toughening, some of which were immediately implemented by industry.

The negative effect of heat toughening on purge, shelf-life and the ageing potential of beef muscles has resulted in the recommendation that heat toughening be incorporated in to the MSA model for assuring beef quality. This will be possible once a method for identifying heat toughening on an individual carcass basis is finalised.

The project has also shown that moderately high rigor temperatures in lamb carcasses can be used to accelerate tenderisation. Conversely, under experimental conditions it was shown that heat toughening has negative effects on purge, shelf-life and the ageing potential of lamb muscles, similar to those in beef.

The impact in five years will be that due to the increased level of awareness of heat toughening in beef and lamb carcasses, and the research conducted to demonstrate strategies to reduce heat toughening, the incidence of heat toughening will be lower. In addition, heat toughening will be incorporated into the MSA model.

10 Conclusions and recommendations

The overall incidence of heat toughening in beef carcasses across seven abattoirs in Australia was high (74.6%). It is recommended that efforts to reduce the incidence of heat toughening continue through industry support and development of education materials.

The effect of electrical inputs on the slaughter-floor on the rigor temperature (Temp@pH6) was demonstrated. It is recommended that continuing support is available to beef abattoirs to monitor and optimise electrical inputs at the immobiliser, bleed stimulator, electrical stimulator and at the hide puller.

A number of options for reducing muscle temperature post-mortem in order to reduce rigor temperature have been presented. It is recommended that these undergo trials with commercial companies.

The high incidence of heat toughening in beef carcasses was identified and the metabolic load during grain feeding and stress events pre-slaughter were identified as important factors. Betaine feeding showed promise as a live animal intervention. It is recommended that betaine feeding, and other strategies identified in the review, should undergo trials with industry.

The negative effects of heat toughening (high rigor temperature) on ageing potential, purge and retail shelf-life were demonstrated. It is recommended that the inclusion of heat toughening in the MSA model is pursued as a matter of priority.

Using the filter paper score method at grading, a reasonable proportion of carcasses were identified as having high rigor temperature. This method is simple to implement and further evaluation of the method for identifying heat toughening on an individual carcass basis is recommended.

As a high priority, it is recommended that the methods developed, or in development (Smartstim), for measuring heat toughening on an individual carcass should be pursued.

In Australia, sheep carcasses are susceptible to the negative effects of low rigor temperature on tenderness (cold-toughening). The research demonstrated that at high rigor temperatures, lamb can exhibit the same problems with ageing potential, colour and purge that has been seen in beef carcasses. The recent monitoring of pH-temperature decline and optimisation of electrical stimulation units across several abattoirs, high rigor temperatures are sometimes achieved. It is recommended that the sheep CRC phenotyping experiments investigate the effects of high rigor temperatures on lamb tenderness, purge and retail colour.

The QOP model has been unavailable for assessment or training of staff in Australia. This has impeded progress of the the implementation of the QOP model in Australia and the upskilling of key meat scientists. It is recommended that this be pursued as a matter of urgency, in order for the Australian meat industry to benefit from the industry money invested in the model.

11 Appendices

Appendix A: Abattoir engagement, communication and collaboration

Abattoirs involved

- Rockdale Beef, Yeeton NSW
- AMH's Beef City, Toowoomba Qld
- Stanbroke, Grantham Qld
- Griffin Coals Carpenter Group, Harvey WA
- John Dee Abattoir , Warwick Qld
- Tasman Group Services, in collaboration with Your company, Brooklyn abattoir, Vic
- Teys abattoir in Naracoorte, SA