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Accelerated processing of sheep meat

SmartStretch™/SmartShape™

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Abstract

Attempts over the years to speed up the slaughter and processing of meat have been limited by the impact on important meat quality traits, such as tenderness. There are numerous studies that have shown that if meat is prevented from shortening prior to *rigor mortis* then this will confer benefits by improving tenderness. These studies have given rise to Tenderstretch (pelvic suspension), Tendercut (skeletal separation), and Tenderbound (Pi-Vac Elasto-Pack system) systems. Both Tenderstretch and Tendercut are applied to whole carcases and are not suitable for hot-boned meat. By contrast Tenderbound is suitable for hot boned meat, but has had limited adoption commercially. In more recent times a novel technology, now called SmartStretch™/Smartshape™, was developed in New Zealand. This technology was also aimed at stretching hot boned meat, however there had been no scientific validation as to the potential benefits of using the technology and it was not ready for commercial application. As a consequence a large project was undertaken to validate the benefits of stretching hot-boned sheep meat pre-*rigor*. The project was extended to include hot-boned beef and to examine the benefits of shaping cold-boned sheep and beef primals. Initial R&D showed that the tenderness of hot-boned sheep topsides could be significantly improved by use of the SmartStretch™ machine and this effect was confirmed in subsequent experiments with hot-boned sheep hindlegs. A series of experiments found that stretching hot-boned beef primals, such as the cuberoll and topside taken from cull cows, had little impact on meat quality. By contrast experimentation on young prime cattle showed that stretching hot-boned rostbiffs could reduce shear force, verifying the value of the technology. In addition to the tenderness benefits it appeared that SmartStretch™ technology had no detrimental affects on meat colour. During the project the technology underwent several modifications in response to feedback from the project team and the durability of the rubber insert was dramatically improved. Commercial interest in the technology was gained by the conduct of a large number of demonstrations across Australia and 4 MDC projects. From this aspect of the project the interest in using the technology to shape cold-boned sheep and beef primals was very strong. It was demonstrated that primals like beef cuberolls could be shaped cold and would retain their shape once removed from the packaging. This interest lead Cargills Australia Beef to order a SmartStretch™/SmartShape™ machine and the project team believes interest in the technology will increase and commercial application will grow.

Executive summary

The challenge from increasing processing efficiency is to maintain or enhance eating quality. Adoption of hot or warm boning in the Australian sheep meat processing industry has been limited to the use of aged sheep. This process has, in some cases, been integrated with electrical stimulation with the intent of reducing muscle contraction following removal from the skeleton. Hot-boning increases the risk of muscle shortening due to the removal of the pre-*rigor* muscle from skeletal constraint resulting in shortening, which is a major influence on meat tenderness. The only published data on the eating quality of hot-boned, electrically stimulated sheep meat shows a low level (~14%) of consumer compliance. In hot-boning situations the only option to improve tenderness is to manipulate primals prior to freezing. With the development of what was originally called the "Boa" this possibility emerged.

An extensive program of research and development was undertaken to validate what potential benefits could arise from the use of the "Boa". As part of the program, with feedback from the program team, the "Boa" under went a series of modifications to enhance the robustness and usefulness of the technology. Subsequently the technology was licensed as SmartStretch™ and SmartShape™.

It was shown that the SmartStretch™ technology lead to a 46% reduction in the shear force of hot-boned sheep topsides (m. *semimembranosus*; SM) at 0 days ageing and after 5 days of ageing a 38% a reduction in shear force was still achieved. A second study found a 37% reduction in shear force at 0 days ageing for the SM and after 5 days of ageing a 16% a reduction in shear force. A similar trend was shown in a third study where SmartStretch™ caused a 19.8% and 11.1% reduction in shear force of the m. *bicep femoris* at 0 and 5 days of ageing respectively. However for the SM, SmartStretch™ treatment only caused a 15.2% reduction in shear force at 0 days of ageing and after 5 days of ageing the benefits of SmartStretch™ were nullified. It was also demonstrated that stretching of hot-boned sheep sub-primals, like the topside, could be achieved without the manipulation of existing electrical stimulation settings. Improvements in tenderness were related to the ability of the SmartStretch™ technology to prevent sarcomere shortening. There was no evidence that proteolysis was accelerated by the treatment. There was however a poor predictive relationship between the increase in primal length due to stretching and measures of shear force or sarcomere length and this suggests that the benefits of the stretching were not solely attributable to changes in sarcomere length.

By contrast it was found that stretching hot-boned sheep loins would require further development of a suitable rubber for the machine. No appreciable tenderness benefits resulted from stretching these primals while there was some damage to the loins. Given this result, and the small cross-sectional area of the resultant stretched loins, it was considered that the investment to rectify the problems that arose was unlikely to make this worth pursuing. Despite this, the project has shown that SmartStretch™ technology could be used by the industry to improve the tenderness of hot-boned hind leg sheep meat. In addition the evidence indicates that cooking loss is reduced in stretched meat, but there is increased purge. There did not appear to be any deleterious effects on fresh colour or colour stability of sheep meat stretched using SmartStretch™ technology.

The project was extended to include hot-boned beef and to examine the benefits of shaping cold-boned sheep and beef primals. A series of experiments found that stretching hot-boned beef primals, such as the cuberoll and topside taken from cull cows, had little impact on meat quality. The SmartStretch™ technology successfully stretched hot-boned topsides (with one treatment resulting in a 52 % increase in length), however this did not translate into an effect on tenderness and there was significant variation in the degree of stretch. By contrast there was an improvement in striploin tenderness with much less stretch (mean 16.5%), which nearly persisted after 14 days of

ageing. Overall it became apparent that there was likely to be minimal tenderness benefit from stretching beef typically hot-boned in Australia. There was however still an interest by industry for the shaping capabilities of the technology in some cuts such as the cube roll for these type of cattle. As part of a related MDC project the subjective sensory and objective tenderness of SmartStretch™ hot-boned topsides and rostbiffs from aged cattle was examined against an untreated control. Although the improved tenderness of the stretched rostbiff was not confirmed, the results suggested that this cut was a candidate for improved tenderness in further validation of the technology's effectiveness using younger animals.

Significant improvements in the tenderness of hot-boned rostbiffs from cattle with a dentition score of 2 or less were made by stretching the muscle pre-*rigor*. In this case a 34% increase in length resulted in a 20% reduction in shear force at 0 days ageing. This positive impact on tenderness was nullified with ageing, but the tenderness improvement indicates that there may be scope for stretching to replace costly chilled storage. These results indicate that in older cattle typically used for hot-boning that the increased connective tissue content of the muscles is negating any benefit that may come from stretching. However, if sarcomere length can be increased, there will be a reduction in shear force, but this reduction will not lower shear force sufficiently to make hot-boned meat from cull cows suitable for use as a table meat. The impact on connective tissue from the use of SmartStretch™ technology was not examined in this project and this is worthy of future investigation. Given the magnitude of the impact on shear force for the sheep and beef primals it is apparent that the size of the rubber used in the SmartStretch™ technology needs to be increased for use with beef primals. In the sheep studies the smaller muscles consistently showed greater reductions in shear force than when, for example, a whole hind leg was stretched. On this basis further study of the benefits from stretching beef primals with an up scaled machine would be worthy of investigation.

The SmartShape™ capability of the machine for cold-boned beef primals has propelled the technology towards commercialisation. Experimentation during the project showed that a combination of injection with plant based enzyme solutions and shaping using SmartShape™ conferred tenderness benefits (26% reduction in shear force after 1 day of ageing), which appears to operate through the myofibrillar component of meat, but this requires confirmation. A study of shape retention revealed that a shaped product can, within 12 hours of treatment, be sliced evenly along its length into portions of consistent dimensions, diameter and circumference, giving a product ideal for weight portioning. The shape will be retained until cooking. The food service industry should find this technology attractive as it allows for weight portioned steaks to have the same physical dimensions, thus consistent and predictable cooking times.

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1 Background

The challenge from increasing processing efficiency is to maintain or enhance eating quality. Adoption of hot or warm boning in the Australian sheep meat processing industry has been limited to the use of aged sheep. This process has in some cases been integrated with electrical stimulation with the intent of reducing muscle contraction following removal from the skeleton. The only published data on the eating quality of sheep meat processed through this system shows a low level (~14%) of consumer compliance (Toohey & Hopkins, 2006). Although there was some evidence that sarcomere shortening contributed to this result, sarcomere length only explained 10% of the variation in sensory assessed tenderness. In contrast when aged sheep were processed at the same abattoir, but conventionally chilled and cold boned, product aged for 7 days achieved a high level (86%) of consumer compliance (Hopkins & Toohey, 2006). In follow up work where loin meat was wrapped after hot-boning and aged for seven days a 14% and 24% improvement respectively in the overall liking and tenderness scores was achieved compared to product unwrapped and frozen at 1 day (Toohey, Hopkins, & Lamb, 2008b). The improvement in shear force was more dramatic at 53%. These results highlight the complex relationship between muscle structure and protein degradation.

In beef Hwang, Park, Cho, & Lee (2004) showed that muscle excised soon after death and held at 36°C had short sarcomeres (1.44 μm), but shear force values similar to muscle that was held at 15°C. At the high temperatures there is a poor relationship between sarcomere length and shear force, whereas at low temperatures (5°C) the relationship is much stronger. It appears that at high temperatures the acceleration of proteolysis overcomes the sarcomere shortening, whereas at low temperatures this does not occur. Even though meat which enters *rigor* at high temperatures may attain higher initial tenderness levels there is a reduction in ageing capacity (Devine et al., 2002a), although it appears that in sheep carcases it is probably impossible to reach high enough temperatures at the onset of *rigor* to detrimentally affect eating quality. Support for this view emerges from the results of Hopkins & Toohey (2006) where the mean temperature at the onset of *rigor* was 26°C, yet the mean overall liking score for loin was 65, as good as can be expected for lamb meat (Hopkins, Walker, Thompson, & Pethick, 2005).

These results suggest that if hot/warm boned sheep meat is subjected to stimulation and then manipulated after boning that very high consumer compliance is possible. Efficiencies will be achieved if the manipulation overcomes the need for long ageing periods. Devine, et al. (2002a) demonstrated that excising and wrapping meat could be used to control sarcomere shortening, but it can also be reduced by stretching muscle pre-*rigor*. The use of tenderstretch in beef carcases by Hwang et al. (2003b) showed the potential of methods to alter meat structure for improving eating quality. A more than 50% improvement in eating quality was found in topsides from carcases which had been tenderstretched, but no effect on shear force was reported and the size of the effect was dependent on cooking method. Given the low eating quality of the topside (Pethick, Pleasants, Gee, Hopkins, & Ross, 2006) this is an important finding.

Hopkins, Littlefield, & Thompson (2000b) reported that by super tenderstretching lamb carcases even further reduction in shear force (26 %) could be achieved in the loin compared with tenderstretching and although some of the gain could be attributed to increased sarcomere length and some to disruption of the I-band proteins (Hopkins, Garlick, & Thompson, 2000a) the individual contribution of each effect is unknown. Of particular interest was the fact that super tenderstretching did not reduce shear force in the topside compared with tenderstretching or produce a significantly longer sarcomere length (Hopkins, et al., 2000b). This data and that presented by Hwang, Gee, Polkinghorne, & Thompson (2002) suggests that there is an upper limit beyond which further stretching will not improve sensory scores or reduce shear force. This

probably reflects the basal tenderness inherent in meat. Although a small study the results of Hwang, et al. (2002) suggest that regions within muscles vary in their response to stretching and this may explain variable responses in some studies. Further the data of Wahlgren, Goransson, Linden, & Willhammar (2002) indicates that tenderstretching does not confer any benefit on some hindleg muscles e.g. *biceps femoris.*

This concept was revealed early by Locker (1960) who concluded that in beef the degree of contraction when a muscle enters *rigor* mortis is highly variable among the different muscles of a carcase. Due to this variance between the different muscles/cuts, this poses another potential advantage of hot/warm boning, such that individual types of muscles/cuts can be manipulated differently in order to maximise meat tenderness and eating quality as opposed to conventionally chilled carcases where all muscles are exposed to the same treatments.

Adopting the concept of super tenderstretching by using weights (Hopkins, et al., 2000b) and applying it to hot boned beef muscle (O'Sullivan, Korzeniowska, White, & Troy, 2003) showed that equivalent tenderness could be achieved to that achieved with the Pi-Vac technology. However the Pi-Vac produced meat with the lowest variation indicating that this method does something different to meat structure compared to tenderstretching and, additionally, the shear force declined from 7 to 14 days of ageing with Pi-Vac treated samples, whereas those weighted showed no change.

Related to these findings Stevenson, Morton, Ilian, & Bickerstaffe (2002) provided evidence that the degradation of the large structural protein titin was more rapid during ageing in meat that was stretched. Data from Bruce & Ball (1990) also suggested that collagen solubility was increased in stretched muscle entering *rigor* at high temperatures. Clearly a number of different mechanisms could be operative, but how they interact has not been clarified and this limits the ability to maximise a process.

The development of technology in New Zealand to potentially stretch hot boned meat provided scope for integration into the Australian processing industry, bearing in mind the likely benefits based on the published literature. However the technology was not validated and as a consequence a large project was undertaken to validate the benefits from initially stretching hot-boned sheep meat. The project was extended to include hot-boned beef and to examine the benefits of shaping cold-boned sheep and beef primals.

2 Project objectives

1. Undertake a research program to test and validate stretching technology that can be used to manipulate muscle form and quality and examine the interaction with electrical stimulation.
2. Develop partnership relationships with sheep meat processors so as to expedite R&D adoption.
3. Contribute to a research program to integrate stretching technology and electrical technologies with a focus on primal manipulation.
4. Collaborate with other EQ programs (eg Joint MQST and Sheep CRC2 processing program) with a focus on pre-rigor stretching.
5. Deliver technical support for the running and maintenance of the Australian modified prototype unit during the full business development of phase 2 (12 months), specifically by providing technical input in a minimum of 6 plant demonstrations and/or technical trials.

2.1 Objective 1

Undertake a research program to test and validate stretching technology that can be used to manipulate muscle form and quality and examine the interaction with electrical stimulation.

2.1.1 Stretching experiments on hot-boned sheep meat

2.1.1.1 Experiment 1: Improving the tenderness of sheep topsides (m. semimembranosus) using a meat stretching device

Introduction

It has been well established that tenderness is one of the most important meat quality traits (for example, Maltin, Balcerzak, Tilley, & Delday (2003), Sørheim & Hildrum (2002) and Tornberg (1996)). There are three factors that determine meat tenderness which include “background toughness”, the toughening phase and the tenderisation phase (Hopkins & Geesink, 2009). The toughening and tenderisation phases take place during the post mortem storage, or aging period, but the extent of the toughening can be modified by altering the degree of muscle shortening (Hopkins & Thompson, 2001). This is particularly important in situations such as hot boning where removal of the muscle from the skeleton prior to *rigor* can lead to excessive shortening when meat is exposed to low temperatures (Marsh & Leet, 1966). Thus it is critical that tenderness is not compromised in the quest for accelerated processing and for this reason hot-boning is often performed in conjunction with electrical stimulation. Hot-boning can be defined as the removal of muscle from the carcase prior to the completion of *rigor mortis* (Devine, Hopkins, Hwang, Ferguson, & Richards, 2004). Both Jeremiah, Martin, & Murray (1985) and Pisula & Tyburcy (1996) highlighted the many benefits from hot-boning including; reduction in weight loss during chilling, reduction in drip loss during storage, hence higher final yields, reduction in chiller space thus saving in energy inputs on refrigeration, faster turnover of meat in the processing plant, reduction in capital costs for buildings and finally savings in both labour and transport.

Despite the many advantages of hot-boning there are major constraints. Pisula & Tyburcy (1996) described the limitations of existing plants being able to adopt the technology due to having to make significant changes to their current processing systems. Another constraint outlined by (Spooncer, 1993), is the increased risk of bacterial growth. However, Spooncer (1993) also showed that this could be controlled by a combination of drying and cooling. The impact that hot-boning has on meat

tenderness is a significant concern with regard to producing quality meat. Hot-boning increases the risk of muscle shortening (Devine, et al., 2004) due to the removal of the muscle from the skeletal constraint and shortening is a major influence on meat tenderness (Tornberg, 1996). Although this shortening can be minimised through the use of electrical stimulation, in order to further improve the tenderness of hot-boned meat another approach to prevent muscle shortening is to restrain the muscles physically until they are in *rigor mortis* (Macfarlane, Harris, & Shorthose, 1974).

Early work by Locker (1960); Herring, Cassens, Suess, Brungardt, & Briskey (1967) and Davey, Kuttel, & Gilbert (1967) all proved the concept that pre-*rigor* excised muscles could be stretched and improved tenderness achieved. The stretching of major muscles can be achieved by carcase suspension or alternatively by removing the cut from the carcase and clamping using a simple mechanical device. More recently, Devine, Payne, & Wells (2002b) demonstrated that excising and wrapping meat by hand could be used to control sarcomere shortening by stretching the muscle pre-*rigor*. This wrapping technique was then further developed into the Pi-Vac Elasto-Pack System and Troy (2006) reported on a series of experiments that linked hot-boning of beef carcases and the use of the Pi-Vac system. Broadly, outcomes from these experiments showed that, when compared to the control, the Pi-Vac treatment enabled hot-boned meat to be packaged and chilled quickly without the risk of cold shortening and hence toughening. It allowed the possibility of extended shelf life and ensured consistent quality. However, as Taylor & Hopkins (2011) (Section 2.1.4) concluded it is difficult to accurately assess the benefits of this technology as any experimentation relating to the Pi-vac system has only been published in conference proceedings, industry publications or book chapters, hence the experiments have not been placed under any scrutiny by peers.

The adoption of hot or warm boning in the Australian sheep meat processing industry has been limited to the use of adult sheep meat. This process in most cases has been integrated with electrical stimulation with the intent of not only reducing muscle contraction subsequent to removal from the skeleton, by hastening the onset of *rigor*, but also decreasing the risk of bacterial growth due to high pH (Spooncer, 1993). The only published data on the eating quality of sheep meat processed through this system shows a low level of consumer compliance with only 14% of samples tested achieving the 'good everyday' requirement (Toohey & Hopkins, 2006). In contrast, when adult sheep were processed at the same abattoir, but conventionally chilled and cold boned, product aged for 7 days achieved a high level of consumer compliance with 86% of samples tested achieving a 'good everyday' ranking (Hopkins & Toohey, 2006). This 'good everyday' score is derived from consumer sensory testing which is explained by Polkinghorne et al. (1999) and Watson, Gee, Polkinghorne, & Porter (2008). In follow up work where hot boned loin meat was either wrapped and aged for 7 days or unwrapped and frozen at 1 day, the consumer overall liking score was significantly improved from 57 to 64 respectively as was the tenderness score derived from consumer sensory testing from 52 to 64 respectfully. This equates to a 14% and 24% improvement in the overall liking and tenderness scores respectively compared to product unwrapped and frozen at 1 day (Toohey, et al., 2008b). In addition to these improvements in sensory scores there was a significant reduction in meat toughness based on objective tenderness results with unwrapped frozen meat at 1 day requiring on average 62N of force to be sheared in half compared to 29N for wrapped and 7 day aged meat. In addition to these studies it was also concluded by Rosenvold et al. (2008) that even without electrical stimulation acceptable tenderness levels could still be achieved at high pre *rigor* temperatures when a similar wrapping technique as used by Toohey, et al. (2008b) was applied.

Hence the aim of this study was to evaluate the effect of both stretching and ageing on meat tenderness of hot boned sheep topsides (m*. semimembranosus, abductor* & m. *gracilis*) using a pre-production stretching prototype device (licensed as SmartStretch™), under commercial processing conditions where electrical stimulation was applied. The intention was to establish

whether this additional processing step would further enhance the tenderness of hot boned sheep topsides irrespective of the stage of *rigor*.

Materials and Methods

Animals

For testing the effect of the SmartStretch™ prototype machine and post-mortem ageing, a total of 40 sheep of mixed sex (ewes and wethers) from three different randomly selected consignments were assessed. The sheep used from these different consignments were of varying backgrounds, to represent the typical animals processed by the abattoir. However all sheep used were the same breed (Merino) and were all aged between 3 and 4 years old.

Experimental Design

Using a randomised complete block design with 10 replicates, the treatments were randomised to topside within a carcase. The treatment combinations used were; 0 days ageing + SmartStretch™, 0 days ageing + control, 5 days ageing + SmartStretch™ and 5 days ageing + control. There were two stages to the design for this experiment. The treatment combinations were randomised between carcase and side within carcase.

Sample collection

The carcases were processed under the normal commercial procedures of the abattoir. As apart of this process carcases were exposed to a number of electrical inputs routinely used by the cooperating abattoir including; high frequency immobilisation unit, applied for 25-35 secs (2000 Hz, 400 volts, and a maximum current of 9 amps over 7 animals, pulse width of 150 microseconds), moderate frequency immobilisation (800 Hz, 300 peak volts, a constant current of 1.7 amps, pulse width 150 microseconds) applied for 5-7secs, low voltage electronic bleed (15 Hz, 550 peak volts, constant current of 0.8 amps, pulse width 500 microseconds) applied for 20 seconds and post dressing medium voltage electrical stimulation (MVS) with a constant current 1.0 amp and pulse width of 2500 microseconds, but variable frequency across the 6 electrodes (the frequency for electrodes 1 & 2 was set at 25 Hz, 3 & 4 at 15 Hz and 5 & 6 at 10 Hz, with 300 peak volts) applied for 30-35 seconds. Carcases then passed through a drying room for approximately 35 minutes with an average temperature of 8ºC. Following this process both the right and left topsides (m. *semimembranosus, adductor* & m. *gracilis*) HAM. 5073 (Anonymous, 2005) from 40 carcases (*n* = 80) were collected and trimmed removing all fat and placed into their predetermined treatments within approximately 2 hours of death.

Muscle measurements

Some ‘descriptive’ measurements were taken on each of the whole primal topsides including initial length (Li) and initial circumference (Ci) which was measured at two different points. Topsides that underwent the SmartStretch™ treatment were re-measured once the treatment was completed and a final length (Lf) and circumference (Cf) were recorded. From these results both the percentage increase in length and percentage decrease in circumference at sites 1 and 2 were calculated using the following formulae:

- Length Increase (%) = 100 – (Lf/Li* 100)
- Circumference decrease (%) = 100 – (Cf/Ci* 100)

Initial pH & Temperature

The pH and temperature were measured in all topsides (in the m*. semimembranosus*) just prior to the application of the stretch treatment. Muscle pH was measured using a glass combination pH probe (potassium chloride) Ionode intermediate junction pH electrode, (TPS Pty Ltd., Brisbane, Queensland) attached to a data recording pH meter (TPS WP-80). While muscle temperature was measured using a stainless steel cylindrical probe attached to the same meter. The pH meter was calibrated before use and at regular intervals using buffers of pH 4 and pH 6.8 at room temperature.

Treatments

The stretch treatment was applied within approximately 2 hours of death. The treatment was achieved using a meat stretching prototype (SmartStretch™), under development by Meat & Livestock Australia and Meat & Wool New Zealand. The SmartStretch™ technology uses a flexible rubber sleeve which is surrounded by four inflatable bladders that are housed within an airtight chamber. To insert meat into the machine air is pumped out of the chamber under vacuum which causes the rubber sleeve to expand. Once meat has been inserted into the chamber the vacuum is removed and air is then pumped into the four inflatable bladders which surround the rubber sleeve causing the meat to be compressed by force perpendicular to the direction of the muscle fibres. This also applies peristaltic action, moving the meat towards the same end of the sleeve that it was inserted into. Air pressure is then applied to the exterior of the sleeve by pumping air into the chamber, forcing the meat upwards and into packaging. In the current experiment the meat was inserted into a 100 µm polyethylene packaging tube so as to constrict the muscle to prevent any subsequent contraction of the muscle. In this experiment the packaging unit size was 63mm diameter using 100mm layflat packaging. The control samples were vaccum packed and then frozen after predetermined aging periods.

Figure 1: Australian SmartShape™/SmartStretch™ prototype Version 1 used in this experiment.

The 0 day samples were frozen within approximately 4 hours of slaughter and stored in a freezer at -22ºC until sampling. The 5 day aged samples were chilled at an average temperature of 2ºC and following 5 days of ageing the remaining samples were also frozen and stored in a -22ºC freezer.

Sample preparation

Topsides were tempered at an average temperature of 21ºC for approximately 2 hours to allow the m. *abductor* & m. *gracilis* to be removed from the m*. semimembranosus*. Then sarcomere, shear force, and particle size samples were cut from the m*. semimembranosus* (SM) whilst the SM was still predominately frozen.

Sarcomere length

Sarcomere length was measured using laser diffraction as described by (Bouton, Harris, Ratcliff, & Roberts, 1978) on samples aged for 0 and 5 days.

Warner Braztler shear force

Shear force samples were cut into approximately 65 gram blocks, with dimensions of approximately 60-70mm length, 40-50mm width, 20-25mm thick. These shear force samples were cooked for 35 min in plastic bags at 71°C in a 90 L water bath with a thermoregulator and a 2000 W heating

element (Ratek Instruments, Boronia, Victoria, Australia) and measured using a Lloyd Texture analyser as previously described (Hopkins, Toohey, Warner, Kerr, & van de Ven, 2010).

Cooking loss

Samples used for Warner Braztler shear force determination were weighed pre and post cooking to measure the amount of cooking loss. After cooking the samples were cooled in running water patted dry using paper towelling prior to weighing. Cooking loss percentage was calculated as follows:

Cooking loss (%) = 100 – (cooked weight/fresh weight * 100)

Particle Size

A 1-2 g sample was collected from the m. *semimembranosus* (SM) for 0 day and 5 day aged samples. The particle size analysis method has been described by (Karumendu, Ven, Kerr, Lanza, & Hopkins, 2009) and was conducted on 1g samples.

Final pH

A 1 gram sample was taken for determination of final pH on both 0 and 5 day aged samples. This was determined using an iodoacetate method adapted from that described by (Dransfield, Etherington, & Taylor, 1992) and as described by (Hopkins & Toohey, 2006).

Purge loss percentage

The purge loss was derived from the 5 day aged samples. The weight of the samples and packaging was taken at collection. Just before freezing the weight of the samples (patted dry) and the weight of the packaging were taken. Purge loss percentage was then calculated using the following formula:

Purge loss (%) = (Initial weight – final weight – packaging weight)/(initial weight – packaging weight) * 100

Statistical analysis

Linear mixed model (LMM) analysis was undertaken using ASReml, (Gilmour, Gogel, Cullis, & Thompson, 2006) via the statistical package *asreml* (Butler, 2009) under R (R Development Core Team, 2009). Variance components of the model were tested for significance using a likelihood ratio test whilst fixed effects were tested using Wald-related test statistics developed by Kenward & Roger (1997). These Wald-related test statistics have been developed to accommodate small sample inference. The degrees of freedom (df) are rounded down to be conservative. Generalized LMM's (GLMM), e.g. logistic regression, are handled in ASReml using a Schall linearization approach (Schall, 1991), with tests for significance of random and/or fixed effects as for LMM's. The model contained fixed effects for stretch treatment (control or SmartStretch™), ageing time (0 or 5 days) and significant interactions between these. The random terms used in the model were consignment, replicate and carcase. There were 10 replicates derived from the four treatment combinations within carcase.

Regression analysis was used to derive the relationship between sarcomere length and shear force, sarcomere length and percent increase in length, sarcomere length and initial pH, shear force and percent increase in length and lastly shear force and initial pH. The model fitted for the linear mixed

model regression analysis was Y = baseline + X + ***Animal + error.*** In this case the random terms are in **bold** and Y = (shear force or sarcomere length) and X = (sarcomere length, percent increase in length or initial pH). A spline regression model was used to test the regression of sarcomere length and log (shear force) and the model included animal as a random effect. Note that percent increase in length is only available for stretched samples.

Results

Muscle measurements

A summary of statistics of characteristics of the sheep meat used in this experiment are shown in Table 1 to give an indication of the variance within the data. There was no significant difference (*P > 0.05*) between stretch and ageing treatments for any of the traits shown in Table 1 nor were there any interactions. This indicates that the random allocation of muscles across treatment groups was balanced, however of the random terms fitted to the model carcase was significant.

Table 1: Summary of statistics predicted mean, standard error (s.e.) and range for SmartStretch™ (stretch) and control treatments.

Trait	Control	Range	Stretch
Leg weight (kg)	3.30 *(0.07)*	2.32-4.20	3.17 *(0.07)*
Initial pH	6.20 *(0.03)*	5.87-6.63	6.24 *(0.03)*
Initial Temperature (°C)	33.9 *(0.32)*	28.5-37.8	33.0 *(0.32)*
Increase in length (%)	*	*	24 *(1.09)*
Decrease in circumference (%)	*	*	24 *(1.28)*

*percentages are only given for the SmartStretch™ treatment.

One of the most important aspects that Table 1 highlights is that, based on the initial pH and temperature, the *m. semimembranosus* muscles on average were still in the pre-*rigor* phase with a mean initial pH of 6.22 however given the SD was 0.81, it suggests that some would be in stages of *rigor*. The range in the leg weights of the samples processed represents the diverse range of product processed.

Table 1 also shows that there was on average a 24% increase in m. *semimembranosus* muscle length and a 24% decrease in circumference after the SmartStretch™ treatment was applied. SmartStretch™ also transformed the m. *semimembranosus* into a consistent shape (**Figure 2**).

Figure 2: Examples of the effect of the SmartStretch™ treatment on the shape of the topside.

Warner Bratzler shear force

Table 2 shows the significant treatment effects and relevant covariates on shear force, cooking loss, sarcomere length and particle size. For shear force the interaction between stretch and ageing treatment was significant ($P < 0.01$) as shown in Table 2. This interaction showed that the 0 day aged control group (no SmartStretch™) meat was the toughest and 5 day aged SmartStretch™ treatment was the most tender (Table 3). The random term fitted to the model (carcase) as expected was significant which could indicate that some muscles may not have impacted on the SmartStretch™ treatment response.

Table 2: F-ratio for effects stretch, age, stretch x age along with relevant covariates for initial pH on shear force, cooking loss %, sarcomere length and particle size.

Terms	Shear force		Cooking loss %		Sarcomere length		Particle size	
	*D*f	F-ratio	*D*f	F-ratio	df	F-ratio	df	F-ratio
Stretch	^	^	1,73	35.3***	1,47	134.3***	1,75	3.71 ^{ns}
Age	^	^	1,73	1.10 ^{ns}	1,25	4.02 ^{ns}	1,75	8.90*
Age x Stretch	1,37	10.74**	1,38	0.05 ^{ns}	1,39	0.02 ^{ns}	1,37	5.60 ^{ns}
Initial pH	1,56	1.45 ^{ns}	#	#	1,40	0.52 ^{ns}	#	#

*** $P < 0.001$; ** $P < 0.01$;* $P < 0.05$, ^{ns} $P > 0.05$, ^ Not tested because there was a significant interaction, # was not used as covariate in model.

Table 3: Predicted means (av. s.e.d.) of SM shear force in newtons, according to treatment groups.

	Shear force	
Treatments	**SmartStretch™**	**Control**
0 days aged	40.8b	74.9d
5 days aged	33.8a	53.9c
Ave SED		*2.5*

Means followed by a different letter are significantly different (*P* < 0.001*).*

The present study also examined the impact of treatments on the distribution of shear force. **Figure** shows that the variation in shear force of the SmartStretch™ treatment groups after both 0 and 5 days of ageing was less than the control treatment groups.

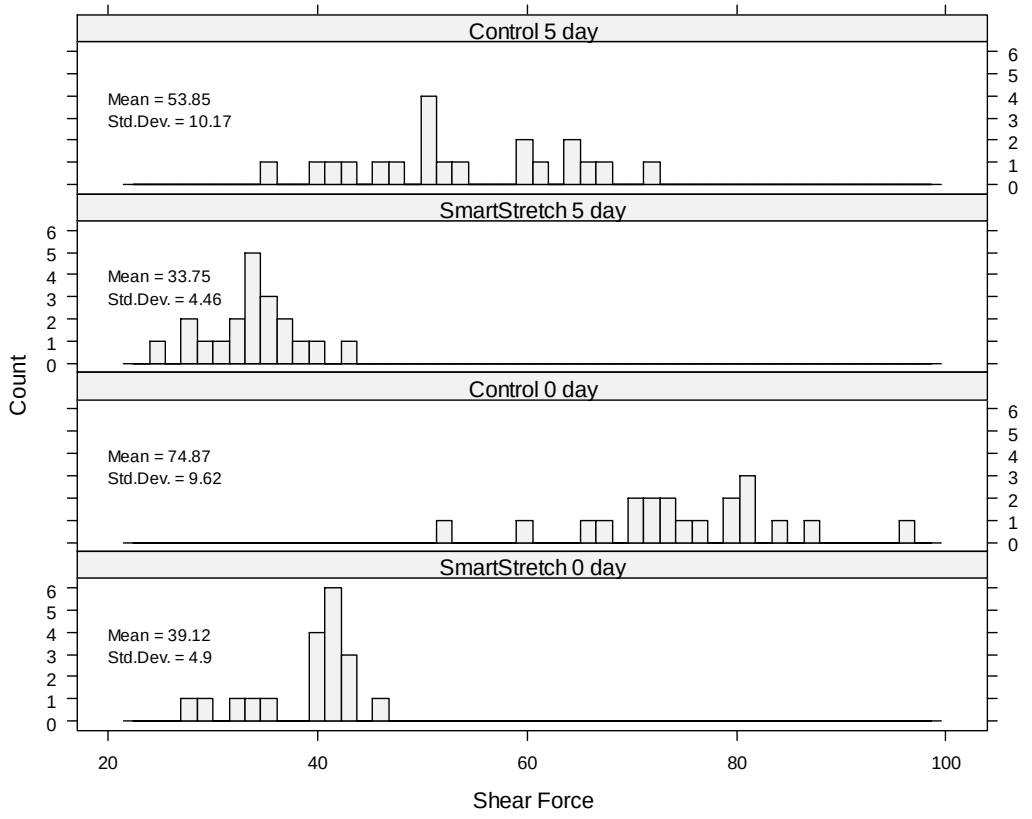

Figure 3: Histogram showing the effect that the SmartStretch™ and control treatment at 0 and 5 days had on shear force (N) distribution.

Cooking loss

Cooking loss results reveal a significant difference between SmartStretch™ treatment and control (*P* < 0.001) with SmartStretch™ treatment having significantly lower cook loss (Table 4), but this trait was unaffected (*P* > 0.05) by ageing period and there was no interaction between the SmartStretch™ and ageing treatments as shown in Table 2.

Table 4: Predicted means (av. s.e.d.) of SM cooking loss (%), according to treatment groups.

	Cooking loss	
Treatments	**SmartStretch™**	**Control**
0 days aged	20.6a	24.2b
5 days aged	19.8a	23.7b
Ave SED		*0.87*

Means followed by a different letter are significantly different ($P < 0.001$).

Sarcomere Length

The results in Table 2 show that there was a significant difference ($P < 0.001$) between SmartStretch™ treatment and control for sarcomere length, with the former having longer sarcomeres (Table 5). There was no significant difference ($P > 0.05$) between ageing periods or interaction between ageing and SmartStretch™ treatment (Table 2).

Table 5: Predicted means (av. s.e.d.) of SM sarcomere length (µm).

	Sarcomere length (µm)	
Treatments	**SmartStretch**	**Control**
0 days aged	2.19a	1.54b
5 days aged	2.22a	1.60b
Ave SED		*0.72*

Means followed by a different letter are significantly different ($P < 0.001$).

The impact of stretch treatment on the variation or distribution of sarcomere length was examined (Figure 4) and the results showed that there was greater variation in the SmartStretch™ treatment for sarcomere length.

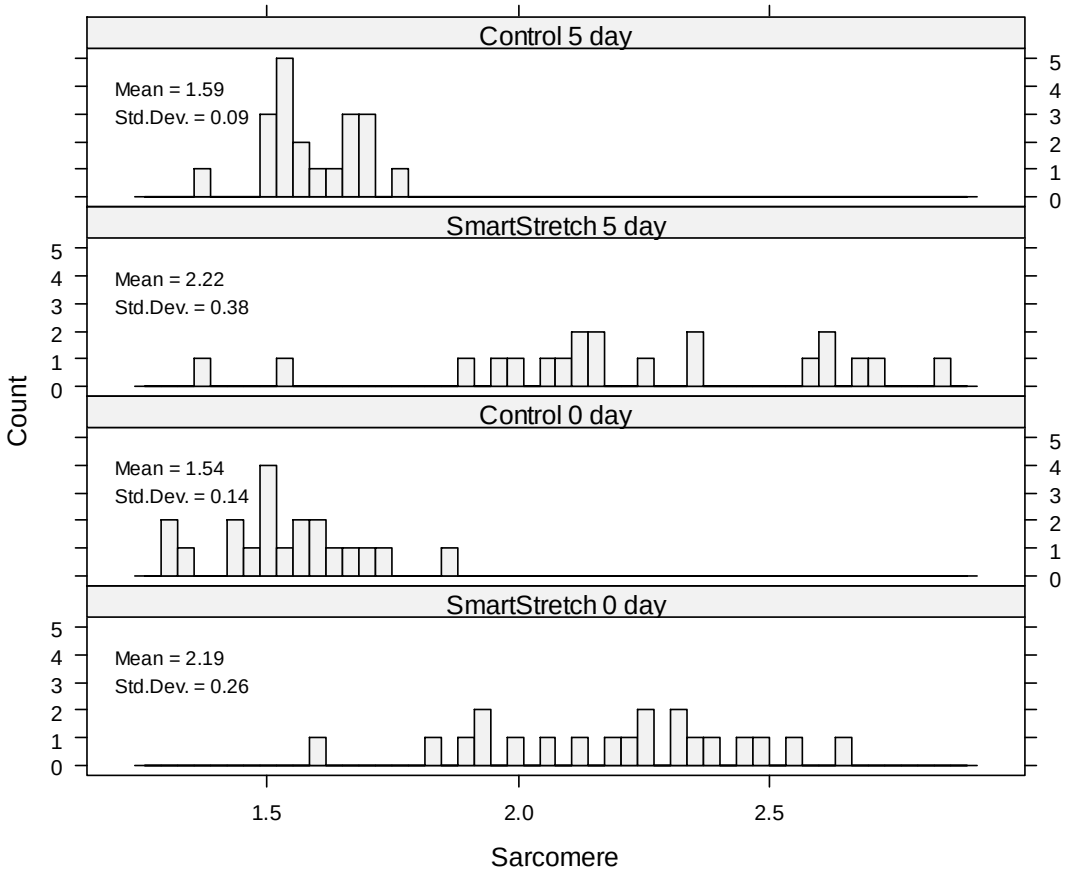

Figure 4: Histogram showing the effect of SmartStretch™ and control treatment at 0 and 5 days on the distribution of sarcomere length (µm).

Particle Size

Particle size results showed that there was no significant difference ($P > 0.05$) between SmartStretch™ treatment and control or interaction between ageing and SmartStretch™ treatment, but there was a significant difference ($P < 0.001$) between ageing periods (Table 2). As such 5 day aged samples had a lower PS than 1 day aged samples at 158 µm and 185 µm respectfully with an average s.e.d. of 9.22 µm.

Regression analysis

To determine whether the stage of *rigor* impacted on shear force initial pH was included initially as a linear effect, however it was determined not to be significant (Table 2; $P = 0.23$). In addition to this there was no significant relationship ($P = 0.80$) shown between initial pH and sarcomere length (Table 2). If the results within each treatment were examined separately, there was no significant correlation ($P > 0.05$) between shear force and sarcomere length within any treatment as shown in Figure 5. However there was a marginally significant ($P \approx 0.10$) negative correlation for control samples aged for 5 days.

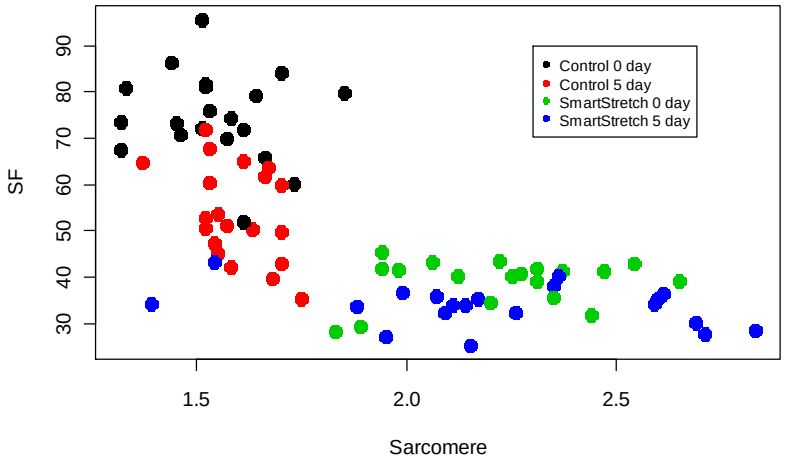

Figure 5: Regression analyses of shear force (SF) measured in Newtons and sarcomere length (µm) for each stretch and ageing treatment.

However there does appear to be a relationship between shear force and sarcomere length if a trend line is fitted to the logSF versus sacromere length data, ignoring treatments, using a spline model, this trend is shown in Figure 6. This trend suggests a threshold in sacromere length (at about 2.0 microns above which SF plateaus).

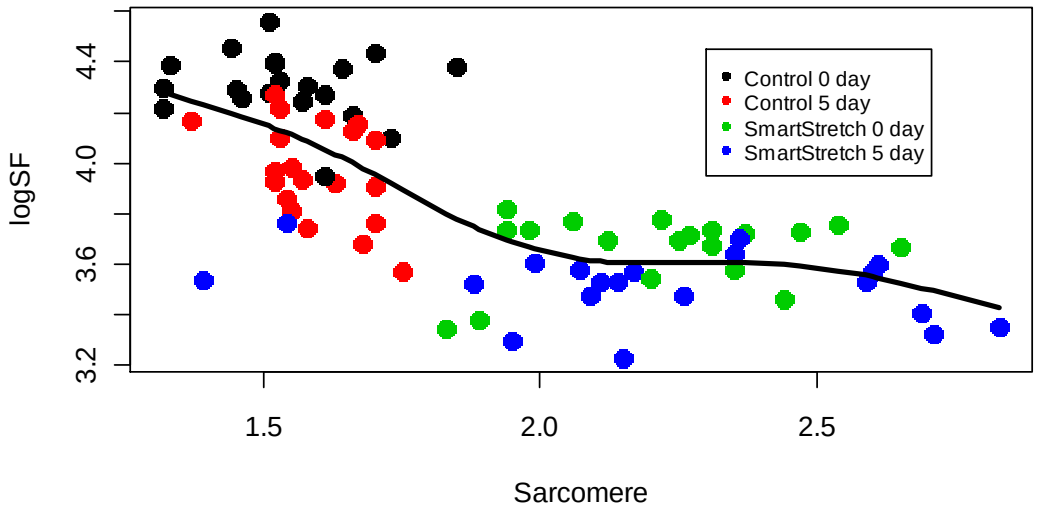

Figure 6: Spline analysis for logSF (Newtons) and sarcomere length (µm).

When the residuals about the trend were examined, separately for each treatment, via box-plots (Figure 7), the residuals were not independent and identically distributed N(0, σ^2). This indicated that logSF was not solely related to sarcomere length and that the treatments were having some additional effect causing differences in shear force.

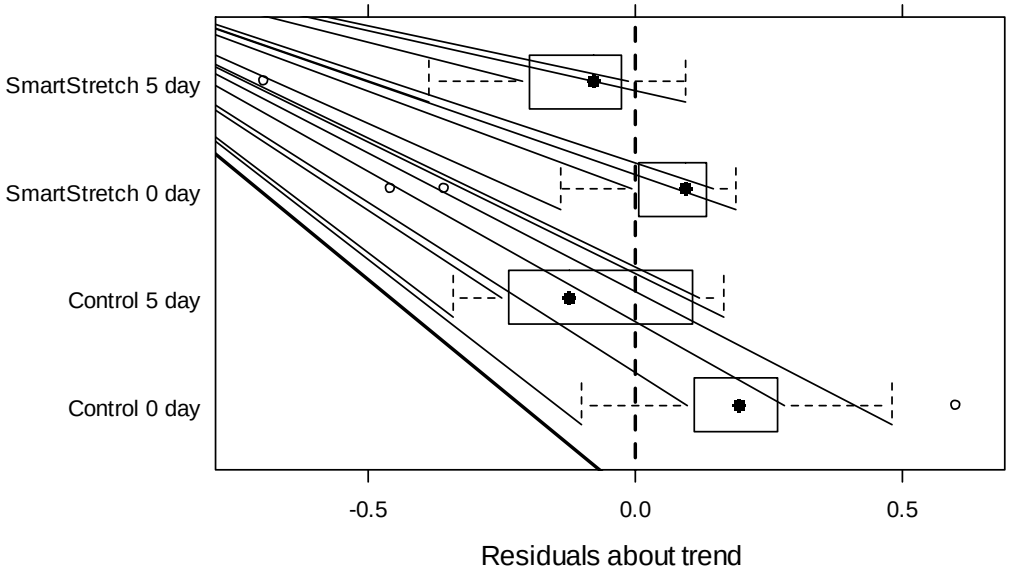

Figure 7: Box-plot of the residuals about the trend for each stretch and ageing treatment.

The percent increase in muscle length did not show a significant relationship with sarcomere length (P = 0.55) or shear force (P = 0.42).

Discussion

The SmartStretch™ treatment caused on average a 24% increase in m. *semimembranosus* muscle length and a 24% decrease in circumference, hence transforming the m. *semimembranosus* into a consistent shape. This consistency was considered a desirable trait by the food service industry (MLA, 2009) as it standardised shape for the preparation of roasts and slices and minimised cutting losses. In addition to this Tarrant (1998) reported that consumer demand has also shifted to more uniform, small pre-packaged retail portions. This is an important industry outcome as to our knowledge there is no other machine that can take a whole primal (*m. semimembranosus*) and shape it to a consistent size and shape.

Based on the threshold derived by Hopkins, Hegarty, Walker, & Pethick (2006) only 10% of samples from the 5 day aged SmartStretch™ treatment would be within the given threshold. It should be noted that the threshold derived by Hopkins, et al. (2006) was based on eating quality results from lamb loins and if the same threshold were derived on the current data set results may vary. Hwang, et al. (2003b) showed that the high connective tissue in the *m. semimembranosus* meant that shear force was less useful in predicting sensory tenderness when compared to low connective tissues cuts such as the loin. However, it can be concluded that without the use of SmartStretch™ the product is extremely tough at day 0 and was still far from acceptable at day 5, especially given the SmartStretch™ resulted in a 34N and 20N drop in shear force after 0 and 5 day respectively compared to the controls.

The interaction between stretch and ageing treatments for shear force in the current study supports the outcomes reported by Devine, Wahlgren, & Tornberg (1999) in that hand wrapped hot-boned beef *m. longissimus* had significantly lower shear force values when compared to control *m.*

longissimus after 0 and 7 days of ageing. In addition to this Hildrum, Anderson, Nilsen, & Wahlgren (2000) also reported a significant improvement in tenderness for wrapped hot-boned beef *m.longissimus* after 2 and 9 days of ageing. However Hildrum, et al. (2000) in the same study reported on wrapped hot-boned beef *m. semimembranosus* and there was no significant improvement in meat tenderness. In a review by Sørheim & Hildrum (2002) the authors summarised that this null effect of wrapping on the *m. semimembranosus* was most likely due to size and shape of the cut and hence the physical difficulty of reducing contraction in the muscle when compared to *m. longissimus* muscle. In addition to these studies Rosenvold, et al. (2008) and Troy (2006) also reported on the benefits of constricting pre-*rigor* muscle contraction through wrapping and the use of Pi-vac respectively on shear force.

The mechanisms by which SmartStretch™ impacts on meat quality has many similarities to the principles of tenderstretching as both techniques are applied on pre-*rigor* muscle. Tenderstretching is achieved by suspending carcases from the aitch bone (*obturator foramen*) in beef or the pelvis in sheep as it comes off the slaughter chain, hence placing increased tension on major leg muscles *(Semimembranosus, Gluteus medius, Vastus lateralis, Biceps femoris)* and loin *(Longissimus)* muscles before they pass through *rigor* (Hopkins, 2004; Thompson et al., 2005). As reported by Thompson (2002) the increased tension is aimed at either, stretching or minimising shortening (reducing the overlap of actin and myosin) of muscles and hence improving meat tenderness. However there are reports where super tenderstretching resulted in clear breaks in the I-band and disassembly of the Z disks indicating disruption of proteins such as actin, titin and nebulin, hence weakening the sarcomere and increasing tenderness, but it is unlikely that SmartStretch™ can create this level of disruption.

Although there are parallels between the two techniques of SmartStretch™ and tenderstretch there are many differences in the fact that SmartStretch™ is performed on excised hot boned primals and tenderstretch is performed on whole carcases hence it is expected commercially there would be differences in cooling rates. These are important factors to remember when comparing techniques as the study of Locker & Hagyard (1963) and the more recent work by Devine, et al. (2002b) stressed the impact of carcase restraint and *rigor* temperature with regard to meat tenderness.

In the current study after 0 days of aging the SmartStretch™ caused a reduction of 46% or 34N in shear force relative to muscle that was allowed to shorten during *rigor*. Even after 5 days of aging there were still large benefits evident, with a reduction in shear force of 38% or 20N. These improvements in shear force caused by the SmartStretch™ are comparable to those reported by Hopkins, et al. (2000b) by using tenderstretching and super tenderstretching of the loin where on average tenderness was improved by 40%. This dramatic improvement was also observed in earlier work by (Bouton, Harris, Shorthose, & Baxter, 1973b), which examined the impact of tenderstretch on sheep m. *semimembranosus* amongst other muscles. In a more recent study by Thompson, et al. (2005) in both lamb and sheep meat although the differences were not as dramatic, it was also shown that by tenderstretching there was an improvement in both eating quality and shear force. The results presented by Thompson, et al. (2005) suggest the effect appeared to be a function of *rigor* temperature.

Given that the primary cause of consumers not repurchasing red meat is due to the variability in eating quality, especially meat tenderness (Bindon & Jones, 2001) the present study examined the impact of treatments on the distribution of shear force. Figure 4 shows that the variation in shear force of the SmartStretch™ treatment groups after 0 and 5 days of ageing, was less than the control treatment groups. This supports outcomes reported by Devine, et al. (1999) which showed that by wrapping meat smaller variation in shear force was achieved compared to unwrapped meat. This indicates that by restricting the muscle from contracting one can reduce the variation in meat tenderness hence producing a more consistent product.

Based on earlier studies conducted by Bouton, Harris, & Shorthose (1972) and Bouton, Fisher, Harris, & Baxter (1973a) it was concluded by Bouton, et al. (1973b) that stretched muscles have a greater water holding capacity, which is reported to result in less moisture loss during subsequent ageing. However, there appears to be contrasting results, as both, O'Sullivan, et al. (2003) and Troy (2006) reported a reduced drip loss as a result of Pi-vac treatment of hot boned beef *m. longissimus.* This was not observed in the study by Toohey, et al. (2008b) where sheep *m. longissimus* was wrapped using the same method as Devine, et al. (1999). In contrast, it was found that the wrapped treatment had significantly higher drip loss, but when cooking loss was examined it was unaffected by the wrapped treatment. Devine, et al. (1999) and Rosenvold, et al. (2008) both showed that the percentage of drip was unaffected by a wrapping treatment when *m. longissimus* from hot boned beef was examined. When Devine, et al. (2002b) examined cooking loss in hot boned sheep *m. longissimus* there was no significant difference between the wrapped treatment and control or ageing treatments, supporting the outcome of Toohey, et al. (2008b). Although in the current study there was a prominent difference between the SmartStretch™ treatment and control for cooking loss at 0 and 5 days ageing, this result may be attributed to the varying amount of initial purge that was lost before samples were processed. Given that purge has not been reported on in any of the above studies, it was concluded that further investigation into the impact that wrapping, constricting or stretching the muscle has on overall water holding capacity of individual muscles needs to be conducted.

Suzuki, Yamadera, Kido, & Watanabe (1997) reported that excised-restrained muscle strips from the m. *semimembranosus* had longer sarcomeres compared to control and there was no significant change in sarcomere length from 1 to 3 days *post mortem* onward supporting the findings in the current study. Similar outcomes were also shown by Devine, et al. (2002b) and Devine, et al. (1999) where sarcomere shortening was controlled by wrapping meat. This wrapping method is a similar concept to the SmartStretch™ as the aim was to restrain and hence potentially stretch the de-boned muscle to prevent the muscle fibres contracting or shortening. In addition, results from studies using the Pi-vac (again using the same principles of preventing muscle fibres contracting by placing an overwrap) found sarcomere lengths to be significantly longer when compared to the control group (Hildrum, et al., 2000; O'Sullivan, et al., 2003, and Troy, 2006).

The impact of stretch treatment on the variation or distribution of sarcomere length (see Figure 5) indicated that there was greater variation in the SmartStretch™ treatment for sarcomere length. This is an interesting outcome given muscle shortening is known as a cause of meat toughness (Macfarlane, et al., 1974) and in the current experiment SmartStretch™ reduced the variation in shear force. However, based on previous studies the relationship between shear and sarcomere length would appear to be complex and varied. Many studies have examined the relationship between sarcomere length and shear force (e.g. Smulders, Marsh, Swartz, Russell, & Hoenecke, 1990) and conclusions on this relationship have been far from unanimous. Many studies have found the relationship to be strong such that as shear force increases sarcomere values decrease (Bouton, et al., 1973b; Davis, Smith, Carpenter, Dutson, & Cross, 1979; Devine, et al., 1999; Herring, Cassens, & Briskey, 1965; Herring, et al., 1967, and Locker & Hagyard, 1963) and other studies have found no relationship (Culler, Jr, Smith, & Cross, 1978; Koohmaraie, Shackelford, Wheeler, Lonergan, & Doumit, 1995; Parrish, Vandell, & Culler, 1979; Seideman, Koohmaraie, & Crouse, 1987; Shackelford, Koohmaraie, & Savell, 1994, and Smith, Kastner, Hunt, Kropf, & Allen, 1979). Hence this begs the question: why are there such contrasting results? Previous studies show that a number of factors may impact on the relationship between shear force and sarcomere. These factors include: rate of glycolysis (Smulders, et al., 1990) and thus the temperature at *rigor mortis* (Devine, et al., 2002a; Devine, et al., 1999, and Geesink, Mareko, Morton, & Bickerstaffe, 2001) and thresholds for sarcomere length (Macfarlane, et al., 1974 and Marsh & Leet, 1966). Based on conclusions from these previous studies it is not surprising that there is not a simple linear

relationship between shear force and sarcomere length given the range in both initial pH (5.84-6.72) and sarcomere length (1.32-2.83µm) data.

The stage of *rigor* can impact the effectiveness of the stretch treatment, crudely *rigor* can be when the muscle reaches a pH of 6.0 (Hwang, Devine, & Hopkins, 2003a). However it is known that this does not occur across all muscle fibres simultaneously (Jeacocke, 1984) and is dependent on initial glycogen levels (Hwang, et al., 2003a). If muscles have reached *rigor mortis* meaning adenosine triphospate (ATP) is depleted, then permanent cross bridge formation of the contractile components actin and myosin occurs (Hwang, et al., 2003a) the muscle becomes stiff and the stretch treatment would be less effective. Based on the initial pH and temperature of the SM in the current study, muscles were on average still in the pre-*rigor* phase with a mean pH of 6.22 ± 0.81 and a mean temperature of 33.5 ± 2.02. This indicates that some muscles would have entered the stages of *rigor*. However it does not appear that this has significantly impacted the effectiveness of the stretch treatment given the relationship between initial pH and both shear force and sarcomere length was not significant. Hence the initial pH does not explain any of the variation in shear force or sarcomere length. In addition the present study also investigated the relationships between the percent increase in length of the muscle for both sarcomere length and shear force. It was found that there was no relationship between either traits and hence the percent increase in length also has not explained any of the variation in shear force or sarcomere length.

Particle size (PS) analysis is one approach to measuring the degree of proteolysis that has occurred in meat and has been found to explain some of the variation in shear force (Karumendu, et al., 2009). Results from the current study showed that the stretch treatment had no effect on proteolysis, but the ageing treatment did. As such 5 day aged samples had a lower PS than 0 day aged samples at 158 µm and 185 µm respectively. This indicated that the fibres had degraded more during ageing, an outcome supported by the results of Karumendu, et al. (2009). This degradation was not influenced by the stretching treatment and is, as expected, due to ageing (e.g. Devine, et al., 1999 and Koohmaraie, Doumit, & Wheeler, 1996). However the results also suggest that the stretching treatment did not impact on the rate of protein degradation and thus the improvement in tenderness must reflect a change in sarcomere structure independent of proteolysis, an aspect that is worthy of further investigation.

2.1.1.2 Experiment 2: Improving the tenderness of sheep legs using a meat stretching device

Introduction

Given the potential negative effect that hot boning can have on meat quality, the adoption of hot boning in the Australian sheep meat processing industry has been limited to adult sheep carcases. Section 2.1.1.1 highlighted there are many advantages and disadvantages with hot boning (Devine, et al., 2004; Jeremiah, et al., 1985; Pisula & Tyburcy, 1996, and Spooncer, 1993). However it was also noted that with additional processing interventions such as electrical stimulation and some form of stretching intervention the overall meat quality in particular tenderness can be improved (Davey, et al., 1967; Devine, et al., 2002b; Herring, et al., 1967; Locker, 1960; Macfarlane, et al., 1974, and Troy, 2006).

The effect of both stretching and ageing on the tenderness of hot boned sheep topsides (m*. semimembranosus*) using a pre-production stretching prototype device called SmartStretch™ was outlined in section 2.1.1.1. This work showed that tenderness of the m*. semimembranosus* was significantly improved by applying SmartStretch™ treatment, such that after 0 days of ageing the SmartStretch™ treatment caused a 46% or 34N reduction in shear force and 38% or 20N after 5

days of ageing compared to non-stretched meat. Based on these results it was concluded that the accelerated tenderness achieved by a pre-*rigor* stretching device could remove the need for aged chiller storage of hot boned product to achieve acceptable tenderness levels.

This section describes an experiment which investigated the effect of stretching, using a prototype device (SmartStretch™), and ageing on meat tenderness, of whole, hot boned legs from sheep carcases. The intention was to quantify whether this additional processing step would further enhance the tenderness of hot tunnel boned sheep legs as it did with the m*. semimembranosus* as outlined in section 2.1.1.1. To gain an understanding on how SmartStretch™ impacts on tenderness, an experiment was undertaken which focussed on three key muscles (m. s*emitendinosus,* m*. semimembranosus* and m. *biceps femoris*) which make up a tunnel boned sheep leg*.*

Materials and Methods

Animals

For testing the effect of the SmartStretch™ prototype machine and post-mortem ageing, a total of 40 sheep from various consignments were assessed over two kill days. The sheep used were randomly selected from different consignments and hence were of varying backgrounds, representative of the typical animals processed by the abattoir. The sheep were mixed sex (ewes and wethers), Merino and aged between 3 and 5 years old.

Experimental design

Using a randomised complete block design with 10 replicates, the treatments were randomised to leg within a carcase. The treatment combinations were; ageing 0 days + SmartStretch™, ageing 0 days + control, ageing 5 days + SmartStretch™, ageing 5 days + control. There were two stages to the design for this experiment. The treatment combinations were randomised between carcase and side within carcase.

Sample collection

The carcases were processed under the normal commercial procedures of the abattoir. As apart of this process carcases were exposed to a number of electrical inputs routinely used by the cooperating abattoir as previously described in section 2.1.1.1. Carcases then passed through a drying room for approximately 35 minutes with an average temperature of 8ºC. Following this process both the left and right legs (Anonymous, 2005; HAM. 5060) were excised from the carcases pre-*rigor* using a tunnel boning technique (n = 80). Then the boneless legs were trimmed to approximately < 10mm of fat and placed into their predetermined treatments. The SmartStretch™ treated samples were processed using a packaging unit 105mm in diameter and 164mm layflat packaging.

Histology

A 1 gram sample was taken from the lateral side of the m*. semimembranosus* aged for 0 and 5 days. The 0 day aged sample was collected within approximately 2 hours of exsanguination and then samples were collected after 5 days of ageing. The muscle was fixed in a solution of 2.5% glutaraldehyde in 2% paraformaldehyde in 0.1M phosphate buffer and was used to determine the number of breaks in muscle fibres. The method for determining fibre breaks was adapted from that

reported by Taylor & Frylink (2003). This involves the fixing, embedding and staining of muscle samples. Digital images were collected at 40x magnification using a Leica DMR microscope and Nikon DXM1200F digital camera. Breaks across the fibres were quantified for 40 fibres per sample and if the fibres were not flat, but distorted this was also recorded.

Sample preparation

The 0 day aged frozen whole boneless legs were tempered for approximately 6 hours at an average room temperature of 21.4ºC to allow the *m. semimembranosus* (SM), *semitendinosus* (ST) and *biceps femoris* (BF) to be excised.

The 5 day aged whole boneless legs were thawed to a muscle temperature of approximately 2ºC at a room temperature of 21.7ºC. This enabled purge to be measured on the whole leg and the *m. semimembranosus* (SM), *semitendinosus* (ST) and *biceps femoris* (BF) to be separated.

Refer to section 2.1.1.1 for further experimental methodology.

Statistical analysis

The statistical analysis was determined using the same methods as described in section 2.1.1.1. The model contained fixed effects for SmartStretch™ treatment (control or SmartStretch™), ageing time (0 or 5 days) and the interaction. The random terms used in the model were consignment, replicate and carcase. There were 10 replicates derived from the four treatment combinations within carcase.

Regression analysis was used to derive the relationship between sarcomere length and shear force, sarcomere length and percent increase in length, sarcomere length and initial pH, shear force and percent increase in length and lastly shear force and initial pH. The model fitted for the linear mixed model regression analysis was Y = baseline + X + ***Animal + error*** as described in section 2.1.1.1. Note that percent increase in length was only available for stretched samples and sarcomere length was only available for 0 day aged samples.

Results

Muscle measurements

The summary of statistics (mean, standard deviation and range) for the various carcase characteristics and meat quality traits are shown in Table 6 to give an indication of the variance in the data. There was no significant difference ($P > 0.05$) between stretch and ageing treatments for any of the traits shown in Table 6 nor were there any interactions. This indicates that the random allocation of muscles across treatment groups was balanced. For final SM pH there was a significant interaction between stretch and ageing treatments ($P = 0.02$) such that 0 day control treatment had significantly lower pH (5.77) compared to 5 day control (5.87).

Table 6: Summary of statistics for carcase and meat quality traits predicted means and standard error (s.e.) and range for stretch treatments across.

Trait	Control	Range	Stretch	Range
Leg weight (kg)	1.96 *(0.05)*	1.37-2.68	1.92 *(0.05)*	1.40-2.47
Initial pH SM	6.15 *(0.03)*	5.91-6.57	6.17 *(0.03)*	5.77-6.65
Initial temperature ºC – SM	27.8 *(0.41)*	20.9-32.1	27.5 *(0.42)*	21.8-33.4
Final pH – SM	5.79 *(0.05)*	5.44-6.73	5.85 *(0.05)*	5.52-6.95
Initial pH – ST	6.30 *(0.04)*	5.68-6.92	6.30 *(0.04)*	5.91-6.96
Initial temperature ºC – ST	24.7 *(0.40)*	18.2-30.4	24.6 *(0.40)*	20.1-30.2
Final pH – ST	6.24 *(0.05)*	5.59-7.00	6.27 *(0.05)*	5.65-6.94
Final pH – BF	5.97 *(0.05)*	5.54-6.73	6.03 *(0.05)*	5.48-6.77
Increase in length (%)	*	*	14 *(0.93)*	2.4-24.0
Decrease in circumference (%)	*	*	45 *(1.71)*	21.4-65.4

*percentages are only given for the SmartStretch™ treatment.

One of the most important factors that Table 6 highlights is that, based on the initial pH and temperature, the SM and ST muscles on average were still in the pre-*rigor* phase however, given the SD was 0.18 and 0.25, it suggests that carcases would be in stages of *rigor*. The range in the leg weights of the samples processed represents the diverse product processed. This was also evident, based on the random terms fitted in the model (consignment, replicate and carcase) where the carcase variance component was significant for all traits shown in Table 6.

Warner Bratzler shear force

Table 7 shows the significance of treatment effects and relevant covariates on shear force and cooking loss for both the SM and BF muscles. There was a significant interaction between stretch and ageing treatments ($P < 0.05$) for the SM shear force and none of the random terms fitted in the model were significant. The interaction for the SM showed that the un-aged control group (no SmartStretch™) meat was the toughest (Table 8). The benefits of the stretching treatment diminished after 5 days of ageing. For the BF shear force both stretch ($P < 0.01$) and ageing ($P < 0.001$) were significant (Table 7), but there was no significant interaction ($P > 0.05$) between the two treatments and none of the random terms fitted in the model were significant. For the BF the 0 day aged control group meat was the toughest and 5 day aged SmartStretch™ treatment was the most tender.

Table 7: F-ratio for effects stretch, age, stretch x age along with relevant covariate for initial pH on shear force SM, shear force BF cooking loss % SM and cooking loss %BF.

Terms	Shear force SM		Shear force BF		Cooking loss % SM		Cooking loss % BF	
	df	*F*-ratio	df	*F*-ratio	df	*F*-ratio	df	*F*-ratio
Stretch	^	^	1,52	9.51**	1,61	1.69 ^{ns}	1,59	5.50*
Age	^	^	1,50	39.18***	1,65	4.25*	1,61	5.38*
Age x Stretch	1,35	4.16*	1,36	2.32 ^{ns}	1,37	4.11 ^{ns}	1,37	2.04 ^{ns}
Initial pH	1,58	2.34 ^{ns}	1,58	2.34 ^{ns}	#	#	#	#

*** $P < 0.001$; ** $P < 0.01$;* $P < 0.05$, ^{ns} $P > 0.05$, ^ Not tested because there was a significant interaction, # was not used as covariate in model.

Table 8: Predicted means (s.e) of biceps femoris (BF) and m. semimembranosus (SM) shear force in newtons according to treatment groups.

	Shear force BF		Shear force SM	
Treatments	**SmartStretch™**	**Control**	**SmartStretch™**	**Control**
0 days aged	41.4 *(2.08)* b	47.9 *(2.45)* d	51.3 *(2.87)* b	60.5 *(3.40)* c
5 days aged	31.0 *(1.58)* a	34.8 *(1.82)* b	40.6 *(2.34)* a	38.8 *(2.12)* a

Means followed by a different letter within rows and columns for a trait is significantly different ($P < 0.05$).

The present study also examined the impact of the treatments on the distribution of shear force for both the SM and BF as shown in Figures 8 and 9 respectively. The histogram for the SM muscle indicates that the variation in shear force from the SmartStretch™ treatment is slightly less than the control treatment irrespective of ageing period.

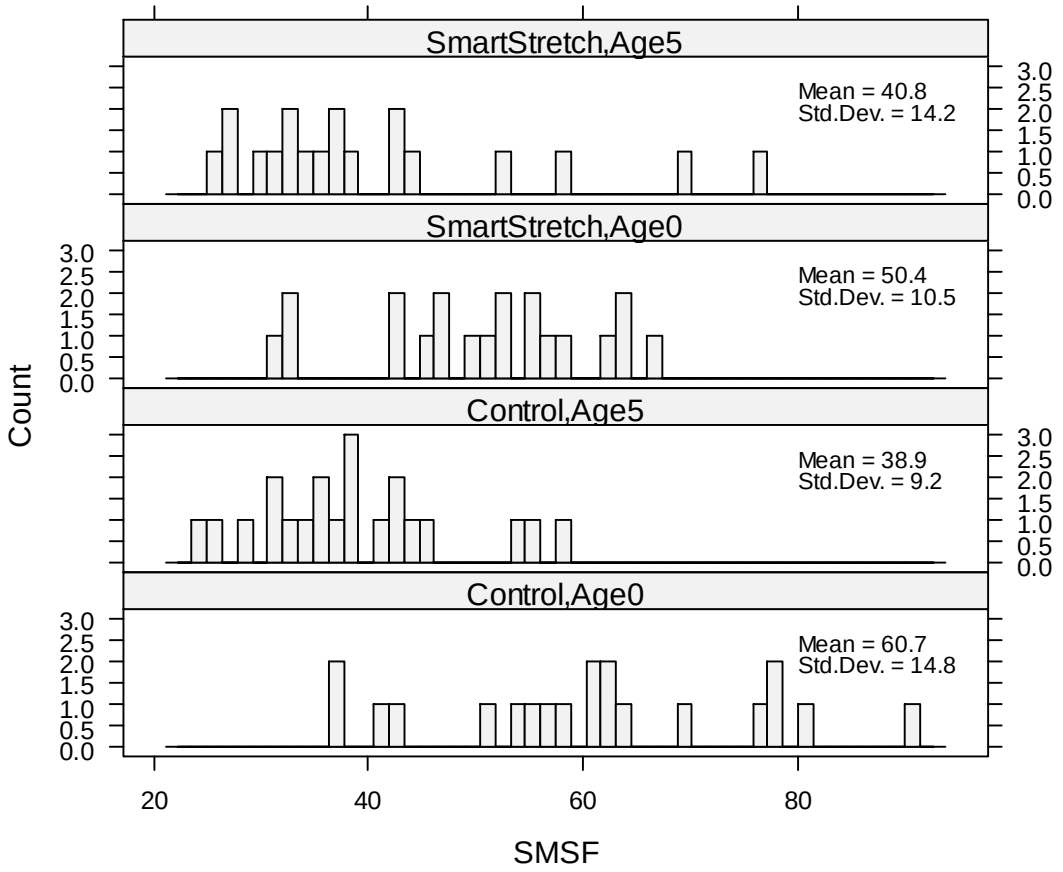

Figure 8: Histogram showing the effect that the SmartStretch™ and control treatment at 0 and 5 days of ageing had on shear force (N) distribution of the SM.

However the histogram (Figure 9) for the BF muscle shows that the variation is similar between SmartStretch™ and control treatment group although there was a greater standard deviation for the SmartStretch™ treatment irrespective of ageing.

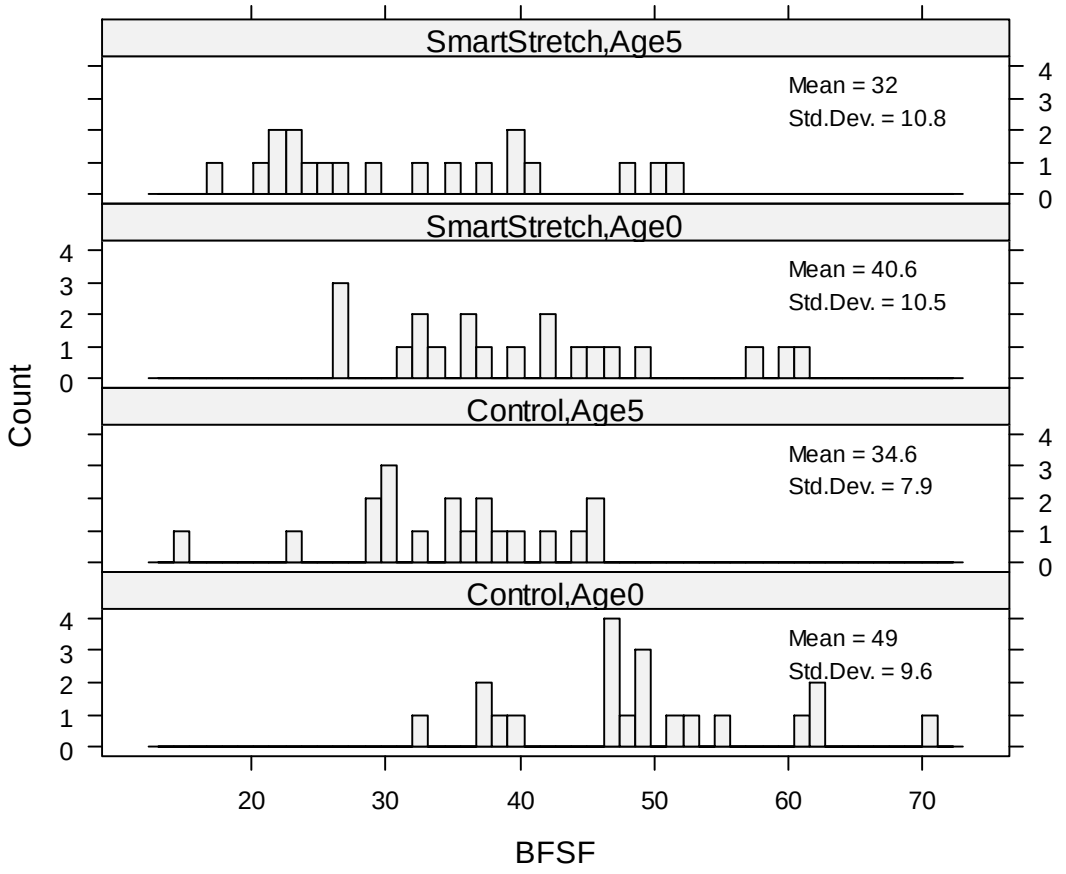

Figure 9: Histogram showing the effect that the SmartStretch™ and control treatment at 0 and 5 days of ageing had on shear force (N) distribution of the BF.

Cooking loss and Purge

The cooking loss of the stretched BF was lower ($P < 0.05$) than non-stretched BF and 0 day aged BF had a lower ($P < 0.05$) cooking loss than 5 day aged BF (Table 9), but this latter effect was the converse in the SM (Table 9) and there was no significant difference between stretching treatments. For both muscles there was no significant ($P > 0.05$) interaction between treatment and ageing for cooking loss (Table 7). Greater ($P < 0.001$) purge loss was found for stretched meat as shown in Table 9 *(Wald: F(1,28)=16.4 P=0.001)*.

Table 9: Predicted means, standard error (s.e) and LSD ranking of m. biceps femoris (BF) and m. semimembranosus (SM) cooking loss percentage and 5 day aged purge percentage according to treatment groups.

	BF cooking loss %		SM cooking loss %		5 day aged purge %	
Treatments	**Stretch**	**Control**	**Stretch**	**Control**	**Stretch**	**Control**
0 day aged	14.6 *(0.76)* a	16.5 *(0.77)* b	20.6 *(0.79)* b	21.7 *(0.79)* b	-	-
5 day aged	16.5 *(0.77)* b	18.3 *(0.77)* c	19.1*(0.81)* a	20.0 *(0.79)* a	2.87 *(0.20)* b	1.74 *(0.19)* a

Means followed by a different letter within rows and columns for a trait is significantly different ($P < 0.05$).

Sarcomere Length

The results in Table 10 show that there was a significant difference ($P < 0.05$) between SmartStretch™ treatment and control for both the SM *(Wald: F(1,27)=6.32 P=0.018)* and ST *(Wald: F(1,19)=15 P=0.001)* sarcomere length at 0 days of ageing.

Table 10: Predicted means (s.e) of m. semimembranosus (SM) and m. semitendinosus (ST) sarcomere length (µm) according to treatment.

	Sarcomere length µm	
	SmartStretch™	**Control**
SM	1.82 *(0.05)* a	1.61 *(0.04)* b
ST	2.12 *(0.07)* a	1.84 *(0.03)* b

Means followed by a different letter in a row (a, b) are significantly different ($P < 0.05$).

The impact of stretch treatment on the variation or distribution of sarcomere length for both the SM and ST is shown in Figure 10 and Figure 11 respectively. The results for both muscles show that there was a greater variation in sarcomere length for the SmartStretch™ treated muscles.

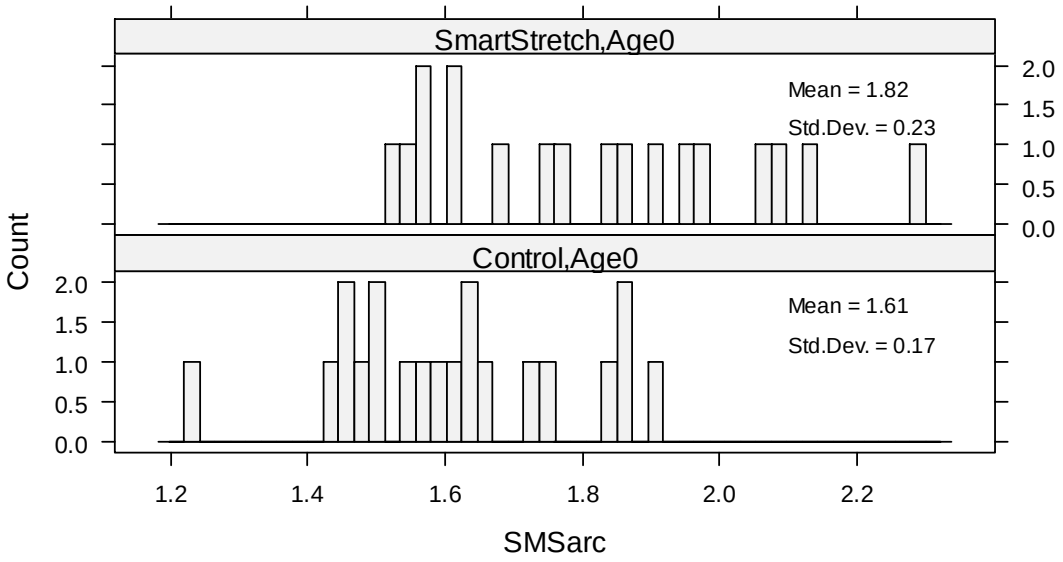

Figure 10: Histogram showing the effect of SmartStretch™ and control treatment on SM sarcomere length (µm) distribution for samples aged for 0 days.

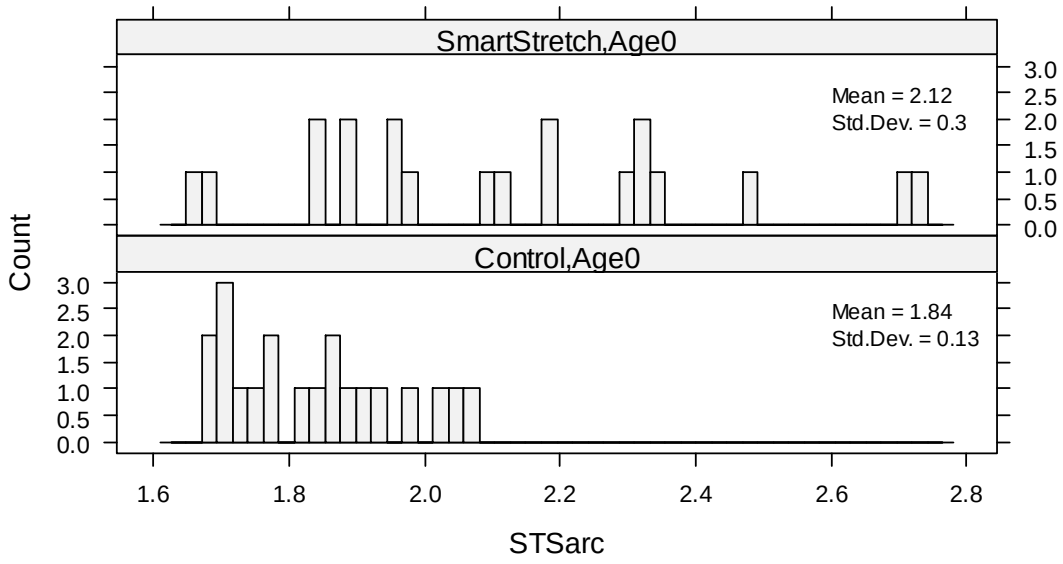

Figure 11: Histogram showing the effect of SmartStretch™ and control treatment on ST sarcomere length (µm) distribution for samples aged for 0 days.

Histology

Samples were taken from the SM to examine the structure of the myofibres and a sample of images is shown below. In Figure 12 a major break across a fibre is shown.

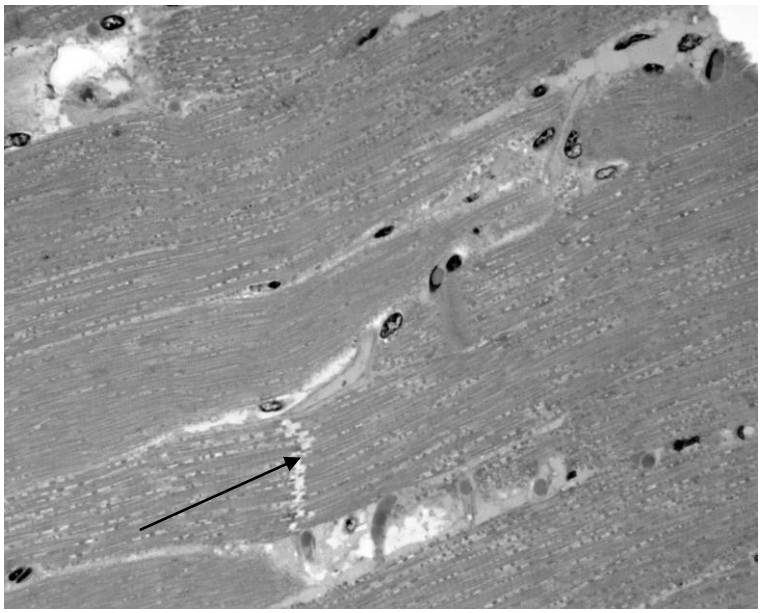

Figure 12: Image of muscle fibres with a major break across the fibre indicated. Muscle came from non-stretched SM after 5 days of ageing. 40x magnification.

An example image from muscle subjected to the SmartStretch™ with no ageing is shown in Figure 13. This shows a wavy pattern indicative of fibres under pressure. These waves combined with bent fibres were also counted and termed distorted fibres.

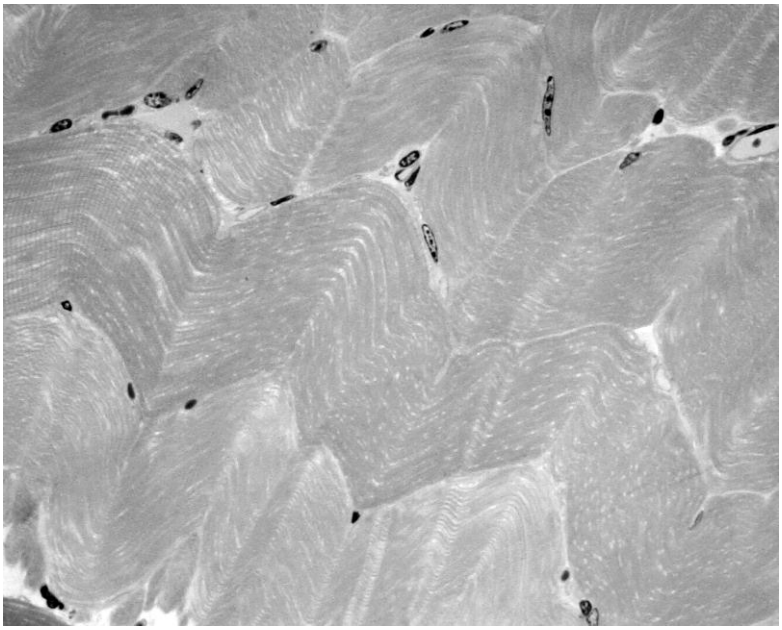

Figure 13: Image of muscle fibres showing a wave pattern.

Muscle came from a stretched SM after 0 days of ageing. 40x magnification.

Table 11 shows the significance of treatment effects on percentage fibre breaks, percentage of distorted fibres and particle size.

Table 11: F-ratio for effects stretch, age, stretch x age on percentage of breaks in fibres (fibre break) and the percentage of either wavy or bent fibres (distorted fibres) and particle size.

Terms	Fibre breaks		Distorted fibres		Particle size	
	Df	*F*-ratio	Df	*F*-ratio	df	*F*-ratio
Stretch	1,36	1.23 ^{ns}	1,74	0.109 ^{ns}	1,59	7.07 ^{ns}
Age	1,50	33.6***	1,75	110.0***	1,62	3.88***
Age x Stretch	1,33	1.59 ^{ns}	1,39	2.06 ^{ns}	1,40	2.00 ^{ns}

*** $P < 0.001$; ** $P < 0.01$;* $P < 0.05$, ^{ns} $P > 0.05$.

There was no effect of stretching on myofibrillar degradation of the SM measured as breaks in fibres, but there was a significant ($P < 0.001$) effect of ageing, with no interaction between stretching and ageing. There was also no effect of stretching on the distortion of fibres, but again a significant effect of ageing ($P < 0.001$) with a reduction in distortion due to ageing (Table 12). There was no interaction between stretching and ageing.

Table 12: Predicted means (s.e) for the percentage of breaks in fibres (break) and the percentage of either wavy or bent fibres (distorted) for the m. semimembranosus (SM) according to treatment groups.

	Break		Distorted	
Treatments	**SmartStretch™**	**Control**	**SmartStretch™**	**Control**
0 days aged	3.4 *(2.58)* a	5.4 *(2.58)* a	66.7 *(4.66)*a	74.6 *(4.66)*a
5 days aged	22.2 *(5.45)* b	34.0 *(5.19)* b	24.5 *(4.78)*b	19.6 *(4.58)*b

Means followed by a different letter within rows and columns for a trait is significantly different ($P < 0.05$).

Particle Size

The SmartStretch™ treatment had no effect on myofibrillar degradation of the SM which was measured using particle size analysis (Table 11). There was a significant difference ($P < 0.001$) between ageing treatments (Table 11). This difference showed that 0 day aged samples had a predicted mean particle size of 190µm and at 5 day aged it was 140µm with average standard error of difference of 8.3µm.

Regression Analysis

To determine whether the stage of *rigor* impacted on shear force initial pH was included into the model and was determined not to be significant ($P = 0.13$). To examine the relationship between SM shear force (SMSF) and SM sarcomere (SMSarc) on 0 day aged samples a bi-variate mixed model analysis was performed. This allowed different means for each trait within each level of stretch, correlated random effects for each trait across animals and correlated residuals. The results indicated that there was no significant ($P > 0.05$) correlation at either the animal or the residual level (Figure 14).

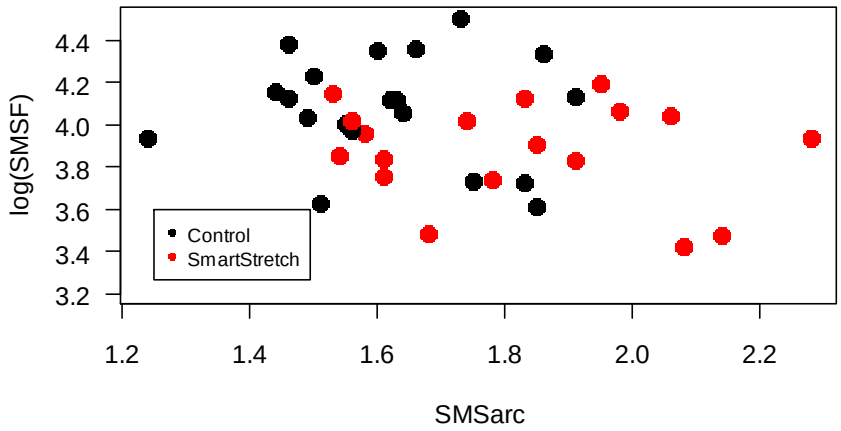

Figure 14: Relationship between the SM shear force (logSMSF) and SM sarcomere length µm (SMSarc) according to treatment for 0 day aged samples.

In addition to this there was no significant relationship ($P = 0.35$) shown between SM initial pH and SM sarcomere length. The percent increase in muscle length did not show a significant relationship with sarcomere length ($P = 0.72$) or shear force ($P = 0.50$). There was however a significant relationship ($P < 0.05$) between the percentage of fibre breaks and SM shear force, such that as the percentage of fibre breaks increased the shear force decreased.

Discussion

Given that on average after SmartStretch™ treatment was applied a 14% increase in leg length and a 45% decrease in circumference occurred it is clear that the SmartStretch™ treatment transformed the overall shape of the leg, which was consistent with the results presented in section 2.1.1.1. Although the results from section 2.1.1.1 did show a greater increase in length of 24% the results in the current experiment had a greater decrease in circumference of 45% as opposed to 24%. This is most likely due to the more complex structure of multiple muscle structure of the hindleg compared to a single muscle. The transformation of the sheep leg is an important industry outcome as to our knowledge there is no other machine that can take a whole sheep leg and shape it to a consistent size and shape. As outlined in section 2.1.1.1 the ability to produce a consistent shape is considered a desirable trait by the food service industry (Tarrant, 1998) irrespective of any potential tenderness benefits.

In the present study the SmartStretch™ treatment was effective in improving meat tenderness after 0 days of ageing in both shear force results from the BF and SM. This was despite the fact that due to the application of electrical stimulation the muscles were on an accelerated path to *rigor*, although clearly not all fibres were in *rigor* when they would be fully depleted of ATP (Honikel, 2004). It is known that *rigor* does not occur across all muscles simultaneously and this is dependent on the initial glycogen levels within the muscle fibre (Hwang, et al., 2003a) hence this could occur anywhere from a range as great as pH 6.2 to 5.8. Based on the initial pH and temperature, the SM and ST, muscles were on average still in the pre-*rigor* phase with a mean pH of 6.16 ± 0.18 and 6.30 ± 0.20, respectively and a mean temperature of 27.7 ± 2.60 and 24.7 ± 2.54 respectively. There was no significant effect found when initial pH was added as a covariate in the model for SM shear force, indicating that although some muscles may have been in the stages of *rigor* the muscles had not completed *rigor mortis* the term that refers to when muscles are physically stiff (Hwang, et al., 2003a), hence enabling the stretch treatment to have an effect. Results presented in section 2.1.1.1 describe an experiment designed to look at the impact of SmartStretch™ technology on individual sheep SM muscle which were processed under the same conditions as the present study. That study showed a 46% (or 34N) reduction in shear force after 0 days of ageing and 38% (or 20N) after 5 days of ageing. A similar trend was shown in the present study for BF shear force results where SmartStretch™ treatment caused a 19.8% (6.5N) and 11.1% (4.8N) reduction in shear force at 0 and 5 days of ageing respectively. In the present study shear force results from the SM showed SmartStretch™ treatment caused a 15.2% (9.2N) reduction in shear force at 0 days of ageing However, after 5 days of ageing the benefits of SmartStretch™ treatment were nullified. It appears the benefits from the SmartStretch™ treatment were not as profound when applied to a whole leg where multiple muscles are involved as compared to an individual SM muscle. This is most likely due to the fact that when an individual muscle is processed, such as the SM, it is easy to ensure that muscle fibres are aligned longitudinally in reference to the rubber sleeve inside the SmartStretch™ machine thus ensuring that the stretch potential of the muscle is achieved. In addition to this, all pressure applied by the SmartStretch™ machine is solely received by the individual muscle.

Previous work by Thompson, et al. (2005) on both lamb and mutton BF indicated that significant improvements in subjective tenderness could also be achieved by tenderstretching. These benefits are likely to be a result of the improvements achieved in sarcomere length due to the increased

tension placed on muscle fibres by stretching hence inhibiting the physical ability of muscle fibres to contract (Bouton, et al., 1973a).

It is evident in the current study that the SmartStretch™ treatment was an effective tool in controlling muscle contraction given the sarcomere were increased from 1.61 to 1.82 µm and 1.84 to 2.12 µm for both the SM and ST muscles respectively. These results support the findings reported by Troy (2006) where meat wrapping using the Pi-vac system was found to be effective in controlling sarcomere shortening. This wrapping method is a similar concept to the SmartStretch™ as the aim is to restrain and potentially stretch the de-boned muscle to prevent the muscle fibres contracting. However work by Devine, et al. (2002b) where samples were hand wrapped using polyethylene cling film 11 µm thick, indicated that the wrapping method employed by Devine, et al. (2002b) only stopped the muscle from shortening rather than applying stretch. Results presented in section 2.1.1.1 which examined the effect of SmartStretch™ treatment on solely the SM also support the results of the current study. The SmartStretch™ treatment increased sarcomere length from 1.54 to 2.19 µm when compared to the control as outlined in section 2.1.1.1 results. This outcome was on average 0.42 units greater than the sarcomere length in the current study and it could be concluded that, based on the percentage increase in length, on average the SM muscle in section 2.1.1.1 experienced greater stretch. However, results in the current study show the changes in the percentage increase in length are not reflected in those for sarcomere length and this outcome is supported by results in section 2.1.1.1. This indicates that other factors are reflected in changes in sarcomere length. Another interesting outcome was the greater variation in sarcomere length for SmartStretch™ treated samples. It was concluded by Hopkins, et al. (2000a) that the greater variation in sarcomere length for tenderstretched samples was caused by disrupted Z disks, but this is unlikely in the current study.

Particle size (PS) analysis is one approach to measuring the degree of proteolysis that has occurred in meat by examining myofibrillar degradation (Karumendu, et al., 2009). However in the current study it was shown that myofibrillar degradation or proteolysis of the SM was not altered by SmartStretch™, this outcome was also evident in section 2.1.1.1 and in the study of Devine, et al. (1999) where the utilisation of hand wrapping of meat had no effect on proteolysis, but ageing did. Many studies (e.g. Section 2.1.1.1; Devine, et al., 1999; Karumendu, et al., 2009, and Koohmaraie, et al., 1996) have shown that during ageing proteolysis is evident. The decline in particle size over time indicates that the fibres had degraded during ageing as verified by the histology results.

Simply, muscle is made up of contractile fibres which are attached to each other by connective tissue (Taylor & Frylink, 2003 and Tornberg, 1996). Given the degradation of collagen, hence connective tissue post mortem is limited to 1-5% total (Maltin, et al., 2003) most of the changes that occur post mortem are caused from the detachment of the endomysiun, breaks in sarcomere and fibre contraction (Taylor & Frylink, 2003). It was concluded by Taylor & Frylink (2003) that both fibre detachment and fibre breaks affect meat tenderness. To gain a better understanding of the impact that SmartStretch™ has on muscle structure fibre histology was measured in the SM. The results confirm that the SmartStretch™ treatment did not impact on the number of fibre breaks or distortion ratio hence did not accelerate proteolysis. The significant relationship shown between fibre breaks and shear force in the current study supports work by Taylor & Frylink (2003) and Martin, Hopkins, Gardner, & Thompson (2006). However it is of interest that the distortion of fibres decreases significantly with ageing as previous work by Taylor & Frylink (2003) showed that there was no real effect of ageing and concluded that this may be an effect of slaughter. A possible explanation for this difference could be that the fibres sampled at day 0 were not fully in *rigor* given that samples were collected and fixed in solution within approximately 2 hours of exsanguination and that with ageing this process progressed in samples aged for 5 days leading to a straightening of fibres.

The reduction in cooking loss in the SM from section 2.1.1.1 for stretched muscle was consistent with the effect in the current study for the BF However in the current experiment stretch treatment had no effect on cooking loss of the SM, which is similar to the findings of Devine, et al. (2002b) and Toohey, et al. (2008b). In these studies wrapping and ageing hot boned sheep *m. longissimus* had no effect on cooking loss percent. A possible explanation for this could be due to the fact that the previous work by Devine, et al. (2002b) and Toohey, et al. (2008b) only constricted the muscle with the wrapping technique employed and did not stretch the muscle. Following on from this, as indicated the current study was unable to achieve the same degree as stretch as shown in section 2.1.1.1 and hence similar findings to Devine, et al. (2002b) and Toohey, et al. (2008b) were shown in the SM. With ageing in the current study there was a contrast between treatments across muscles such that BF 0 day aged product had a lower cooking loss compared to 5 day aged samples and the reverse was found for the SM. Devine, et al. (2002b) also showed that cooking loss decreased as ageing period increased although it was not shown to be significant. This decrease in cooking loss as ageing time increases could support the theory reported in early work by Bouton, et al. (1973a), Bouton, et al. (1972) and Bouton, et al. (1973b) that stretched muscles had greater water holding capacity which results in less water loss during subsequent ageing. Given that greater stretch was achieved in results presented in section 2.1.1.1 and neither result in the current study is supported by outcomes in section 2.1.1.1 as ageing treatment had no effect on cooking loss, it is inconclusive. However anecdotal evidence based on observations in section 2.1.1.1, suggest that there were varying amounts of initial purge and it was speculated that the SmartStretch™ treatment may have lost more initial purge. Hence in the current study the percentage of purge lost after 5 days of ageing was measured and it confirmed a greater percentage of purge loss in the SmartStretch™ treatment compared to the control. This could potentially nullify the differences found in cook loss. Hence ultimately the SmartStretch™ treatment does not appear to have any significant effect on overall water holding capacity of the end product.

2.1.1.3 Experiment 3: Improving the tenderness of sheep loins (m. longissimus lumborum) using a meat stretching device

Introduction

Hot-boning of sheep meat has many financial advantages to the sheep processing industry. Savings can be made primarily by reduction in storage, refrigeration and transport costs as compared to cold-boned mutton (Pisula & Tyburcy, 1996). There is however, a negative perception of hot-boning on the consumer acceptance of the product. The eating quality of hot-boned sheep meat showed a low level of consumer compliance with only 14% of samples tested achieving the 'good everyday' requirement (Toohey & Hopkins, 2006). In contrast, when adult sheep were processed at the same abattoir, but conventionally chilled and cold boned, product aged for 7 days achieved a high level of consumer compliance with 86% of samples tested achieving a 'good everyday' ranking (Hopkins & Toohey, 2006). Stretching pre-*rigor* of hot-boned beef striploins (Toohey, Hopkins, van de Ven, Thompson, & Geesink, 2009b; Section 2.4.3), sheep meat topsides (Toohey, Hopkins, Lamb, Nielsen, & Gutzke, 2008c; Section 2.1.1.1) and sheep meat legs (Toohey, Hopkins, Nielsen, & Gutzke, 2009a; Section 2.1.1.2), using the same technology as this study in all cases, resulted in a significant reduction in shear force, suggesting that stretching of hot-boned primals results in improved tenderness.

Of interest from the inception of the SmartStretch™ project was the novel use of the technology to assist with making the best use of difficult cuts. The potential to bind and then quickly and easily package a small cut, such as the sheep loin, to create a product with a greater cross-sectional area is of great interest to the industry. In this study the ability of the SmartStretch™ technology to improve the tenderness of the sheep loin was examined.

Materials and Methods

Experimental design

Hot-boned loins were removed from 27 similar mutton carcasses from both sides of the carcase at a commercial hot-boning abattoir. Each loin was trimmed from the cranial end to approximately 30 – 35 cm in length to remove the very long thin tail. Each loin collected was randomly allocated to either a stretch treatment or control treatment. The loins allocated to the SmartStretch™ treatment were ejected from the SmartStretch™ machine into the packaging unit with a circumference of 11cm. Then each sample (stretch and control) was portioned into two sub-samples (cranial and caudal) which were randomly allocated to ageing treatments of 0 or 5 days. Samples were also allocated to one of eight cooking batches for shear force testing.

Rubber and packaging unit

Unlike previous experiments this study used a specially designed sheep rubber with a resting diameter of 25mm. The rubber used in all previous experiments had a resting diameter of ≈ 65mm. The rubber had the external ribs roughly trimmed off to improve flexibility and had been inserted into a sleeve of PVC piping to prevent it from warping in the expand phase of the SmartStretch™ process. A packaging unit ≈ 40mm diameter was also developed for this experiment. This unit used packaging 38mm in diameter (60mm lay flat). The rubber and the packaging unit are both shown in Figure 15.

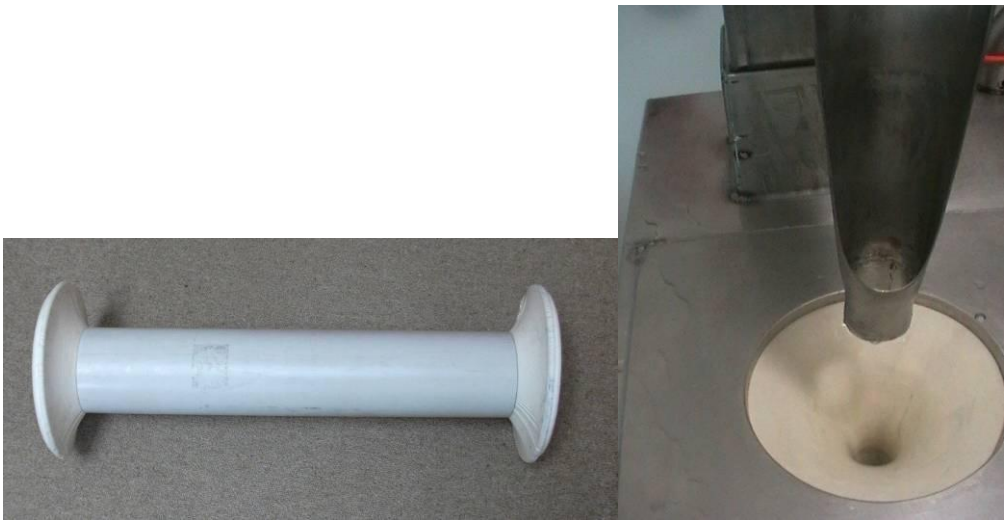

Figure 15: Sheep rubber and packaging unit used in this experiment.

Figure 16: Samples collected during the experiment after freezing – SmartStretch™ treated samples at the top and control at the bottom.

Sampling procedures

The 0 day aged samples were frozen within four hours post-mortem. These samples were then transported frozen back to the laboratory where they were stored in a -22°C freezer. The samples for shear force testing were cut from frozen using a bandsaw. The 5 day aged samples were held at 3-4°C and then purge was measured on the whole cut. Other samples were also cut to size and frozen and stored in a -22ºC freezer until ready for shear force and pH testing.

Refer to Experiment 1 (Section 2.1.1.1) for further experimental methodology.

Figure 3: Colour samples prepared on trays and covered with plastic wrap through which colour is measured.

Colour stability

Retail colour display was examined on both 0 and 5 day aged samples. A frozen slice of LL (3 cm thick) was taken from each sample, placed on trays and allowed to thaw overnight in a chiller set at 3-4°C. The following day a fresh surface was cut on each sample and they were placed individually on black foam trays (13.5 cm x 13.5 cm) and over wrapped with PVC food film wrap (15 μm thickness). After a blooming period of 30-40 min, each sample was measured (initial colour values) with a Hunter Lab meter (Model 45/0-L) with an aperture size of 25 mm. The instrument was calibrated with black and white tiles using Illuminant D-65, with 10 degree standard observer. Samples were displayed in the chiller under lighting (1000 lux) and measured once a day for 4 days (final colour value). Each sample was measured twice at each measurement time and the values averaged.

Figure 4: Colour samples on display under 1000 lux lighting.

Statistical analysis

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) were used to analyse the data.

The model fitted for initial pH, initial temperature and purge loss % was:

Y = constant + stretch treatment + **animal** + **error**

The model fitted for shear force was:

Y = constant + stretch treatment + ageing + (stretch treatment x ageing) + **animal** + **(animal x side)** + **cook batch** + **error**

The model fitted for cooking loss % was:

Y = constant + stretch treatment + ageing + (stretch treatment x ageing) + **animal** + **(animal x side)** + **cook batch** + **error**

Initial pH had originally been included in the models for shear force and cook loss % as a covariate, but was removed because it was not significant.

The model fitted for retail display colour measurements taken with the Hunter Lab meter (*L**, *a**, *b** and ratio) was:

Y = constant + time + Ftime + stretch treatment + (stretch treatment x time) + (stretch treatment x FTime) + **animal + (animal x time) + (animal x FTime) + (animal x stretch treatment) + (animal x stretch treatment x time) + error**

The terms in bold were fitted as independent random effects and the model allowed the error variation (the variation for results within a slice).

Results and Discussion

The characteristics of the mutton loins used in this experiment are shown in Table 13. The predicted means and average standard error for initial pH, final pH and initial temperature, as well as the actual mean percentage length increase are shown.

Table 13: Predicted means (av s.e.) for initial pH, initial temperature and final pH for all samples and % increase in length for the stretch treatment and range of measurements for initial pH and initial temperature.

	Predicted Mean	Standard Error	Range
Initial pH	6.60	*0.03*	6.24 - 6.89
Final pH – 0 day	5.91	*0.04*	5.54 - 6.33
- 5 day	5.85	*0.04*	5.49 - 6.46
Initial temperature (°C)	25.3	*0.43*	19.8 - 31.2
Increase in length (%)	7.1	*1.4*	-13.5 - 16

As expected there was no significant difference between the initial pH and initial temperature for each treatment. The average temperature and pH for the muscles shows that they were still pre-*rigor* when stretched. No significant increase in length was shown for the stretched samples with only a small increase in length (7%). Sarcomere length (Table 14) was significantly ($P < 0.05$) increased by stretching, but this was not matched by significant tenderness improvements at 0 days (Table 15), giving further credence to the lack of a relationship between sarcomere length and tenderness in stretched samples (Section 2.1.1.1).

Table 14: Predicted sarcomere means and standard errors.

Treatment	Sarcomere (µm)		
	0 day		
Control	1.50	*0.04*	a
Stretch	1.61	*0.04*	b

Means having a following letter different are significantly different ($P < 0.05$).

Ageing significantly ($P < 0.05$) improved the tenderness of the samples for both the control and stretch treatments (Table 15). Stretching also significantly ($P < 0.05$) improved tenderness, but only for the aged samples. This is at odds with the results of a previous experiment involving mutton where initial tenderness gains resulting from stretching had disappeared with ageing in full legs

(Toohey, et al., 2009a; Section 2.1.1.2), but consistent with the earlier work of Toohey, et al. (2008c) for sheep topsides (Section 2.1.1.1). Substantial physical damage was done to the samples during the stretching process, with some samples being torn into pieces. Figure 19 shows a stretched loin that was torn during treatment. It is contended that the rubbers which were supplied for this work were imperfect, with weak sections in the wall of the rubber and thus under vacuum bulging developed and this made it difficult to fed the loins into the rubber. As a consequence there was damage to the integrity of the loin structure. It is unknown why the shear force of the aged stretched loins was much lower than the control.

Table 15: Predicted shear force means (N) and standard errors (s.e.) for stretch

Treatment	Shear force (N)					
	0 day			5 day		
Control	65.8	*3.86*	c	48.6	*3.86*	b
Stretch	60.8	*3.86*	c	29.2	*3.86*	a

Means having a following letter different are significantly different ($P < 0.05$).

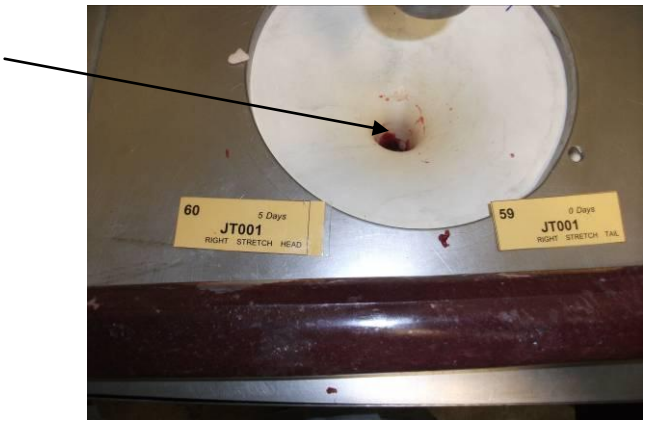

Figure 5: Stretched loin with a portion that was torn off during the eject process visible inside the rubber (see arrow).

Cooking loss %, was significantly ($P < 0.05$) reduced by stretching and ageing (Table 16). (Toohey, et al., 2008c; Section 2.1.1.1) suggested that there may be a relationship between purge loss and cooking loss as a result of stretching. In this data there is no significant ($P > 0.05$) relationship between purge loss and cooking loss, but there was increased purge loss ($P < 0.05$) due to stretching consistent with the results in section 2.1.1.2. Purge loss is important because it negatively affects the retail presentation/purchaser acceptability of the product, by making the product unsightly and reducing saleable weight (Payne, Durham, Scott, & Devine, 1998). Purge is also a breeding ground for bacteria (Pringle, Johnson, Bernkopf, & Williams, 1996). Higher cooking losses are viewed unfavourably by consumers as they represent a loss of product content, juiciness and tenderness (Barbera & Tassone, 2006). Stretching and ageing in combination in this study had a positive impact on cooking loss.

Table 16: Predicted cooking loss % and thaw loss % and standards errors (s.e.) for stretch and ageing treatments.

Treatment	Cooking loss %					
	0 day			5 day		
Control	23.5	0.98	c	21.1	0.98	b
Stretch	22.1	0.98	b	19.7	0.98	a
	Purge loss %					
Control				0.5	0.09	a
Stretch				2.3	0.27	b

Means having a following letter different within a test are significantly different ($P < 0.05$).

The predicted means and standard errors for lightness (*L**), redness (*a**), yellowness (*b**) and brownness (ratio 630/580nm) measured with the Hunter Lab meter over 72 hours of retail display are presented in Table 17. Stretching significantly ($P < 0.05$) affected lightness for all three days of measurement, but had no impact on the other colour parameters.

Table 17: Predicted means and standard errors (s.e.) for each stretch and ageing treatment over display time for colour samples including L*, a*, b* and ratio 630/580nm values.

		5 day aged and displayed for 3 days					
Treatment	**Time (hours)**	**Control**			**Stretch**		
L*							
	0	30.3	*0.68*	a	31.8	*0.68*	bc
	24	33.0	*0.69*	c	34.8	*0.69*	d
	48	32.1	*0.71*	b	34.3	*0.71*	d
	72	30.0	*0.75*	a	32.5	*0.75*	bc
a*							
	0	17.1	*0.35*	bc	17.6	*0.35*	c
	24	16.8	*0.37*	bc	16.9	*0.37*	b
	48	15.3	*0.42*	a	15.0	*0.42*	a
	72	17.4	*0.51*	bc	16.7	*0.51*	bc
b*							
	0	15.6	*0.23*	b	15.6	*0.23*	b
	24	18.2	*0.23*	c	18.2	*0.23*	c
	48	15.1	*0.24*	a	15.1	*0.24*	a
	72	19.9	*0.26*	d	19.9	*0.26*	d
Ratio 630/580nm							
	0	5.7	*0.22*	e	5.8	*0.22*	e
	24	4.1	*0.22*	d	4.1	*0.22*	d
	48	3.2	*0.24*	ab	3.0	*0.24*	a
	72	3.8	*0.28*	cd	3.4	*0.28*	bc

Means having a following letter different within a colour parameter (across rows and down columns) are significantly different ($P < 0.05$).

Figure 20 shows graphs of the predicted means of colour measurements over time. The expected trends are for the lightness, redness, yellowness and 630/580nm ratio (brownness) to reduce over time. Curiously, the redness, yellowness and brownness appear to reduce until 48 hours in this experiment, before increasing again at the 72 hours measurement. Experimental procedure was

maintained throughout the colour measurement; indeed the operator conducting the measurement remained the same at each time interval. Therefore, no procedural error can be blamed for these results.

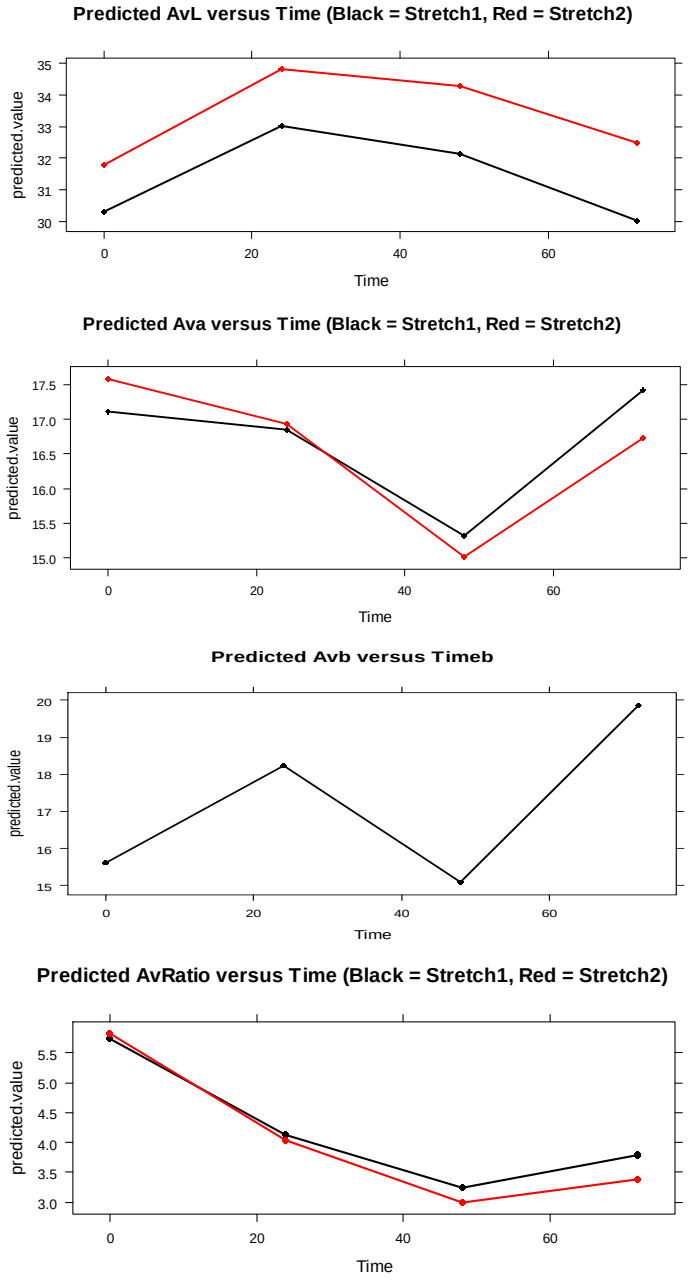

Figure 20: Graphs of colour parameters from top to bottom - *L*, a*, b** **and 630/580nm ratio.**

The decision by consumers to purchase meat is influenced by meat colour more than any other trait, because colour is considered an indicator of freshness (Mancini & Hunt, 2005). Meat on retail display will begin to brown within 1–7 days and retailers often price discount red meat after 2 days on display (Jacob, D'Antuono, Smith, Pethick, & Warner, 2007). This is at significant cost to industry. Here time on display affected the colour of the meat, with stretch treatment having little effect. Khliji, van de Ven, Lamb, Lanza, & Hopkins (2010) found that consumers find meat unacceptably brown if the 630/580nm ratio falls below 3.3. After one day on retail display 37% of

the samples were unacceptable to consumers, with 67% of the samples being unacceptably brown after two days on retail display regardless of stretch treatment. Overall stretching, as a value adding process, will not impact on colour significantly and will not impact on consumer perceptions of colour in their purchase decision based on the results of this study.

2.1.1.4 Experiment 4: The impact of medium voltage stimulation and SmartStretch™ technology on sheep topside (m. semimembranosus) meat quality traits under commercial processing conditions

Introduction

Consumer satisfaction is a major factor affecting repeat purchasing of any product (Lorenzen et al., 2003). Visual appearance and overall eating quality are two main factors which influence consumer choice to purchase and repurchase red meat (Egan, Ferguson, & Thompson, 2001; Maltin, et al., 2003 and Thompson, 2002). In a recent review paper by Mancini & Hunt (2005) it was stated that 'meat purchasing decisions are influenced by colour more than any other quality factor because consumers use discoloration as an indicator of freshness and wholesomeness'. This has been shown by earlier work to have a negative economic impact on the meat industry (Smith, Belk, Sofos, Tatum, & Williams, 2000). Meat colour and tenderness are both influenced by many *post-mortem* factors, for example electrical stimulation, hanging method (Achilles tendon or tenderstretch), boning technique (cold or hot boned), chilling regime, storage and packaging (Devine, et al., 2004; Hopkins & Geesink, 2009; Maltin, et al., 2003; Mancini & Hunt, 2005; Monin, 2004; Thompson, 2002, and Tornberg, 1996). Hence it is critical that these two traits are not compromised in the quest for accelerating the processing of meat.

Hot boning is a technique used to accelerate the processing meat from a carcase into a carton (Pisula & Tyburcy, 1996), however despite the many advantages as outlined by both Jeremiah, et al. (1985) and Pisula & Tyburcy (1996) (for example, higher yield, reduction in chiller space hence resulting in saving in energy inputs on refrigeration, faster turnover of meat in the processing plant, reduction in capital costs for buildings, finally labour and transport savings), there are many concerns about the ability to produce a quality product through this system. This is because as previously outlined in section 2.1.1.1 hot-boning increases the risk of muscle shortening (Devine, et al., 2004) due to the removal of the muscle from the skeletal constraint and shortening is a major influence on meat tenderness (Tornberg, 1996). To combat this hot boning is almost always performed in conjunction with electrical stimulation. The role of electrical stimulation is to hasten the onset of *rigor* (Hwang, et al., 2003a) and hence reduce the degree of muscle shortening when the muscles are removed from the skeletal constraint.

Macfarlane, et al. (1974) highlighted that another approach to preventing muscle shortening is to restraining muscles physically until they are in *rigor mortis*. Many studies such as Herring, et al. (1967); Locker (1960); Davey, et al. (1967); Devine, et al. (2002b), and Troy (2006) all proved the concept that pre-*rigor* excised muscles could be stretched in various ways which resulted in improved tenderness.

The results outlined in sections 2.1.1.1 and 2.1.1.2 showed that the stretching prototype device (licensed as SmartStretch™) significantly improved sheep meat tenderness and significantly increased sarcomere length when processed under commercial conditions. This meant that all carcases were exposed to a number of electrical inputs including immobilisation; electronic bleed and medium voltage electrical stimulation (Toohey, Hopkins, & Lamb, 2008a). Despite these electrical inputs it was concluded based on the results outlined in sections 2.1.1.1 and 2.1.1.2 that on average the muscles examined were still in a pre-*rigor* state. The *m. semimembranosus* in section 2.1.1.1 had a mean pH of 6.22 ± 0.81 and a mean temperature of 33.5 ± 2.02 and in section

2.1.1.2 where both the *m. semimembranosus* and *m. semimemtenosus* were assessed the mean pH's were 6.16 ± 0.18 and 6.30 ± 0.20, respectively at mean temperatures of 27.7 ± 2.60 and 24.7 ± 2.54 respectively. The variation around the mean for these data indicates that some muscles would have entered the *rigor* phase. This begs the question could application of electrical stimulation to achieve a lower pH be counterproductive to the effectiveness of SmartStretch™ treatment as fibres become bound as they enter *rigor*, preventing effective stretching?

Hence the aim of this study was to evaluate the interaction between medium voltage electrical stimulation, stretching and ageing on key meat quality traits including meat tenderness and meat colour of hot boned sheep m*. semimembranosus* using the stretching prototype device SmartStretch™.

Materials and Methods

Animals

For testing the effect of the medium voltage stimulation, SmartStretch™ prototype machine and post-mortem ageing, a total of 80 sheep of mixed sex (ewes and wethers) were randomly selected from various consignments over two days. The sheep used from these different consignments were of varying backgrounds, to represent the typical animals processed by the abattoir. All sheep used in this experiment were classified as mutton, (Anonymous, 2005) meaning that animals were over 10 months of age and had more than two permanent incisors.

Experimental Design

The experiment was designed as a blocked split-plot experiment examining three treatments including; medium voltage electrical stimulation (carcases were either stimulated or not stimulated), stretch (topsides were either stretched using SmartStretch™ or not stretched) and ageing (samples were either aged for 0 or 5 days). Eighty carcasses were randomly selected and killed over two days with 40 carcases processed each day, within each kill day, 20 carcasses were randomly allocated to stimulation and 20 carcases to non stimulated treatment group. Both the right and left topsides (m*. semimembranosus, adductor* & g*racilis*) (HAM. 5073; Anonymous, 2005) from each carcase were collected and each pair of halves were assigned either stretch or non stretch treatment and assigned either to 0 or 5 days ageing. The design balanced stretch × ageing combinations to sides within and across carcases. The treatment combinations used were; Stimulation + 0 days ageing + SmartStretch™, Stimulation + 0 days ageing + control, Stimulation + 5 days ageing + SmartStretch™, Stimulation + 5 days ageing + control, No Stimulation + 0 days ageing + SmartStretch™, No Stimulation + 0 days ageing + control, No Stimulation + 5 days ageing + SmartStretch™ and No Stimulation + 5 days ageing + control. In addition allocations to either one of 20 cooking batches were made for shear force samples.

Treatments and sample collection

The carcases were processed under the normal commercial procedures of the abattoir. All animals were exposed to the high frequency immobilisation unit, applied for 25-35 secs (2000 Hz, 400 volts, and a maximum current of 9 amps over 7 animals, pulse width of 150 microseconds), moderate frequency immobilisation (800 Hz, 300 peak volts, a constant current of 1.7 amps, pulse width 150 microseconds) applied for 5-7secs and low voltage electronic bleed (15 Hz, 550 peak volts, constant current of 0.8 amps, pulse width 500 microseconds) applied for 20 seconds. Traditionally all carcases are also normally exposed to a post dressing medium voltage electrical stimulation system however in the current experiment carcases were randomly allocated to one of two stimulation treatments. Half of the carcases (n = 40) were exposed to post dressing medium voltage

electrical stimulation (MVS) with a constant current 1.0 amp and pulse width of 2500 microseconds, but variable frequency across the 6 electrodes (the frequency for electrodes 1 & 2 was set at 25 Hz, 3 & 4 at 15 Hz and 5 & 6 at 10 Hz, with 300 peak volts) applied for 30-35 seconds. This treatment was applied within approximately 40 minutes of death and the other half of the carcases (n = 40) were not stimulated.

Once stimulation treatments were applied carcases then passed through a drying room for approximately 35 minutes with an average temperature of 8ºC. Following this both the right and left topsides (*m. semimembranosus, adductor & gracilis)* (HAM. 5073; Anonymous, 2005) from 80 carcases (n = 160) were hot boned, collected and trimmed removing all fat and placed into their predetermined stretch and ageing treatments within approximately 2 hours of death. The stretched samples were stretched using the SmartStretch™ machine as previously described in section 2.1.1.1 using a 75mm diameter packaging ring and 100mm layflat packaging. The 0 day aged treatment was frozen in a freezer set at -18ºC or less within 4 hours of death. The 5 day aged treatment was chilled at 3-4ºC for 5 days, cut into laboratory test subsamples and then frozen at -18 ºC until testing.

Sample preparation

The 0 day aged topsides were tempered at an average temperature of 21.2ºC for approximately 2 hours to allow the m. *adductor* and m. *gracilis* to be dissected from the m*. semimembranosus*. Then sarcomere, shear force, final pH and meat colour samples were cut from the m*. semimembranosus* (SM) whilst the SM was still predominately frozen. After 5 days of ageing at a chilled temperature of 3-4 ºC the m. *adductor* and m. *gracilis* were dissected from the SM and samples cut into test subsamples for shear force, final pH and meat colour and then frozen at -18 ºC until testing.

Refer to section 2.1.1.1 for further experimental methodology.

Statistical analysis

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) via the statistical package *asreml* (Butler, 2009) under R (R Development Core Team, 2009) were used to analyse the data. The model fitted for initial pH, initial temperature, shear force, cooking loss % and final pH had fixed effects for the treatments, Electrical Stimulation (levels = NoStim and Stim), Stretch (levels = NoStretch and Stretch) and Ageing (levels = 0 and 5 days) and the interaction effects between these treatments. Random effects included were effects for Kill Day (levels = Kill Day 1 and Kill Day 2), Carcase within Kill Day (forty Carcases were included in each Kill Day), Cooking batch (was included for shear force and cooking loss percent) and random error. For initial pH initial temperature was included in the model. For Sarcomere length there are no age effects in the fixed effects part of the model as sarcomere length was only measured on 0 day aged samples. In addition, as there was only a single result for each carcase, the carcase effect was removed from the random effects in the model (carcase confounded with random errors).

The model fitted for initial and final colour traits (*L*, a*, b** and ratio values 630nm/580nm) at either 0 or 5 day aged was Y = baseline + Stimulate + Stretch + Stimulate:Stretch ***+ KillDay + error.*** Here Y denotes the trait and terms in bold/italic are fitted as random effects. A repeated measures analysis, using a linear mixed model analyses, was performed on each of the four colour traits (*L*, a*, b** and ratio 630/580um) to examine the change over time.

Results

Muscle measurements

A statistical summary of the characteristics of the sheep meat used in this experiment is shown in Table 18 to give an indication of the variance within the data. There was no significant difference (*P > 0.05*) between stretch and ageing treatments or were there any interactions for any of the traits in Table 18. Initial temperature and stimulation treatment did have a significant effect on the initial pH. There was no variation attributable to kill day indicating that animals were well balanced across the kill days. The analysis indicated that, for a given stimulation treatment, initial pH declined by 0.013 (s.e ± 0.006) units for each 1ºC increase in initial temperature. At a given initial temperature, stimulated carcasses had an initial pH 0.17 (s.e ± 0.03) units lower than non stimulated carcases. For example when the initial temperature was 32ºC the non stimulated treatment had an initial pH of 6.27 (s.e ± 0.02) and the stimulated treatment was 6.10 (s.e ± 0.02). Both stretch treatment and stimulation treatment did not have a significant effect (*P* > 0.05) on final pH. Ageing treatment did have a significant effect on final pH such that after 5 days of ageing final pH was significantly lower at 5.80 (s.e ± 0.024) compared to 0 day aged samples which had a final pH of 5.85 (s.e ± 0.024).

Table 18: Summary of statistics mean, standard deviation (S.D.) and range for carcase traits across treatments.

Trait	Mean	SD	Range
Initial pH	6.20	0.16	5.70-6.63
Initial Temp (°C)	30.9	1.96	27.1-35.8
Final pH 0 day aged	5.85	0.20	5.60-6.63
Final pH 5 day aged	5.79	0.23	5.56-6.64
Increase in length* (%)	30	7.03	11.8-46.9
Decrease in circumference* 1 (%)	50	12.76	14.9-85.0
Decrease in circumference* 2 (%)	19	10.91	11.9-47.6

*percentages are only given for the SmartStretch™ treatment.

Warner Bratzler shear force

Shear force results showed that stimulation treatment had no significant effect (*P* > 0.05) on shear force either as a main effect or at individual combinations of stretch and ageing. There were significant differences (*P* < 0.001) found between both stretching and ageing treatments and there was also a significant interaction (*P* < 0.001) between these two traits as shown in Table 19.

Table 19: Predicted shear force means (N) and standard errors (s.e.) for stretch, stimulation and ageing treatments.

	SmartStretch™				Control			
Ageing	**Stim**		**No stim**		**Stim**		**No stim**	
0 day	46.9 *(2.39)*	b	46.6 *(2.39)*	b	74.4 *(2.39)*	c	73.9 *(2.39)*	c
5 day	38.6 *(2.39)*	a	38.1 *(2.39)*	a	45.7 *(2.39)*	b	45.3 *(2.39)*	b

Means having a following letter different are significantly different (*P* < 0.05).

The present study also examined the impact of treatments on the distribution of shear force. Figure 21, shows that the variation in shear force for stretch, stimulation and ageing treatment groups. Based on the results in this figure it does not appear that any of the treatments consistently reduced the variation in shear force. However the 5 day aged, stretched and stimulated samples exhibited the least variation and the 0 day aged, stretch and non stimulated treatment showed the greatest

variation. When stimulation and ageing treatments were dropped from the model, overall SmartStretch™ reduced the variation in shear force compared to the control (means ± S.D. Control 60 ± 17.6N, SmartStretch™ 42 ± 9.3N).

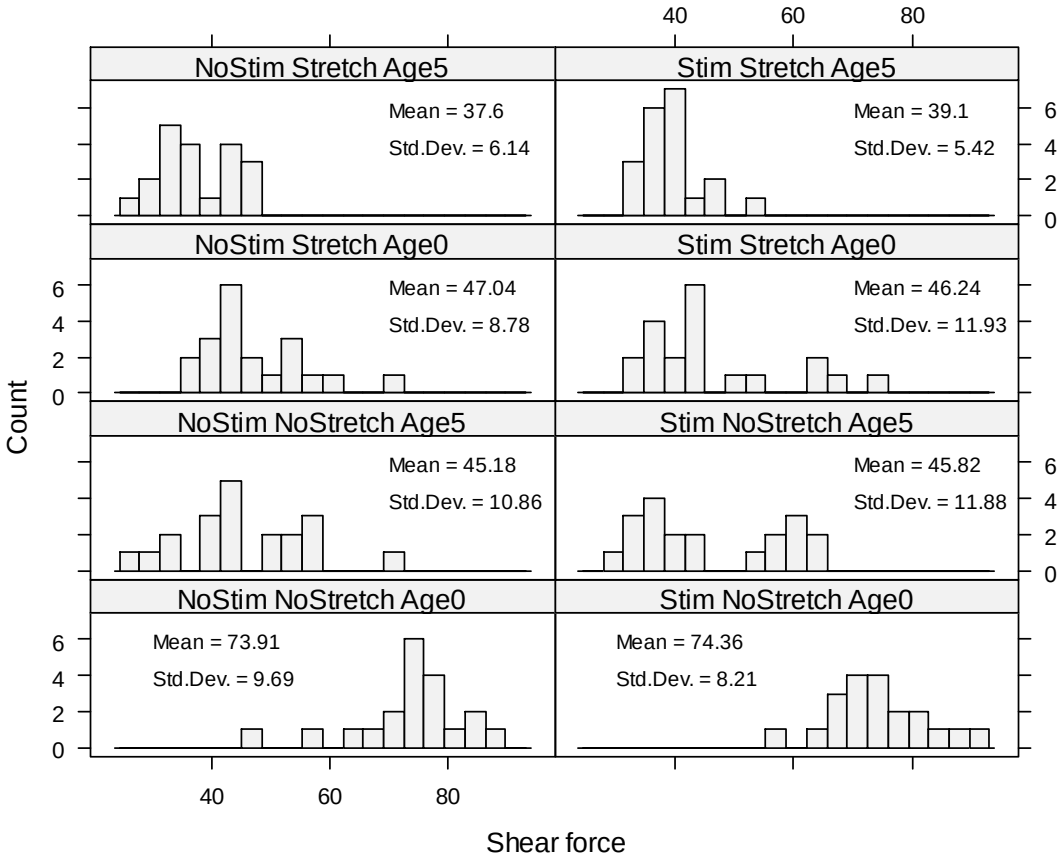

Figure 21: Histogram showing the effect that the stretch and stimulation treatments at 0 and 5 days had on the distribution of shear force (N).

Cooking loss

There was a significant difference between stretch and ageing treatments ($P < 0.05$) for cooking loss as shown in Table 20, but stimulation treatment and the interaction between treatments had no impact on cooking loss ($P > 0.05$). These results showed that the no stretch (control) treatment had significantly ($P < 0.05$) greater cooking loss when compared to SmartStretch™ treatment irrespective of ageing and stimulation treatment. The results also showed that the 5 day aged samples had significantly greater cooking loss when compared to 0 day aged irrespective of stretch and stimulation treatment.

Table 20: Predicted Cooking loss % and standard errors (s.e.) for stretch, stimulation and ageing treatments.

	SmartStretch™				Control			
Ageing	**Stim**		**No stim**		**Stim**		**No stim**	
0 day	18.1 *(0.50)*	a	18.3 *(0.50)*	a	20.4 *(0.50)*	b	19.9 *(0.50)*	b
5 day	20.4 *(0.50)*	c	20.4 *(0.50)*	c	23.4 *(0.50)*	d	22.6 *(0.50)*	d

Means having a following letter different are significantly different ($P < 0.05$).

Purge loss

There was a significant difference between stretch treatments ($P < 0.05$) for purge loss percent, but stimulation treatment or the interaction between any treatments had no impact on purge loss ($P > 0.05$). These results showed that the SmartStretch™ treatment had significantly greater purge loss when compared to control treatment 2.4 % (se ± 0.24) and 0.5 % (se ± 0.05) respectively.

Sarcomere Length

Stimulation treatment had no significant ($P > 0.05$) effect on sarcomere length, but there was significant ($P < 0.001$) effect due to SmartStretch™ treatment. The sarcomere lengths were significantly increased by SmartStretch™ treatment compared to no stretch (control) 2.27 (se ±0.09) and 1.53 (se ±0.06) µm respectively.

The impact of treatments on the distribution of sarcomere length was examined. Based on Figure 22 the variation appears larger for the SmartStretch™ treatment compared to the control treatment irrespective of stimulation treatment.

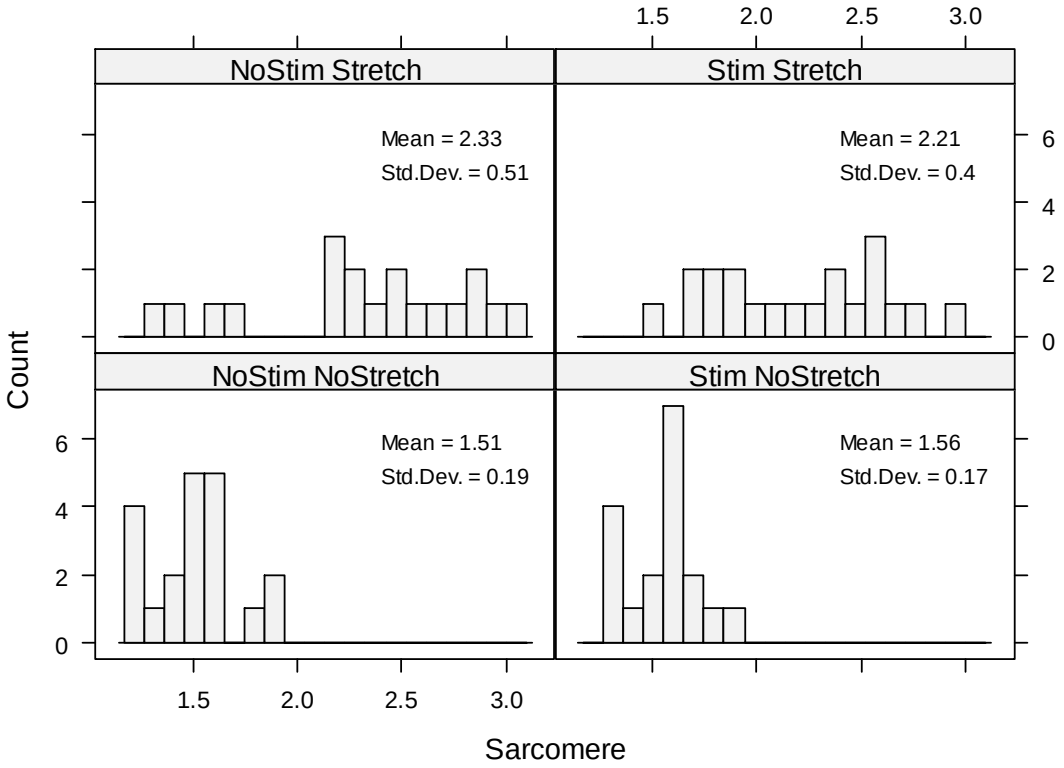

Figure 22: Histogram showing the effect of SmartStretch™ and no stretch treatment at level of stimulation level (Stim and NoStim) on the distribution of sarcomere length (µm).

Colour stability

The 0 day colour results indicate that stretch and stimulation treatments had a significant effect ($P < 0.05$) on L^* values at both 0 and 72 hours, a^* values at 72 hours and b^* values at 0 hours (Table 21). The SmartStretch™ treatment irrespective of display time tended to result in higher L^* values meaning the meat was lighter compared to the control. The 72 hour a^* values showed SmartStretch™ no stim was significantly redder when compared to control no stim. There was no significant effect ($P > 0.05$) at 0 hour on a^* values, 72 hour b^* values or ratio 630/580um values at 0 or 72 hours (Table 21).

Table 21: Predicted means and standard errors (s.e.) for each stretch and stimulation treatment over display time (hours) for 0 day aged colour samples including L*, a*, b* and ratio 630/580um values.

	Time	SmartStretch™		Control	
*L**		Stim	No Stim	Stim	No Stim
	0	30.1 *(0.58)* c	28.7 *(0.58)* bc	27.0 *(0.58)* a	27.4 *(0.58)* ab
	72	30.8 *(0.78)* b	29.4 *(0.78)* ab	28.2 *(0.78)* a	29.8 *(0.78)* a
*a**					
	0	17.5 *(0.75)* a	17.1 *(0.75)* a	16.8 *(0.75)* a	17.5 *(0.75)* a
	72	13.0 *(0.34)* ab	13.6 *(0.34)* b	12.9 *(0.34)* ab	12.5 *(0.34)* a
*b**					
	0	14.1 *(0.59)* b	13.0 *(0.59)* ab	12.6 *(0.59)* a	13.4 *(0.59)* ab
	72	14.0 *(0.51)* a	13.9 *(0.51)* a	13.3 *(0.51)* a	13.8 *(0.51)* a
Ratio 630/580um					
	0	5.56 *(0.28)* a	5.61 *(0.28)* a	5.76 *(0.28)* a	5.95 *(0.28)* a
	72	2.33 *(0.14)* a	2.60 *(0.14)* a	2.56 *(0.14)* a	2.23 *(0.14)* a

Means followed by a different letter in a row (a, b) are significantly different $P = 0.05$.

Stimulation and stretch treatments had no significant effect ($P > 0.05$) on 5 day aged meat colour traits (*L*, a*, b** and ratio 630/580um) at either 0 or 72 hours, except for 0 hour b* values (Table 22). There was a significant effect ($P < 0.05$) such that the no stretch stimulation treatment had significantly higher *b** values when compared to SmartStretch™ no stimulation treatment.

Table 22: Predicted means and standard errors (s.e.) for each stretch and stimulation treatment over display time (hours) for 5 day aged colour samples including L*, a*, b* and ratio 630/580um values.

	Time	SmartStretch™		Control	
*L**		Stim	No Stim	Stim	No Stim
	0	29.3 *(0.66)* a	29.6 *(0.66)* a	30.6 *(0.66)* a	29.3 *(0.66)* a
	72	31.1 *(1.1)* a	31.5 *(1.1)* a	32.0 *(1.1)* a	31.7 *(1.1)* a
*a**					
	0	17.5 *(0.56)* a	17.6 *(0.56)* a	17.3 *(0.56)* a	17.5 *(0.56)* a
	72	13.4 *(0.38)* a	12.9 *(0.38)* a	12.7 *(0.38)* a	13.2 *(0.38)* a
*b**					
	0	13.2 *(0.76)* ab	13.1 *(0.76)* a	14.3 *(0.76)* b	13.7 *(0.76)* ab
	72	15.1 (0.61) a	15.0 *(0.61)* a	15.1 *(0.61)* a	15.1 *(0.61)* a
Ratio 630/580um					
	0	6.04 *(0.27)* a	5.74 *(0.27)* a	5.95 *(0.27)* a	6.10 *(0.27)* a
	72	2.34 *(0.02)* a	2.17 *(0.02)* a	2.16 *(0.02)* a	2.35 *(0.02)* a

Means followed by a different letter in a row (a, b) are significantly different $P = 0.05$.

A repeated measures analysis, using linear mixed model analyses, was performed on each of the four traits (*L*, a*, b** and ratio 630/580um) to examine the change over time. Based on this analysis, irrespective of stimulation or stretch treatment for both 0 and 5 days aged samples display time had a significant effect ($P < 0.05$) on *L*, a** and ratio 630/580um values, but the *b** values were not significantly affected ($P > 0.05$). This effect showed that as display time increased *L** values increased hence the samples became lighter over time. The *a** values and ratio 630/580um values

decreased over time hence samples were losing redness and the degree of browning in meat was more visible.

Discussion

In both sections 2.1.1.1 and 2.1.1.2 it was shown that the SmartStretch™ treatment was successful in transforming the *m. semimembranosus* and whole tunnel boned sheep legs into a consistent shaped product. In the present study on average there was a 30% increase in *m. semimembranosus* muscle length and a 50% decrease in circumference at the first measurement site and 19% decrease in circumference at the second measurement. This consistency is considered a desirable trait by the food service industry (Anonymous, 2003) as it standardises shape for the preparation of roast and slices and minimises cutting losses.

Tenderness is another trait for which consumers desire consistency (Maltin, et al., 2003). Many previous studies and reviews (Devine, et al., 2004; Hwang, et al., 2003a; Chrystall & Devine, 1978; Polidori, Lee, Kauffman, & Marsh, 1999; Pearce, Hopkins, Toohey, Pethick, & Richards, 2006, and Toohey, Hopkins, McLeod, & Nielsen, 2006) have shown that the advantages of the use of various types of electrical stimulation in improving meat quality.

In the present study although medium voltage stimulation (MVS) did have a significant impact on initial pH which is consistent with results by Toohey, et al. (2008a), it did not provide any additional improvements in shear force when used in combination with the SmartStretch™ treatment. In contrast a study by Pearce et al. (2009) showed the benefits of MVS on shear force even after 30 days of ageing. However, in the current study all carcases were exposed to a number of other electrical inputs including; high frequency immobilisation, moderate frequency immobilisation and low voltage electronic bleed, which may have nullified the shear force benefits of applying MVS. In the study by Toohey, et al. (2008a) which was conducted at the same abattoir as the present study, three of the four electrical inputs used in the current experiment were compared. From this it was concluded that MVS when applied individually and in combination with moderate frequency immobilisation and or low voltage electronic bleed was effective in lowering initial pH when compared to moderate frequency immobilisation and or low voltage electronic bleed individually or in combination with each other. However the impact on shear force was not quantified to know if the initial pH benefits would translate into tenderness benefits. Earlier work by Toohey & Hopkins (2007) did quantify that high frequency immobilisation did not have a significant effect on shear force.

Hence irrespective of stimulation treatment the results in the present study are similar to the results shown in section 2.1.1.1 which examined the effects of an earlier model of the SmartStretch™ technology and ageing on tenderness. In section 2.1.1.1 it was shown that the SmartStretch™ treatment lead to a 46% reduction in shear force at 0 days ageing and after 5 days of ageing a 38% a reduction in shear force was still achieved. In the current study the SmartStretch™ treatment resulted in a 37% reduction in shear force at 0 days ageing and after 5 days of ageing a 16% a reduction in shear force. The interaction between SmartStretch™ treatment and ageing period was mostly consistent with the results in section 2.1.1.1 (SM) and section 2.1.1.2 (BF) for shear force which showed that the un-aged control group (no SmartStretch™) meat was the toughest and samples from the SmartStretch™ and 5 days ageing treatment were the most tender. However it should be noted that there was no significant difference between 0 day SmartStretch™ treatment and 5 day aged control treatment in the present study. As previously outlined in both sections 2.1.1.1 and 2.1.1.2 these benefits are supported by previous studies which aimed to constrict excised pre-*rigor* muscle contraction through wrapping (Devine, et al., 1999; Hildrum, et al., 2000, and Rosenvold, et al., 2008).

Results from section 2.1.1.1, section 2.1.1.2 and Devine, et al.(1999) all indicated that by restricting the muscle from contracting one can reduce the variation in meat tenderness hence producing a more consistent product. However the results in the current study are contrasting with the SmartStretch™ 5 day aged and stimulated treatment samples exhibiting the least variation and the SmartStretch™ treatment 0 day aged, and non stimulated samples having the greatest variation. It is unclear why this has occurred, however overall SmartStretch™ did reduce the variation in shear force when stimulation and ageing treatments were removed from the model.

Results presented in section 2.1.1.1 showed the SmartStretch™ treatment increased sarcomere length from 1.54 to 2.19 µm when compared to the control and this is consistent with the present study where irrespective of stimulation treatment the SmartStretch™ treatment increased sarcomere length from 1.53 to 2.27 µm. Based on these results and the results in section 2.1.1.2 it can be concluded that SmartStretch™ successfully prevents muscle contracture and stretches sarcomeres in hot boned sheep meat. It can also be confirmed that the SmartStretch™ treatment does increase the variability in sarcomere length (sections 2.1.1.1 and 2.1.1.2) in hot boned sheep meat.

Brewer (2004) defined water holding capacity as 'the ability of meat to hold it's own or added water when force is applied'. The majority of water in muscle is held either within the myofribrils or between myofribrils, between the myofribrils and cell membrane, between muscle cells and between muscle bundles (Huff-Lonergan & Lonergan, 2005). It has been shown that the amount and location of water can change once the muscle is harvested (Honikel, 2004). Honikel, Kim, Hamm, & Roncales (1986) concluded that the release of drip from muscles appeared to be dependent on the state of contraction (contracted sarcomeres, fibrils or fibres) after the onset of *rigor.* It was thought that this was due to the shrinkage of filament spacing which results in the release of water from cells (Honikel, et al., 1986).

The effect that SmartStretch™ has on water holding capacity was examined in section 2.1.1.2 by the assessment of purge and cooking loss. This assessment came about after there was some anecdotal evidence in section 2.1.1.1 that although the control had significantly greater cooking loss in the SM there did appear to be more purge from SmartStretch™ samples. There was an inconsistent cooking loss result in section 2.1.1.2 between the two muscles assessed (BF and SM). SmartStretch™ caused a reduction in cooking loss for the BF which was consistent with results in section 2.1.1.1 and no change for the SM. It was hypothesised that this was because the SM was not stretched to the same extent in the whole leg scenario. This theory was further supported in the current study given the significant degree of stretch shown in the SM and the fact that SmartStretch™ also reduced the amount of cooking loss irrespective of stimulation treatment. However as eluded to in section 2.1.1.1, SmartStretch™ also increased the amount of purge lost irrespective of stimulation treatment in the current study. This also supports the theory proposed in section 2.1.1.2 that SmartStretch™ may not impact the overall water holding capacity of sheep meat when compared to control non stretched meat. Based on these conclusions the question is how does this impact on the consumer? Both purge (Payne, et al., 1998) and cooking loss (Barbera & Tassone, 2006) can be viewed negatively by the consumer.

Given consumers decision to purchase meat is influenced by meat colour more than any other trait (Mancini & Hunt, 2005) it is considered to be one on the most important meat quality traits. It has been concluded that post slaughter factors can significantly impact meat colour such as electrical stimulation (Devine, et al., 2004). Pearce, et al. (2009) reported that medium voltage stimulation had no detrimental effect on retail colour display. This outcome supports the results in the current study. It could be concluded in the current study that based on the minimal differences in treatments it is unlikely that either stretch or stimulation treatments would impact on consumer perceptions of colour in their decision to purchase.

2.1.1.5 Overall conclusions

The adoption of hot or warm boning in the Australian sheep meat processing industry has been limited to the use of adult sheep meat. Unlike hot-boned beef, though, the sheep processed are not necessarily cast for age. All four hot-boned sheep experiments were conducted at the Fletchers International plant in Dubbo, NSW between January 2008 and December 2010.

The results of Experiment 1 (Section 2.1.1.1) could not have been more promising. Meat tenderness of the topside was improved significantly by applying the SmartStretch™ treatment, such that after 0 days of ageing the SmartStretch™ caused a 46% or 34N reduction in shear force. The benefits of the SmartStretch™ were still evident after 5 days of aging, with a reduction in shear force of 38% or 20N. There was no evidence based on measurement of particle size that the SmartStretch™ treatment impacted on protein degradation, so the improvements from this treatment appear to partially reflect an increase in sarcomere length. It was also shown that the SmartStretch™ treatment resulted in less cooking loss. It was evident that further work needed to be completed to determine if the cooking loss result reflected the loss of more moisture (ie purge) from SmartStretch™ treated samples. Based on these results this study highlighted the potential to the improve sheep meat quality and consumer satisfaction for a lower grade hot-boned product using SmartStretch™. It remained to be seen whether this benefit could be translated to other primals in the sheep carcase.

The results of Experiment 2 (Section 2.1.1.2) showed that meat tenderness of the m. *semimembranosus* and m. *biceps femoris* was improved significantly by applying the SmartStretch™ treatment, such that after 0 days of ageing the SmartStretch™ caused a 15.2% (9.2N) and 19.8% (6.5N) reduction in shear force respectively. The SmartStretch™ treatment also caused an 11.1% reduction in m. *biceps femoris* shear force after 5 days of ageing, however the benefits of the SmartStretch™ diminished after 5 days of ageing in the m. *semimembranosus.* Significant differences were found between SmartStretch™ and control for m. *semimembranosus* and m. *semitendinosus* sarcomere length such that the SmartStretch™ treatment increased sarcomere length. These results suggested that the SmartStretch™ treatment prevented the muscle from shortening and that the fibres could have been physically disrupted by this treatment, but the histology results did not suggest that SmartStretch™ caused more distorted fibres. Both the particle size and histology results showed that the SmartStretch™ treatment did not cause the acceleration of proteolysis. There was no relationship between shear force and sarcomere length indicating that other mechanisms were impacting on the variation in shear force. A possible explanation is that the SmartStretch™ treatment altered muscle structure or connective tissue. Ultimately, based on these results, this study highlighted the potential of SmartStretch™ for improving the tenderness of whole hot boned hind legs, although the benefit was less than stretching individual muscles as reported in Experiment 1.

Experiment 3 (Section 2.1.1.3) was planned from the earliest stages of the project. The hope had been to develop a system to bind and package hot-boned sheep loins, creating a product with a cross-sectional area of greater use to the food processing industry. Commercial work on stretching of bound product had been unsuccessful, but the intent here was to establish the efficacy of stretching on the loin as a cut. Once established the binding issues could be addressed. Unlike previous studies there was no reduction in shear force at day 0 due to stretching by 7%, but there was a significant reduction after 5 days of ageing. The physical damage observed in the samples was unusual compared to previous experiments. Important presentation traits were affected by stretching in different ways – cooking loss was improved consistent with earlier studies, purge loss was worsened consistent with section 2.1.1.2, although there was little effect on colour.

The two rubbers developed to stretch the loins contained weak spots, causing both to fail before the experiment as designed could be completed. The inconsistent behaviour of the rubber along its length, resulting from inconsistent rubber wall width, may have contributed to excessive force being applied to samples, which tore some samples to pieces during the ejection process.

In the results of Experiment 4 (Section 2.1.1.4) MVS did not impact on any of the meat quality traits tested except it caused a lower initial pH as expected. The null effect of MVS could be due to the other electrical inputs which all carcases were exposed to that are routinely used by the abattoir. Meat tenderness of the m. *semimembranosus* muscle was improved significantly by applying SmartStretch™, such that after 0 days of ageing the SmartStretch™ caused a 37% reduction in shear force. The benefits of the stretch were still evident even after 5 days of ageing, with a reduction of 16% in shear force. The application of SmartStretch™ also significantly increased sarcomere length. None of the treatments appeared to have any real impact on meat colour consistent with the results of section 2.1.1.3. The accelerated tenderisation by the pre-*rigor* stretching device could remove the need for aged chiller storage to achieve acceptable tenderness levels. SmartStretch™ caused a decrease cooking loss, but an increase in purge loss when compared to control consistent with previous studies. What effect this has on consumers is most likely dependent on how the product is packaged and sold. Overall, the results from this study highlighted significant potential from using the stretching device to improve sheep meat quality and consumer satisfaction and would suggest that MVS did not appear to inhibit the effectiveness of SmartStretch™.

Overall studies conducted on the SmartStretch™ treatment of hot-boned sheepmeat found that stretching reduced shear force, increased sarcomere length, reduced cooking loss, increased purge and had no impact on colour stability or myofibrillar degradation as measured by particle size. The additional impact of electrical stimulation was found to have no effect on these results. When considering that the basis for this technology was to replicate the studies that found that wrapping of hot-boned meat improved tenderness by restricting the contraction of the muscle during *rigor* it can be concluded that the technology successfully does fulfil that goal for hot-boned sheepmeat.

2.1.2 Stretching experiments on hot-boned beef

2.1.2.1 Experiment 5: The effect of SmartStretch™ technology on meat traits in beef topsides (m. semimembranosus)

Introduction

The challenge the meat industry faces when increasing processing efficiency is to maintain or enhance eating quality and this is particularly relevant to the use of warm or hot boning, where the former can be defined as boning with a muscle temperature below 30°C. Previous work in beef has shown that hot boning increases the toughness of loin and topside cuts compared to cold boning (White, O'Sullivan, Troy, & O'Neill, 2006) and in sheep warm boning produced meat with a low consumer compliance (Toohey & Hopkins, 2006), but interventions such as wrapping warm boned meat can increase eating quality when combined with ageing (Toohey, et al., 2008b).

The aim of this study was to evaluate the effect of both stretching and ageing, using SmartStretch™ technology (Section 2.1.1.2) on meat tenderness of hot boned m. *semimembranosus* (SM) from beef topsides. This followed the successful results from the stretching of hot boned sheep topsides. The intent was to simulate different degrees of stretch by altering the dimensions of the topsides.

Materials and methods

To test the effect of SmartStretch™ technology on hot boned m. *semimembranosus* (SM) from beef topsides (Anonymous, 2005; HAM No. 2000) 24 cows from various consignments were selected. Left and right topsides were collected pre-*rigor* and the SM was removed and randomly allocated to one of three treatments: treatment 1 (SM cut to 31-32 cm circumference), treatment 2 (SM cut to 28-29 cm circumference) or treatment 3 (SM cut to 25-26 cm circumference) respectively. The SM muscles were ejected from the SmartStretch™ machine into the packaging unit with a circumference of 24 cm (ring diameter 75mm, using 70mm diameter (110mm layflat) packaging). Each SM was cut in half and the portions were randomly allocated to either freezing on day 0 or ageing for 7 days post treatment. The length and circumference were measured pre- and post-treatment. Samples for ageing were held at 4-5°C for 7 days and then frozen and stored in a -22ºC freezer.

Meat quality measurements

Initial pH and temperature

The initial pH and temperature were measured in both the left and right (SM) of each animal as soon as the muscle was collected. Muscle pH was measured using a glass combination pH probe (potassium chloride) Ionode intermediate junction pH electrode, (TPS Pty Ltd., Brisbane, Queensland) attached to a data recording pH meter (TPS WP-80). Muscle temperature was measured using a stainless steel cylindrical probe attached to the same meter. The pH meter was calibrated before use and at regular intervals using buffers of pH 4 and pH 6.8 at room temperature.

Length and circumference measurements

The initial length of each trimmed sample was measured, along with the initial circumference prior to treatment. Three circumferences were measured on each cut to get a representation of the change in circumference over the whole cut. After the stretch treatment was applied the length and circumference of the samples was measured again.

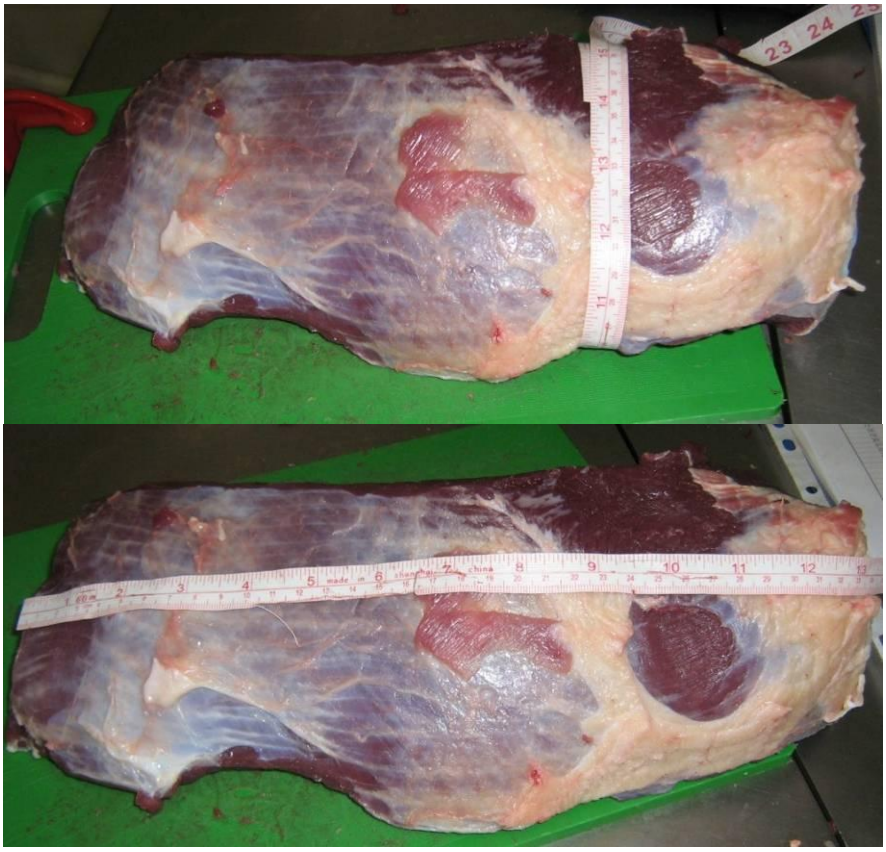

Figure 23: Taking the circumference measurements (top) and length measurements (bottom) prior to stretch treatment.

Shear force - Lloyd Analyser

Warner-Bratzler shearforce testing was conducted on 65 gram blocks cooked from frozen at 70°C for 35 minutes in a water bath. They were then cooled in a coldwater bath for 20 minutes and cut into 6 slices parallel to the muscle fibres each with a cross-sectional area of 1cm² and tested for peak shear force using a Lloyd Analyser.

Shearforce - G2 Tenderometer method

Samples were cut to approximately 100g blocks from both 0 and 14 day aged treatments and were cooked from frozen in zip lock plastic bags at 71°C for 45 minutes in a water bath. Samples were then removed and cooled (for 20 minutes in a cold water bath) and then subsequently tested for peak shear force. For each sample 10 replicates were measured using the Tenderometer device.

Cooking loss percentage

The cooking loss percentage was derived from samples used to test shear force. Before cooking an initial weight was recorded to two decimal places and once the samples were cooled they were patted dry using paper towelling and re-weighed, then a cooking loss percentage was calculated using the following formula;

Cooking loss (%) = 100 – (Final weight/Initial weight * 100)

Sarcomere length

Sarcomere length was measured using laser diffraction as described by Bouton, et al. (1978) on samples aged for 0 days.

Final pH

A 1 gram sample was taken for determination of final pH on both 0 and 14 day aged samples. This was determined using an iodoacetate method adapted from that described by Dransfield, et al. (1992) and as described by Hopkins & Toohey (2006).

Thaw loss percentage

Thaw loss percent was calculated on 0 day aged samples by cutting a portion of meat to the following dimensions 4 x 4 x 5cm. An initial weight was recorded to 2 decimal places and then placed in a chiller on a rack with a drip tray placed below and the upper surface of the samples were covered in foil. Samples were held in the chiller at 3-4°C for 48 hours. After 48 hours the samples were removed from the chiller and placed on paper towelling where they were then patted dry and a final weight was recorded to 2 decimal places. The thaw loss percentage was calculated using the following formula;

Thaw loss (%) = 100 – (Final weight/Initial weight * 100)

Fresh colour

A 3 cm thick slice was taken after 14 days of ageing and the same thickness slice from the sample aged for 0 days that was used for thaw loss. Each slice was placed individually on black foam trays (13.5 cm x 13.5 cm) and over wrapped with PVC food film wrap (15 μm thickness) in a chiller set at 3-4°C. Samples were then left to bloom for a period of 30-40 minutes. Each sample was measured with a Minolta CR400 using Illuminant D-65 and an observer angle of 2° calibrated using a white tile. Each sample was measured twice and the values averaged.

Figure 24: Colour samples prepared on trays and allowed to bloom prior to colour measurement.

Colour stability

Retail colour display was examined on both 0 and 14 day aged samples. A frozen slice of SM (3 cm thick) was taken from each sample, placed on trays and allowed to thaw overnight in a chiller set at 3-4°C. The following day a fresh surface was cut on each sample and they were placed individually on black foam trays (13.5 cm x 13.5 cm) and over wrapped with PVC food film wrap (15 μm thickness). After a blooming period of 30-40 min, each sample was measured (initial colour values) with a Hunter Lab meter (Models 45/0-L) with an aperture size of 25 mm. The instrument was calibrated with black and white tiles using Illuminant D-65, with 10 degree standard observer. Samples were displayed in the chiller under lighting (1000 lux) and measured once a day for 4 days (final colour value). Each sample was measured twice at each measurement time and the values averaged.

Particle size

Particle size analysis was conducted on 2g samples using the method described by Karumendu et al. (2009).

Statistical analysis

Linear mixed model methods were used to analyse the data. For analysis of initial pH, initial temperature, percentage increase in muscle length, percentage decrease in circumference and sarcomere length all measured prior to allocation of ageing treatments within samples, the model included stretch treatment as a fixed effect and an animal effect as a random effect. The model for shear force, measured on each portion assigned an ageing treatment, included stretch treatments, ageing treatments and the interaction between these two factors as fixed effects and included as random effects terms for animal, sides within animal and cook batch. Colour and ratio measures

were analysed using repeated measures analyses and included fixed effects for stretch treatment, ageing, time and interaction of these terms whilst random effects included terms for animals, sides within animals and allowing for correlations for results over time on the same sample. All models were fitted using the statistical package ASReml (Gilmour, et al., 2006) which uses REML based methods and incorporates adjusted Wald statistics (Kenward & Roger, 1997) to test significance of fixed effects under small sample inference.

Results and Discussion

The predicted means and average standard error for initial pH, initial temperature, percentage increase in length, percentage decrease in circumference and sarcomere length for each stretch treatment are shown in Table 23. Given that the design is a balanced incomplete block design (each pair of treatments occurs on the same animal 8 times) the actual animals allocated to the treatments will not affect the treatment comparisons for carcase weight and P8 and the means in Table 1 show that animals were relatively evenly distributed among stretch treatments.

Table 23: Predicted means (av s.e.) of carcase weight, P8, initial pH, initial temperature, % increase in length, % decrease in circumference and sarcomere length for each stretch treatment.

Treatment	1	2	3	*Av SE*
Carcase weight (kg)	226.3	212.8	207.3	*NA*
P8 (mm)	6.7	6.8	6.6	*NA*
Initial pH	5.94	5.91	5.98	*0.07*
Initial temperature (°C)	35.6	36.6	36.9	*0.76*
Increase length (%)	51.9a	41.1b	34.0c	*2.77*
Decrease circumference (%)	28.8a	18.8b	11.1c	*0.52*
Sarcomere length (μm)	2.24	2.28	2.20	*0.08*

Means followed by a different letter in a row (a, b, c) are significantly different $P = 0.05$.

There was no statistical difference between stretch treatments for the initial pH and temperature. The high mean temperature of the muscles indicated that they were still in the pre-*rigor* phase, although the pH values were lower than might be deemed ideal. There were significant differences ($P < 0.05$) between stretch treatments for the percentage increase in length such that treatment 1 displayed a greater increase in length compared to both treatments 2 and 3 and treatment 2 was significantly longer then treatment 3. Treatment 1 also had significantly greater ($P < 0.05$) decrease in circumference followed by treatment 2. These results indicate that the initial dimensions of beef topside muscle were significantly altered by the three different stretch treatments. An example of the degree of this effect is shown in Figures 25 (a) and (b).

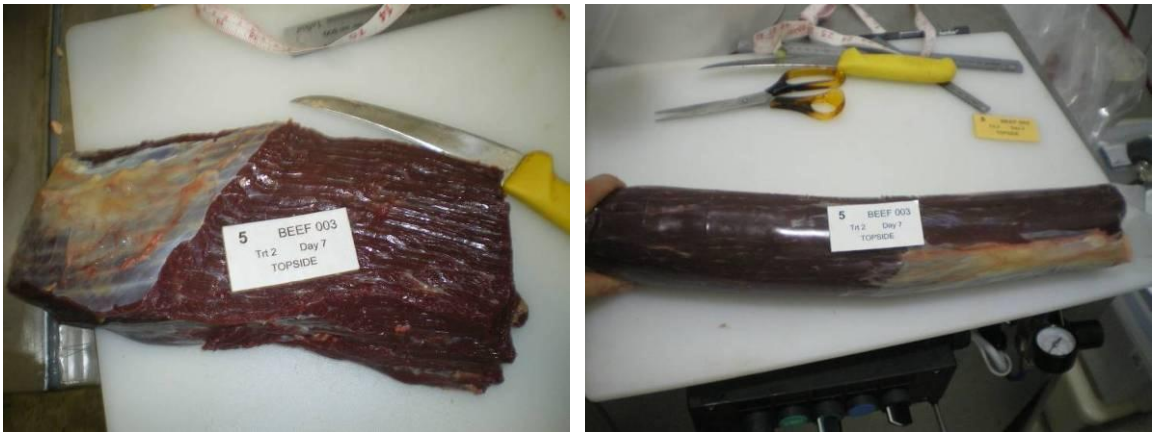

Figure 25: (a) Treatment 2 before stretch treatment measuring 28cm length, (b) Treatment 2 after stretch treatment measuring 46cm length

Given the large percentage increase in length it was surprising that there was no significant difference ($P > 0.05$) between stretch treatments for sarcomere length (Table 23) or shear force when tested using either the Lloyd or the Tenderometer (Table 24).

Table 24: Predicted shear force means (N) and standard errors (s.e.) for both the Lloyd and Tenderometer method and each stretch and ageing treatment.

Treatments	Shear Force (N) Lloyd	
	0 day	**7 day**
1	57.2 *(2.87)* a	52.9 *(2.87)* b
2	57.3 *(2.87)* a	53.1 *(2.87)*b
3	55.1 *(2.86)* a	50.9 *(2.87)* b
	Shear Force (N) Tenderometer	
	0 day	**7 day**
1	76.9 *(2.88)* a	72.7 *(2.88)* b
2	77.1 *(2.88)* a	72.8 *(2.88)* b
3	74.9 *(2.88)* a	70.6 *(2.87)* b

Means followed by a different letter in a row (a, b) are significantly different $P = 0.05$.

The shear force results showed that of the fixed effects, the interaction effects were not significant (P = 0.54), treatment was not significant ignoring the interactions (P = 0.48) whilst ageing and method (of measurement) were significant after adjusting for the other (P = 0.006 and $P < 0.001$ respectively) (Table 24). Of the variance components there was a significant contribution due to cooking batch, carcase and carcase x treatment x ageing. The error variances, comprising within slice variation and repeatability variation due to the method were 40.9 and 77.4 for the Lloyd and Tenderometer respectively. From the results shown in Table 25 it can be seen that those obtained using a Tenderometer are on average 19.7 (s.e. = 1.2) units larger than those for Lloyd.

Table 25: Predicted shear force means (N) and standard errors (s.e.) for 0 and 7 day aged product for both the Lloyd and tenderometer method.

Treatments	0 day	7 day
Shear Force (N) Lloyd	56.6 *(2.6)* b	52.3 *(2.6)* a
Shear Force (N) Tenderometer	76.3 *(2.6)* d	72.0 *(2.6)* c

Means followed by a different letter within columns and rows are significantly different $P = 0.05$.

From all of these results (sarcomere, shear force, percentage increase in length and decrease in circumference) although there were significant changes in dimensions there were no significant meat quality benefits between the stretch treatments. Based on previous work by Hopkins, et al. (2000b) where super tenderstretching did not reduce shear force in the topside compared with tenderstretching or produce a significantly longer sarcomere length and the data presented by Hwang, et al. (2002) which suggested that there is an upper limit beyond which further stretching will not improve sensory scores or reduce shear force it could be concluded that there is an upper threshold where there is no benefit from extra stretching and this was achieved in this current study.

Other previous work by Simmons, Cairney, Auld, Nagle, & Mudford (1999) which studied beef *longissimus thoracis* muscles found similar results. By stretching the muscles to 20, 40 and 60% using clamps and then comparing these to un-stretched muscles, it was shown that the 20% stretching produced significant reductions in shear force, but the 40 and 60% stretching did not further reduce shear force. In the current study we could conclude that the stretching threshold was achieved using SmartStretch™ with treatment 3 (the lowest degree of stretch treatment based on percentage increase in length). Hence there are no significant meat quality benefits of stretching using SmartStretch™ greater then 34% increase in muscle length for beef SM as indicated by the results with no significant difference between treatments for either sarcomere length or shear force.

In the current study there was no un-stretched control treatment to compare the three stretch treatments which in retrospect was an oversight. However, previous work by Toohey, et al. (2008c)(Section 2.1.1.1) using an earlier version of the SmartStretch™ machine showed significant improvements in both shear force and sarcomere length of hot-boned sheep topsides. These improvements were such that after 0 days of ageing the stretch caused a 46% reduction in shear force when compared to the control. The benefits of the stretch were still evident even after 5 days of ageing, with a reduction in shear force of 38%.

Further work to quantify the effect of SmartStretch™ technology was reported by Toohey, et al. (2009a)(Section 2.1.1.2). In this work hot boned sheep hindlegs were tunnel boned and subjected to the stretching technology. Meat tenderness of the m. *semimembranosus* (topside) and m. *biceps femoris* was improved significantly by applying the stretch treatment, such that after 0 days of ageing the stretch caused an 18.5% and 16% reduction in shear force respectively. However, the benefits of the stretch diminished after 5 days of ageing. Significant differences were found between stretch and control for sarcomere length of the m. *semimembranosus* and m. *semitendinosus* such that the stretch treatment produced longer sarcomeres. These results indicated that the fibres were physically disrupted by the stretch treatment, but histology results did not suggest that the stretch caused more distorted fibres.

Based on all these results where the same technology in principle has been used in the same muscle (SM), but a different species it can be concluded that stretching would have improved the baseline tenderness of the beef SM in the current study especially given each treatment had an average sarcomere length greater than 2.20µm.

The relationship of the raw data between the percentage increase in muscle length and both sarcomere length and shear force has been graphed in Figures 26 and 27 respectfully. From the analysis and as illustrated in these two figures there was no relationship between either of the traits and percentage increase in muscle length.

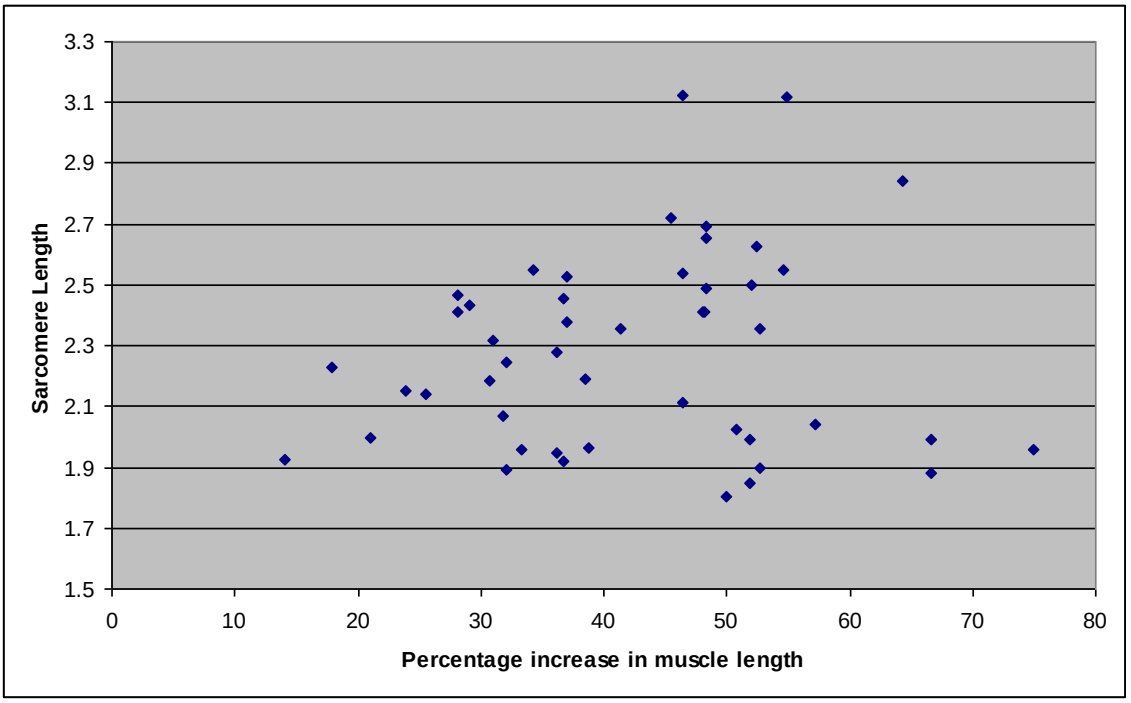

Figure 26: Relationship between sarcomere length (µm) and the percentage increase

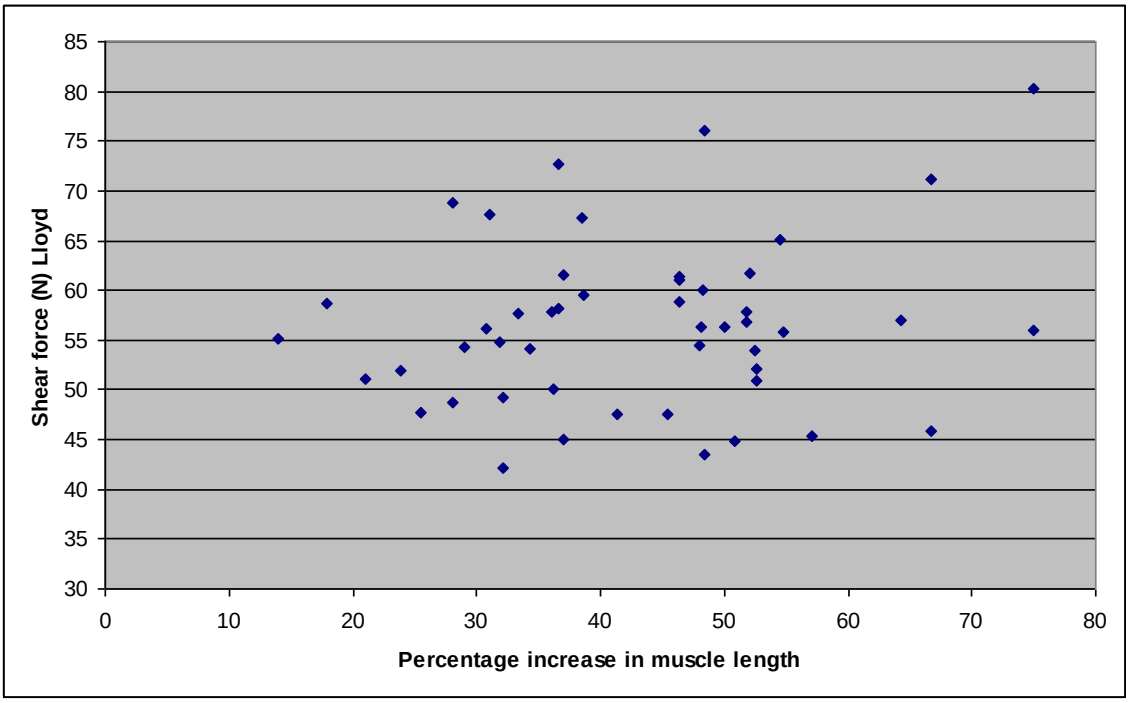

Figure 27: Relationship between Shear force (N) Lloyd and the percentage increase

Particle size results in the current study (Table 26) show that stretching treatment had no significant effect ($P > 0.05$) on myofibrillar degradation of the SM; however there was a significant difference between ageing treatments. This difference was such that 0 day aged samples had a predicted mean particle size of 266 µm and after 7 days ageing it was 156 µm with an average standard error of difference of 11.7 µm. These results indicate that the utilisation of SmartStretch™ does not result in accelerated proteolysis and these outcomes are supported by the previous results (Toohey, et al., 2008c; Section 2.1.1.1; Toohey, et al., 2009b; Section 2.4.3).

Table 26: Predicted particle size means (µm) and standard errors (s.e.) for each stretch and ageing treatment.

Treatments	Particle Size (µm)	
	0 day	**7 day**
1	257 (11.8) a	154 *(11.1)* b
2	282 *(11.8)* a	158 *(11.8)*b
3	258 *(12.2)* a	156 *(11.4)* b

Means followed by a different letter in a row and column (a, b) are significantly different $P = 0.05$.

From Table 27 it is observed that ageing treatment had no significant effect either within or across traits for any of the four analyses for colour values *L**, *a**, *b** and ratio 630/580nm at either the initial or final reading. Stretch treatment was significant for all except for *L** values from 7 day aged product. *L** values from the 0 day aged product at initial and final readings showed treatment 3 to have significantly lighter values when compared to both treatments 1 and 2.

However for all other colour values *a**, *b** and ratio 630/580nm there were significant differences between initial and final values at with both 0 and 7 day aged product. This resulted in all initial *a** values being significantly higher than the final values irrespective of ageing treatment, meaning that they were redder than final values. There were also significant differences between stretch treatments for *a** values with treatments 1 and 2 having significantly higher values than treatment 3. The initial *b** values were also significantly higher than the final values irrespective of ageing treatment, meaning that they were yellower when compared to final values. The *b** values also show that there are significant stretch treatment effects such that at both 0 and 7 days aged initial readings all stretch treatments are significantly different from each other such that as the level of stretch increased so did the amount of yellowness recorded. For the final reading for both 0 and 7 days aged samples, treatments 1 and 2 were significantly yellower compared to treatment 3 (Table 27).

Table 27: Predicted means and (standard errors) for Initial and final *L*, a*, b and ratio for 0 and 7 day aged samples and each stretch treatment.**

Treatments	0 day aged		7 day aged	
	Initial	Final	Initial	Final
		L*		
1	30.6 *(0.8)* ax	30.3 *(0.9)* ax	30.7 *(0.8)* ax	30.0 *(0.9)* ax
2	30.4 *(0.9)* ax	30.0 *(0.9)* ax	31.5 *(0.9)* ax	30.8 *(0.9)* ax
3	32.4 *(0.9)* ay	31.8 *(1.0)* ay	31.5 *(1.0)* ax	30.7 *(1.0)* ax
		a*		
1	20.7 *(0.5)* ax	15.8 *(0.5)* bx	20.6 *(0.5)* ax	15.9 *(0.5)* bx
2	20.3 *(0.5)* ax	16.2 *(0.5)* bx	20.3 *(0.5)* ax	16.3 *(0.5)* bx
3	19.1 *(0.6)* ay	15.1 *(0.5)* by	19.0 *(0.6)* ay	15.2 *(0.6)* by
		b*		
1	18.0 *(0.5)* ax	15.3 *(0.4)* bx	17.8 *(0.5)* ax	14.9 *(0.4)* bx
2	16.9 *(0.5)* ay	14.9 *(0.4)* bx	17.5 *(0.5)* ay	15.3 *(0.4)* bx
3	15.8 *(0.6)* az	14.2 *(0.5)* by	16.1 *(0.6)* az	14.3 *(0.5)* by
		Ratio 630/580nm		
1	7.4 *(0.3)* ax	3.5 *(0.2)* bx	7.5 (0.4) ax	3.7 (0.2) bx
2	7.0 *(0.4)* ay	3.7 *(0.2)* bx	6.8 (0.4) ay	3.7 (0.2) bx
3	6.2 *(0.4)* az	3.3 *(0.3)* by	6.1 (0.4) az	3.3 (0.3) by

Means followed by a different letter in a row (a, b) and Column (x, y, z) are significantly different *P* = 0.05.

The ratio values also decreased between initial and final readings irrespective of ageing treatment meaning that as the display time increased the metmyoglobin formation or browning of the meat increased with the decrease in final ratio values. The ratio values also show that there were significant stretch treatment effects such that at both 0 and 7 days ageing the initial readings for all stretch treatments were significantly different from each other. **So as the level of stretch increased the level of browning was less.** For the final reading at both 0 and 7 days ageing,

treatments 1 and 2 exhibited significantly less browning when compared to treatment 3. Work by Morrissey, Jacob, & Pluske (2008) suggested that when the ratio value falls below 3.5 for lamb topside that consumers consider the meat to be more brown than red and recent work using lamb loins Khliji, et al. (2010) showed that when the wavelength ratio (630/580 nm) values are equal to or greater than 3.3, on average consumers will consider the meat as acceptable. These thresholds need to be increased to 6.8 for ratio to be 95 percent confidence that a randomly selected consumer will consider a sample as acceptable. This indicates that higher levels of stretch in this study produced meat that was more acceptable in terms of colour stability.

2.1.2.2 Experiment 6: The effect of SmartStretch™ on meat traits in hot boned beef cube rolls (m. longissimus lumborum).

Introduction

The challenge the meat industry faces when increasing processing efficiency is to maintain or enhance eating quality and this is particularly relevant to the use of warm or hot boning, where the former can be defined as boning with a muscle temperature below 30°C. Previous work in beef has shown that hot boning increases the toughness of loin and topside cuts compared to cold boning (White, et al., 2006) and in sheep warm boning produced meat with a low consumer compliance (Toohey & Hopkins, 2006), but interventions such as wrapping warm boned meat can increase eating quality when combined with ageing (Toohey, et al., 2008b). The aim of this study was to evaluate the effect of both stretching and ageing, using SmartStretch™ technology (Toohey, et al., 2009a; Section 2.1.1.2), on meat tenderness of hot boned m. *longissimus* (LL) from beef cube rolls. This primal was selected because of the widespread industry interest in value adding this primal when hot boned from cull cows and current use by several processors of “bon bon” wrapping of this primal.

Materials and methods

Hot boned cube rolls (Anonymous, 2005, HAM 2240) were removed from 24 cow carcases from both left and right sides of the carcase at a commercial hot boning abattoir. The cube roll consists of a number of muscles including; m. *longissimus* (LL) and associated muscles underlying the dorsal aspect of the ribs (m. *iliocostalis*, m. *multifidi dorsi*, m. *spinalis dorsi*, m. *trapezius thoracis*). Given the cube roll is predominately made up of m. *longissimus* all meat quality testing was done in this muscle. Each cube roll collected was randomly allocated to one of three stretch treatments and then cut into two portions which were then randomly allocated to either 0 or 14 day ageing treatment. The three stretch treatments that were applied, were determined by cutting the cube roll to have one of two circumferences and the third treatment was a no stretch control; treatment 1 (control), treatment 2 (25-26 cm) or treatment 3 (27-28 cm) respectively. The cube roll muscles were ejected from the SmartStretch**™** machine into the packaging unit with a circumference of 24 cm (ring diameter 75mm, using 70mm diameter (110mm layflat) packaging) within 2 hours of death. Treatment 1 or control samples were vacuum packed.

Initial pH and temperature, shear force, cooking loss, sarcomere length, thaw loss, retail colour, final pH and particle size were assessed. Refer to section 2.1.2.1 for the methodology.

Statistical analysis

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) were used to analyse the data; Initial pH, shear force, cook loss percent, particle size, initial *L**, final *L**, initial *a**, final *a**, initial *b**, final *b**, initial ratio and final ratio. The following model was fitted;

Y = Constant + Ageing + stretch Treatment + (Stretch Treatment x Ageing) **+ *Animal* + *Sides:Animals +Batch + error***

The model for initial pH, initial temperature, percentage increase in muscle length, percentage decrease in circumference and sarcomere length was Y = Constant + stretch treatment + ***Animal + error.*** The terms in bold/italic were fitted as independent random effects.

Results and Discussion

The characteristics of the cube rolls used in this experiment are shown in Table 28 according to treatments.

Table 28: Predicted means (av s.e.) of initial pH, initial temperature, % increase in length, % decrease in circumference and sarcomere length for each stretch treatment.

Treatment	1	2	3	*Av SE*
Initial pH	6.15	6.21	6.12	*0.06*
Initial Temperature (°C)	36.2	35.3	36.4	*0.50*
Increase in length (%)	*	8.5	9.3	*1.80*
Decrease in circumference (%)	*	2.35a	7.31b	*0.74*
Sarcomere length (μm)	1.62b	1.81ab	1.94a	*0.07*

Means followed by a different letter in a row (a, b) are significantly different *P* = 0.05.

There was no statistical difference between stretch treatments for the initial pH and temperature as expected and, given the high mean temperature and the initial pH of the muscles, they were still in the pre-*rigor* phase. No stretch treatment was applied to treatment 1 thus percentage change in length or circumference was not relevant. Although there was a trend for treatment 2 on average to have a lower percentage increase in stretch, there was no significant difference ($P > 0.05$) between stretch treatments for the percentage increase in length. There were however significant differences between stretch treatments ($P < 0.05$) for circumference measurements. These results indicate that the initial dimensions of beef cube roll topside muscle were altered by the different stretch treatments. There was a trend which showed that as the degree of stretch was increased through the treatments sarcomere length increased.

Shear force results showed that of the fixed effects, the interaction effects were not significant (P = 0.93), stretch treatment was not significant ignoring the interactions (P = 0.92), whilst ageing was significant ($P < 0.001$) (Table 29).

Table 29: Predicted shear force means (N) and standard errors (s.e) for each stretch and ageing treatment.

Treatments	Shear Force (N) Lloyd	
	0 day	**14 day**
1	60.9 *(3.95)* b	39.3 *(3.95)* a
2	60.2 *(3.83)* b	37.3 *(3.83)* a
3	60.6 *(3.83)* b	36.7 *(3.83)* a

Means followed by a different letter in a row (a, b) are significantly different *P* = 0.05.

The box plots shown in Figure 28 illustrate that as ageing time increases from 0 day aged to 14 days aged the variability of shear force results (N) decreases. At 0 day aged it would not appear that stretch treatment had any impact on the variation of shear force. However after 14 days ageing treatment 2 appears to have less variation in shear force when compared to treatments 1 and 3.

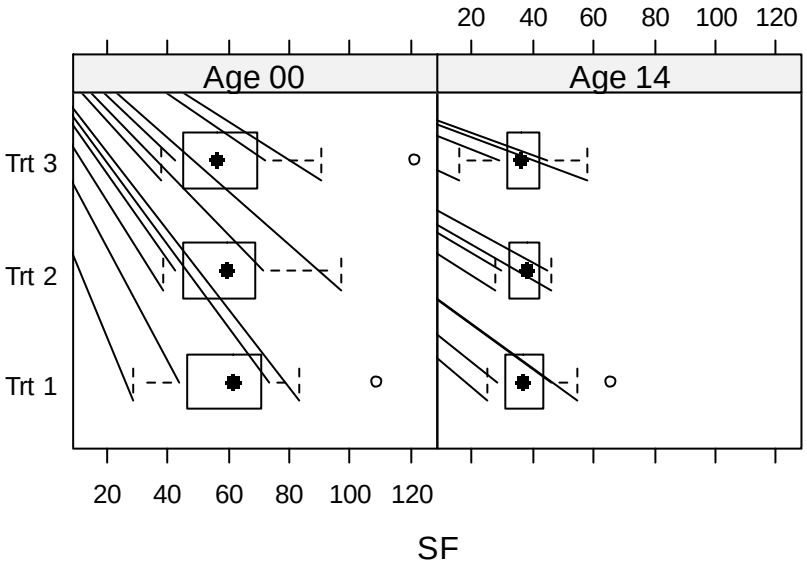

Figure 28: Box plots for each stretch and age treatment for shear force (SF) N.

A regression analysis was conducted to examine the relationship between shear force (N) and sarcomere length. From these results it was determined that sarcomere length explained 37.8% of the variance in shear force, however there was a large standard error (15.6) around these observations. Nevertheless, sarcomere was still used to predict shear force values for each stretch treatment as shown in Figure 29. The results indicate that irrespective of treatment as sarcomere length increased shear force decreased, this supports the strong negative correlation (-0.61) found between the 2 traits.

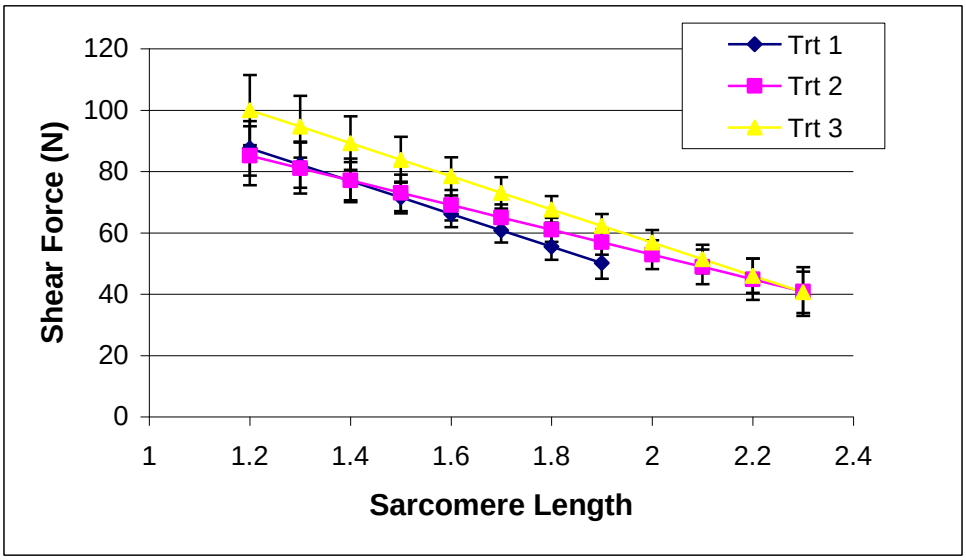

Figure 29: Predicted means and standard errors for shear force (N) against sarcomere length (µm).

The relationship between sarcomere length and percentage increase in length and shear force and the percentage increase in length were also assessed. Given that there was no change for percentage increase in length for treatment 1; only comparisons for treatment 2 and 3 were made. From the results it was determined that percent increase in length explained 15.7 % of the variance in sarcomere length, with a standard error around these observations of 0.26. In addition to this the percent increase in length only explained 0.5 % of the variance in shear force, with large a standard error around these observations of 19.4. **Therefore the percent increase in length in the current experiment is not closely related to either shear force or sarcomere length as found in previous studies.**

Cooking loss results showed that there was no significant difference ($P > 0.05$) between either stretch treatments or ageing treatments or the interaction of these terms. These results are contrasted to previous results (Toohey, et al., 2008c) where differences were reported between treatments (e.g. Section 2.1.1.1). The results obtained in the current study may be a reflection of the lack of stretch achieved. There was also no significant difference between stretch treatments ($P > 0.05$) for thaw loss, but there were significant differences between ageing treatments ($P < 0.05$). The results in Table 30 show that 0 day aged samples had a greater thaw loss percent when compared to 14 day aged samples.

Table 30: Predicted cooking loss % and thaw loss % and standard errors (s.e.) for each stretch and ageing treatment.

Treatments	Cooking Loss %	
	0 day	**14 day**
1	18.2 *(0.72)* a	17.2 *(0.72)* a
2	17.6 *(0.70)* a	17.3 *(0.70)* a
3	17.8 *(0.70)* a	17.1 *(0.70)* a
	Thaw Loss %	
1	11.7 *(0.63)* b	7.7 *(0.63)* a
2	10.5 *(0.61)* b	8.4 *(0.63)* a
3	10.6 *(0.61)* b	7.2 *(0.61)* a

Means followed by a different letter in a row (a, b) are significantly different $P = 0.05$.

Particle size results in this study (Table 31) showed that stretching treatment had no significant effect ($P > 0.05$) on myofibrillar degradation of the LL muscle from the cube roll however there was a significant difference between ageing treatments. This difference was such that 0 day aged samples had a predicted mean particle size of 248 µm and at 14 day aged it was 132 µm with an average standard error of difference of 13.0 µm. These results indicate that SmartStretch™ does not result in accelerated proteolysis and are supported by the previous results (Toohey, et al., 2008c; Section 2.1.1.1; Toohey, et al., 2009b; Section 2.4.3).

Table 31: Predicted Particle size means (µm) and standard errors (s.e.) for each stretch and ageing treatment.

Treatments	Particle Size (µm)	
	0 day	**14 day**
1	239 *(12.9)* b	142 *(11.1)* a
2	252 *(11.8)* b	117 *(12.9)* a
3	253 *(12.2)* b	136 *(12.9)* a

Means followed by a different letter in a row and Column (a, b) are significantly different $P = 0.05$.

The predicted means for colour values *L**, *a**, *b** and ratio 630/580nm were calculated for each stretch and age treatment. Table 32 and Table 33 show the change over time for each trait and stretch treatment. From Table 32 it is shown that there is no significant difference between stretch treatments over time when samples were aged at day 0. However from samples that were aged for 14 days (Table 33), treatment 1 (control treatment) had significantly lower *L** values meaning, on average, samples were darker when compared to either of the stretch treatments and there was no significant difference between treatments 2 and 3.

For 0 day aged samples there were also significant differences between stretch treatments for *a** values. Treatment 1 (control) had significantly lower *a** values when compared to treatments 2 and 3 except at 0 hours on display where there was no difference between treatment 3 (greatest stretch treatment) and the treatment 1. This means that treatments 2 and 3 were mostly significantly redder

when compared to the control treatment 1 (Table 32). As display time increased to 48 and 72 hours, treatment 2 (minor stretch treatment) was significantly redder in colour when compared to treatment 3. Based on the 0 day aged *a** values samples it can be concluded that by applying a stretch treatment meat samples will be redder. To make any further conclusions on which stretch treatment would be more beneficial would be circumstantial given there was no significant difference between stretch treatments for percent increase in length. In addition to this when *a** values were examined on the 14 day aged samples there was no significant difference between treatments (Table 33).

The *b** values for samples aged for 0 days show that the initial reading for treatment 2 samples was significantly higher, meaning a yellower meat colour when compared to both treatments 1 and 3 (Table 32). After 24, 48 and 72 hours on display treatment 2 had significantly higher *b** values and treatment 3 significantly lower values than treatment 2, but higher values than treatment 1. This trend did not follow on to the 14 day aged samples where both treatment 1 and 2 were significantly yellower when compared to treatment 3. In a previous report (Section 2.1.2.1; Hopkins & Toohey, 2009) there were also significant stretch treatment effects such that for both 0 and 7 day aged samples the initial readings of all stretch treatments were significantly different from each other such that as the level of stretch increased so did the amount of yellowness recorded.

Table 32: Predicted means and standard errors (s.e.) for each stretch treatment over display time for 0 day aged colour samples including L*, a*, b* and ratio 630/580um values.

Treatments	Time (hours)	1	2	3
L*				
	0	27.59 *(0.83)* a	27.83 *(0.81)* a	28.25 *(0.81)* a
	24	28.82 *(0.54)* a	28.77 *(0.53)* a	29.01 *(0.53)* a
	48	30.05 *(0.54)* a	29.71 *(0.53)* a	29.77 *(0.53)* a
	72	31.28 *(0.83)* a	30.66 *(0.81)* a	30.53 *(0.81)* a
a*				
	0	19.19 *(0.53)* a	19.73 *(0.52)* b	19.72 *(0.52)* ab
	24	17.97 *(0.35)* a	19.25 *(0.34)* b	19.02 *(0.34)* b
	48	16.75 *(0.35)* a	18.78 *(0.34)* c	18.31 *(0.34)* b
	72	15.53 *(0.53)* a	18.30 *(0.52)* c	17.60 *(0.52)* b
b*				
	0	15.41 *(0.46)* a	16.36 *(0.44)* b	15.80 *(0.44)* a
	24	15.64 *(0.30)* a	16.80 *(0.29)* c	16.21 *(0.29)* b
	48	15.88 *(0.30)* a	17.23 *(0.29)* c	16.61 *(0.29)* b
	72	16.11 *(0.46)* a	17.67 *(0.44)* c	17.02 *(0.44)* b
Ratio 630/580 nm				
	0	7.00 *(0.36)* a	7.58 *(0.35)* b	7.23 *(0.35)* ab
	24	5.66 *(0.24)* a	6.48 *(0.23)* b	6.09 *(0.23)* b
	48	4.33 *(0.24)* a	5.38 *(0.23)* c	4.95 *(0.23)* b
	72	2.99 *(0.36)* a	4.28 *(0.35)* c	3.81 *(0.35)* b

Means followed by a different letter in a row (a, b, c) are significantly different $P = 0.05$.

Perhaps one of the most interesting results from the colour display results was the impact of treatments on the rate of metmyoglobin (browning of meat). From the 0 day aged samples there were significant differences between stretch treatments. Treatment 1 (control) had significantly lower ratio values when compared to treatments 2 and 3 except initially (0 hours on display) there was no difference between treatment 3 (greatest stretch treatment) and treatment 1 (control). This means that treatments 2 and 3 had significantly less browning when compared to the control treatment 1 except at 0 hours (Table 32). However as display time increased to 72 hours, treatment 2 (minor stretch treatment) had significantly less browning or metmyoglobin formation when compared to treatment 3. Based on the 0 day aged ratio values it can be concluded that by applying a stretch treatment meat samples will have less metmyoglobin formation, thus have a longer display life. In a previous report by (Section 2.1.2.1; Hopkins & Toohey, 2009) it was found that as the stretch level increased the ratio value was higher hence the degree of browning was less.

Table 33: Predicted means and standard errors (s.e.) for each stretch treatment over display time for 14 day aged colour samples including L*, a*, b* and ratio 630/580um values.

Treatments	Time (hours)	1	2	3
*L**				
	0	29.69 *(0.92)* a	30.99 *(0.89)* b	30.93 *(0.89)* b
	24	30.25 *(0.60)* a	31.72 *(0.58)* b	31.44 *(0.58)* b
	48	30.82 *(0.60)* a	32.45 *(0.58)* b	31.96 *(0.58)* b
	72	31.38 *(0.92)* a	33.17 *(0.89)* b	32.47 *(0.89)* b
*a**				
	0	21.25 *(0.66)*	21.81 *(0.64)*	21.02 *(0.64)*
	24	19.57 *(0.44)*	19.92 *(0.42)*	19.35 *(0.42)*
	48	17.90 *(0.44)*	18.03 *(0.42)*	17.67 *(0.42)*
	72	16.23 *(0.66)*	16.13 *(0.64)*	16.00 *(0.64)*
*b**				
	0	17.84 *(0.52)* b	17.74 *(0.51)* b	17.04 *(0.51)* a
	24	17.77 *(0.34)* b	17.72 *(0.33)* b	17.00 *(0.33)* a
	48	17.70 *(0.34)* b	17.71 *(0.33)* b	16.96 *(0.33)* a
	72	17.63 *(0.52)* b	17.70 *(0.51)* b	16.92 *(0.51)* a
Ratio 630/580 nm				
	0	7.53 *(0.32)* b	7.41 *(0.31)* b	7.04 *(0.31)* a
	24	6.07 *(0.21)* b	6.02 *(0.20)* b	5.73 *(0.20)* a
	48	4.60 *(0.21)* ab	4.63 *(0.20)* b	4.42 *(0.20)* a
	72	3.14 *(0.32)* a	3.23 *(0.31)* a	3.10 *(0.31)* a

Means followed by a different letter in a row (a, b, c) are significantly different $P = 0.05$.

The results from 14 day aged samples were very different to those on the 0 day aged samples (Table 33). Such that after 0 and 24 hours of display treatment 3 had significantly less metmyoglobin formation when compared to treatments 1 and 2. After 48 hours on display treatment 3 had a significantly higher ratio value when compared to treatment 2, but not treatment 1. Treatment 1 was not statistically different to either treatment 2 or 3 and after 72 hours of display there was not statistical difference between any of the treatments. Although no consumer acceptance levels were measured in the current study previous work by Morrissey, et al. (2008) suggested that when the ratio value falls below 3.5 for lamb topside that consumers consider the meat to be more brown than red. In addition to this recent work using lamb loins (Khliji, et al., 2010) showed that when the wavelength ratio (630/580 nm) values are equal to or greater than 3.3 on average consumers will consider the meat as acceptable. These thresholds for ratio need to be increased to 6.8 to be 95 percent confident that a randomly selected consumer will consider a sample as acceptable. Overall the results suggest that a display life of 72 hours will not be

achievable for cube rolls when aged for 14 days with stretching conferring some benefit for 0 day aged samples, which is the norm for most hot boned beef in Australia.

2.1.2.3 Experiment 7: The effect of SmartStretch™ on hot boned beef topside (m. semimembranosus)

Introduction

Hot-boning of beef has many financial advantages to the beef processing industry. Savings can be made primarily by reduction in storage, refrigeration and transport costs as compared to cold-boned beef (Pisula & Tyburcy, 1996). There is however, a negative perception of hot-boning on the consumer acceptance of the product. White, et al. (2006) found that hot-boning of beef resulted in both higher shear force and poorer sensory tenderness scores. Stretching pre-*rigor* of hot-boned beef striploins (Toohey, et al., 2009b), sheep meat topsides (Toohey, et al., 2008c) (Section 2.1.1.1) and sheep meat legs (Toohey, et al., 2009a)(Section 2.1.1.2), using the same technology in all cases, resulted in a significant reduction in shear force, suggesting that stretching of hot-boned primals results in improved tenderness. In this study tenderness and other meat traits of stretched and unstretched beef topsides were compared using SmartStretch™ technology after the indications from section 2.1.1.1 that significant increases in topside length could be achieved.

Materials and methods

Hot boned topsides were removed from 32 cow carcasses from both sides of the carcase at a commercial hot boning abattoir. The m. *semimembranosus* (SM) was removed from the topside (Anonymous, 2005, HAM 2000) and portioned equally. Each SM collected was randomly allocated to either stretch treatment or control. Irrespective of treatment samples were cut to similar dimensions with an average circumference of 30 cm. The SM muscles allocated to the SmartStretch™ treatment were ejected from the SmartStretch™ machine into the packaging unit with a circumference of 24 cm (ring diameter 75mm, using 70mm diameter (110mm layflat) packaging). Then each sample (stretch and control) was portioned into two sub-samples (cranial and caudal) which were randomly allocated to ageing treatments of 0 or 14 days. Samples were also allocated to one of eight cooking batches for shear force testing.

Initial pH and temperature, shear force, cooking loss, sarcomere length, final pH, thaw loss, fresh colour and retail colour were assessed. Shear force was measured using the G2 Tenderometer. Refer to section 2.1.2.1 for further details of the methodology.

<u>Statistical analysis</u>

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) were used to analyse the data.

The model fitted for initial pH, initial temperature, purge %, thaw loss % and sarcomere length was:

Y = constant + stretch treatment + **animal** + **error**

The model fitted for final pH and fresh colour (*L**, *a** and *b**) on 14 day aged cuts measured using a Minolta CR400 was:

Y = constant + ageing + (stretch treatment x ageing) + **animal** + **(animal x stretch treatment)** + **error**

The model fitted for shear force was:

logY = constant + ageing + (stretch treatment x ageing) + **animal** + **(animal x stretch treatment)** + **portion** + **cooking date** + **cook batch** + **error**

The model fitted for cooking loss % was:

Y = constant + ageing + (stretch treatment x ageing) + **animal** + **(animal x stretch treatment)** + **cooking date** + **cook batch** + **error**

The final model for this trait excluded the (animal x stretch treatment), cooking date and cook batch as sources of variance as they contributed zero variation.

The model fitted for colour measurements taken with the Hunter Lab meter (final *L**, final *a**, final *b** and final ratio) was:

Y = constant + days on display + ageing + stretch treatment + (stretch treatment x ageing) + (stretch treatment x days on display) + (ageing x stretch treatment x days on display) + (days on display)^2 + (ageing x (days on display)^2) + (stretch treatment x (days on display)^2) + (ageing x stretch treatment x (days on display)^2) + **test date** + **(stretch treatment x ageing x measurement)** + **(random linear deviations within days for each sample x stretch treatment)** + **error**

The terms in bold/italic were fitted as independent random effects and the model allowed for error variation.

Figure 30: Samples collected during the experiment – (L – R) 14 day aged control, 14 day aged stretch, nil day aged stretch and nil day control.

Results and Discussion

The characteristics of the beef topsides used in this experiment are shown in Table 34. The predicted means and average standard error for initial pH, initial temperature and sarcomere length,

as well as the actual mean percentage length increase and percentage circumference decrease (taken at three points along the muscle) for each treatment are shown (Table 34).

Table 34: Predicted means (av s.e.) for initial pH, initial temperature and sarcomere length and actual means (av s.e.) of % increase in length and % decrease in circumference for the stretch and control treatments.

Treatment	Control			Stretch		
Initial pH	6.1	*(0.04)*		6.1	*(0.04)*	
Final pH – 0 day	5.57	*(0.02)*		5.58	*(0.02)*	
- 14 day	5.62	*(0.02)*		5.59	*(0.02)*	
Initial temperature (°C)	36.9	*(0.33)*		36.6	*(0.33)*	
Increase in length (%)				40.5	*(2.09)*	
Decrease in circumference 1 (%)				22.4	*(0.62)*	
Decrease in circumference 2 (%)				19.8	*(0.50)*	
Decrease in circumference 3 (%)				21.9	*(0.47)*	
Sarcomere length (μm)	1.77	*(0.03)*	a	2.10	*(0.04)*	b

Means having a following letter different in a row are significantly different ($P < 0.05$).

As expected there was no significant difference between the initial pH and initial temperature for each treatment. The high average temperature and the pH for the muscles shows that they were still pre-*rigor* when stretched. No changes in length or circumference were shown for the control as this was not stretched, although on the path to *rigor mortis*. The average 40% increase in length was matched by a commensurate increase in sarcomere length.

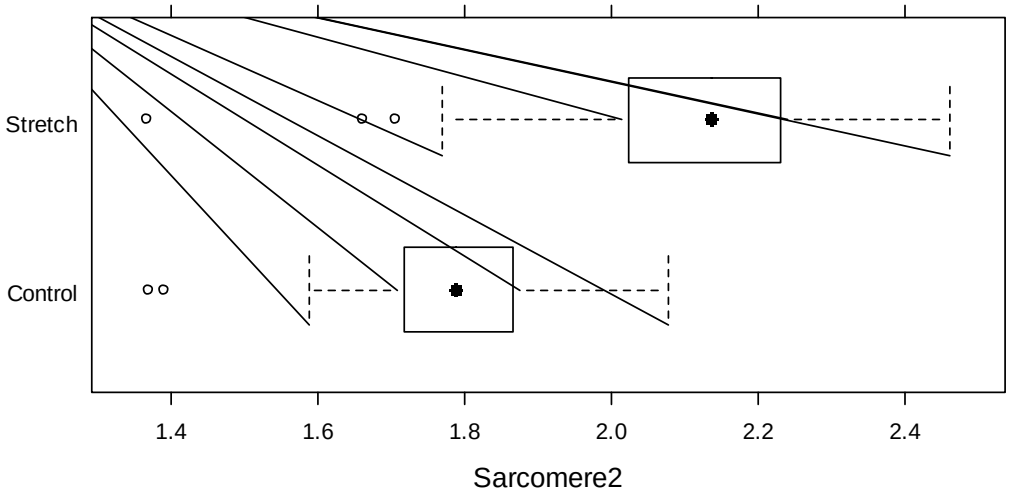

Figure 31. Box plot of sarcomere length for stretch and control treatments.

Sarcomere length increased as a result of the stretching as shown in Figure 31, but was also more variable due to stretching and this directly reflected the variation in the degree of stretch that was

achieved as reported for the sheep studies (Sections 2.1.1.1, 2.1.1.2 and 2.1.1.4). Longer sarcomeres are generally associated with lower shear forces and better sensory test scores, indicators of more tender meat (Smulders, et al., 1990). Shear force values are presented in Table 35. These show that ageing significantly ($P < 0.05$) reduced the shear force. There was a significant increase ($P < 0.05$) in the shear force in the 14 day aged stretch treatment as compared to the control, although there was no significant difference in shear force from stretching at zero days. However stretching did reduce the variation in shear force for zero day aged samples. Initial pH did not significantly account for any variation in shear force. Previous work in sheep (Toohey, et al., 2008c; Section 2.1.1.1) suggested that a reduction in topside shear force would be expected using SmartStretch™ particularly given the degree of stretch achieved. Simmons, et al. (1999) studied beef *Longissimus thoracis* muscles by stretching them to 20, 40 and 60% using clamps and then comparing these to un-stretched muscles. It was shown that the 20% stretch produced a significant reduction in shear force, but the 40% and 60% stretching did not further reduce shear force. The reason for the apparent lack of effect in the current study is not clear. Further to this a plot of the mean shear force for each sample against the change in length is shown in Figure 32 for each ageing period. There is a tendency for the response to decline with increasing stretch, but this was not significant. The graph also shows that a wide range in shear force can be found for the same level of stretch as found in previous studies.

Table 35: Predicted shear force means (N) and standard errors (s.e.) for stretch and ageing treatments.

Treatment	Shear force (N) G2 Tenderometer					
	0 day			14 day		
Control	81.9	*(10.2)*	c	54.4	*(6.8)*	a
Stretch	76.3	*(9.5)*	c	65.6	*(8.3)*	b

Means having a following letter different are significantly different ($P < 0.05$)

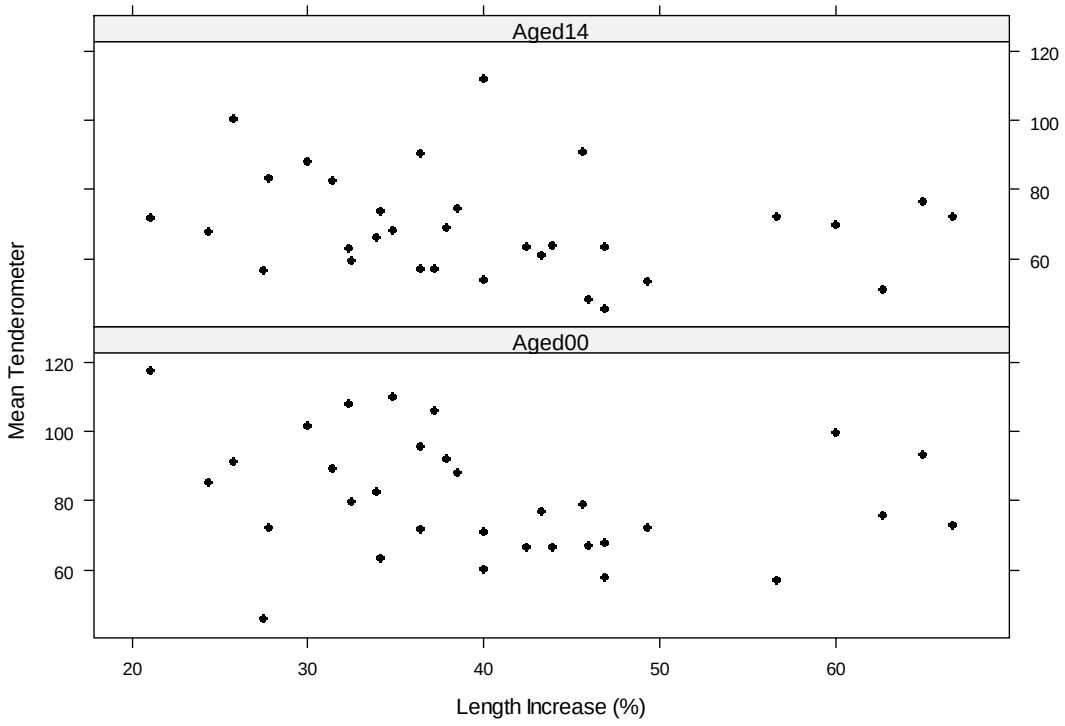

Figure 32: Plot of mean tenderometer results (N) against the change in length due to stretching according to aging period.

Cooking and thaw loss (Table 36), were both significantly (P < 0.05) reduced by stretching. Cooking loss increased significantly (P < 0.05) due to ageing. Thaw loss is important because it negatively affects the retail presentation/purchaser acceptability of the product, by making the product unsightly and reducing saleable weight (Payne, et al., 1998). Cooking loss is viewed unfavourably by consumers as it represents a loss of product content, juiciness and tenderness (Barbera & Tassone, 2006). Stretching, in this study had a positive impact on thaw and cooking loss.

Table 36: Predicted cooking loss % and thaw loss % and standards errors (s.e.) for stretch and ageing treatments.

Treatment	Cooking loss %					
	0 day			14 day		
Control	22.0	*(0.44)*	b	25.5	*(0.44)*	c
Stretch	20.2	*(0.44)*	a	22.4	*(0.44)*	b
	Thaw loss %					
Control	11.3	*(0.55)*	b			
Stretch	9.7	*(0.55)*	a			

Means having a following letter different within a test are significantly different (P < 0.05).

The predicted means and standard errors for lightness (L^*), redness (a^*) and yellowness (b^*) for fresh colour are shown in Table 37. It is evident that ageing has a significant effect on colour

parameters. Stretching significantly increased both the redness and the yellowness in the 0 day aged samples and reduced the yellowness in the 14 day aged samples.

Table 37: Predicted means and standard errors (s.e.) for colour parameters *L*, a* and b measured on a fresh surface.**

Treatment	0 day				14 day				Av s.e.
	Control		Stretch		Control		Stretch		
L*	38.1	ab	37.8	a	38.8	c	38.7	bc	*(0.43)*
a*	17.0	a	18.0	b	19.0	c	18.7	c	*(0.25)*
b*	-2.25	a	-1.82	b	0.35	d	-0.33	c	*(0.23)*

Means having a following letter different within a row are significantly different ($P < 0.05$).

The predicted means and standard errors for lightness (*L**), redness (*a**), yellowness (*b**) and brownness (ratio 630/580nm) measured with the Hunter Lab meter over 72 hours of retail display are presented in Table 38. Ageing significantly ($P < 0.05$) affected lightness after 3 days retail display, with the 14 day aged values being higher than the 0 day aged values. There was a significant ($P < 0.05$) reduction in redness after 3 days retail display as opposed to freshly displayed samples regardless of treatment. Ageing significantly increased redness for fresh displayed samples.

After 3 days display the 0 day aged stretch samples were significantly redder than the control samples, but the 14 day stretch samples were significantly less red than the control samples. Time on display significantly reduced yellowness in the 14 day aged samples, with the stretch treatment resulting in a further significant reduction in yellowness after 3 days on display. Ageing had a significant effect on the freshly displayed samples, with the 14 day aged samples being more yellow than the 0 day aged samples. Time on display, regardless of treatment, negatively impacted on the consumer acceptability of the meat with all samples being significantly browner after 3 days on retail display. Ageing had a positive influence on the metmyoglobin levels with the fresh display samples being less brown at 14 days ageing, but there was no benefit after 3 days on display.

Table 38: Predicted means and standard errors (s.e.) for each stretch and ageing treatment over display time for colour samples including *L*, a*, b and ratio 630/580µm values.**

		0 day						14 day					
Treatment	**Time (hours)**	**Control**			**Stretch**			**Control**			**Stretch**		
L*													
	0	29.0	*(1.04)*	a	28.6	*(1.04)*	a	31.1	*(1.04)*	ac	30.0	*(1.04)*	a
	72	29.9	*(1.04)*	a	29.1	*(1.04)*	a	33.3	*(1.04)*	b	33.4	*(1.04)*	bc
a*													
	0	19.9	*(0.58)*	de	21.1	*(0.58)*	e	23.3	*(0.58)*	f	23.5	*(0.58)*	f
	72	15.9	*(0.65)*	a	17.5	*(0.65)*	bc	18.5	*(0.65)*	cd	16.1	*(0.65)*	ab
b*													
	0	18.6	*(0.86)*	ab	19.2	*(0.86)*	b	22.1	*(0.86)*	c	22.1	*(0.86)*	c
	72	18.2	*(0.85)*	ab	19.2	*(0.85)*	b	18.3	*(0.85)*	b	16.7	*(0.85)*	a
Ratio 630/580nm													
	0	8.0	*(0.46)*	d	8.7	*(0.50)*	d	10.5	*(0.60)*	e	11.0	*(0.63)*	e
	72	3.7	*(0.23)*	ab	4.3	*(0.26)*	bc	4.7	*(0.28)*	c	3.6	*(0.22)*	a

Means having a following letter different within a colour parameter are significantly different ($P < 0.05$).

The decision by consumers to purchase meat is influenced by meat colour more than any other trait, because colour is considered an indicator of freshness (Mancini & Hunt, 2005). Meat on retail display will begin to brown within 1–7 days and retailers often price discount red meat after 2 days on display (Jacob, et al., 2007). This is at significant cost to industry. Here ageing and time on display affected the colour of the meat, with stretch treatment having little effect. In previous work with beef topsides Toohey, Kerr, van de Ven, & Hopkins (2010f) (Section 2.1.2.1) found that an average stretch of 52% did confer some benefit in terms of redness and brownness over topsides stretched 41 or 34%, but this disappeared after a period of display. Overall this indicates that stretching, as a value add process, will not impact on colour significantly and will not impact on consumer perceptions of colour in their purchase decision.

2.1.2.4 Experiment 8: The effect of SmartStretch™ on hot boned beef striploin (m. longissimus lumborum)

Introduction

Hot-boning of beef has many financial advantages to the beef processing industry. Savings can be made primarily by reduction in storage, refrigeration and transport costs as compared to cold-boned beef (Pisula & Tyburcy, 1996). There is however, a negative perception of hot-boning on the consumer acceptance of the product. White, et al. (2006) found that hot-boning of beef resulted in both higher shear force and poorer sensory tenderness scores. Stretching pre-*rigor* of hot-boned beef striploins (Toohey, et al., 2009b), sheep meat topsides (Toohey, et al., 2008c; Section 2.1.1.1) and sheep meat legs (Toohey, et al., 2009a; Section 2.1.1.2), using the same technology as this study in all cases, resulted in a significant reduction in shear force, suggesting that stretching of hot-boned primals results in improved tenderness. In the previous study where pre-*rigor* of hot-boned beef striploins were subjected to SmartStretch™ treatment (Toohey, et al., 2009b) the level of tenderness improvement was similar to the use of tenderstretching, but the cattle used were young

prime cattle. Given the equivocal results for hot boned topsides and cuberolls taken from cull cows (Sections 2.1.2.1, 2.1.2.2 and 2.1.2.3) an experiment was undertaken to establish whether the same improvement evident in striploins from young cattle could be replicated in striploins from cull cows.

Materials and methods

Hot boned striploins (Anonymous, 2005; HAM 2140) were removed from 40 cow carcasses from both sides of the carcass at a commercial hot boning abattoir. Each striploin was randomly allocated to either stretch treatment or control within a carcase. Irrespective of treatment samples were cut to similar dimensions with an average circumference of 30 cm. The striploin muscles allocated to the SmartStretch™ treatment were ejected from the SmartStretch™ machine into the packaging unit with a circumference of 24 cm (ring diameter 75mm, using 70mm diameter (110mm layflat) packaging). Then each sample (stretch and control) was portioned into two sub-samples (cranial or caudal) which were randomly allocated to either ageing for 0 or 14 days. Samples were also allocated to one of ten cooking batches for shear force testing.

Initial pH and temperature, shear force, cooking loss, sarcomere length, final pH, thaw loss, fresh colour and retail colour were assessed. Refer to section 2.1.2.1 for further detail on methodology.

Statistical analysis

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) were used to analyse the data.

The model fitted for initial pH, initial temperature, purge %, thaw loss % and sarcomere length was:

Y = constant + stretch treatment + **animal** + **error**

The model fitted for final pH and fresh colour (*L**, *a** and *b**) on 14 day aged cuts measured using a Minolta CR400 was:

Y = constant + ageing + (stretch treatment x ageing) + **animal** + **(animal x stretch treatment)** + **error**

The model fitted for shear force using initial pH as a covariate was:

logY = constant + ageing + (stretch treatment x ageing) + **animal** + **(animal x stretch treatment)** + **portion** + **cooking date** + **cook batch** + **error**
The model fitted for cooking loss % was:

Y = constant + ageing + (stretch treatment x ageing) + **animal** + **(animal x stretch treatment)** + **cooking date** + **cook batch** + **error**

The model fitted for colour measurements, final *L**, final *a**, final *b** and final ratio was:

Y = constant + days on display + ageing + stretch treatment + (stretch treatment x ageing) + (ageing x days on display) + (treatment x days on display) + (ageing x stretch treatment x days on display) + (days on display)^2 + (ageing x (days on display)^2) + (treatment x (days on display)^2) + (ageing x stretch treatment x (days on display)^2) + **test date** + **(stretch treatment x ageing x measurement)** + **(random linear deviations within days for each sample x ageing and stretch treatment)** + **error**

The terms in bold/italic were fitted as independent random effects and the model allowed for error variation.

Results and Discussion

The characteristics of the beef striploins used in this experiment are shown in Table 39, with the predicted means and average standard error for initial pH, initial temperature and sarcomere length, as well as the mean actual percentage length increase and percentage circumference decrease (taken at three points along the muscle) for each treatment.

Table 39: Predicted means (av s.e.) of initial pH, initial temperature and sarcomere length and actual means (av s.e.) of % increase in length and % decrease in cicumference for the stretch and control treatments.

Treatment	Control		Stretch	
Initial pH	6.2	*(0.03)*	6.2	*(0.03)*
Final pH – 0 day	5.64	*(0.02)*	5.63	*(0.02)*
- 14 day	5.69	*(0.02)*	5.67	*(0.02)*
Initial temperature (°C)	29.7	*(0.41)*	29.9	*(0.41)*
Increase in length (%)			16.8	*(1.56)*
Decrease in circumference 1 (%)			26.2	*(0.76)*
Decrease in circumference 2 (%)			24.0	*(0.74)*
Decrease in circumference 3 (%)			21.8	*(1.09)*
Sarcomere (μm)	1.8	*(0.04)*	1.7	*(0.04)*

Means having a following letter different in a row are significantly different (P<0.05).

As expected there was no significant difference between the initial pH and initial temperature for each treatment. The pH of the muscles shows that they were still pre *rigor* when stretched, but the initial temperature shows the striploins had cooled significantly since death. No changes in length or circumference are shown for the control as this was not stretched and there were no changes.

There was no significant difference in sarcomere length between the stretch and control treatments, regardless of the 16.8% increase in length gained by stretching. Stretching increased the variability in sarcomere lengths, as shown by the box plot in Figure 33.

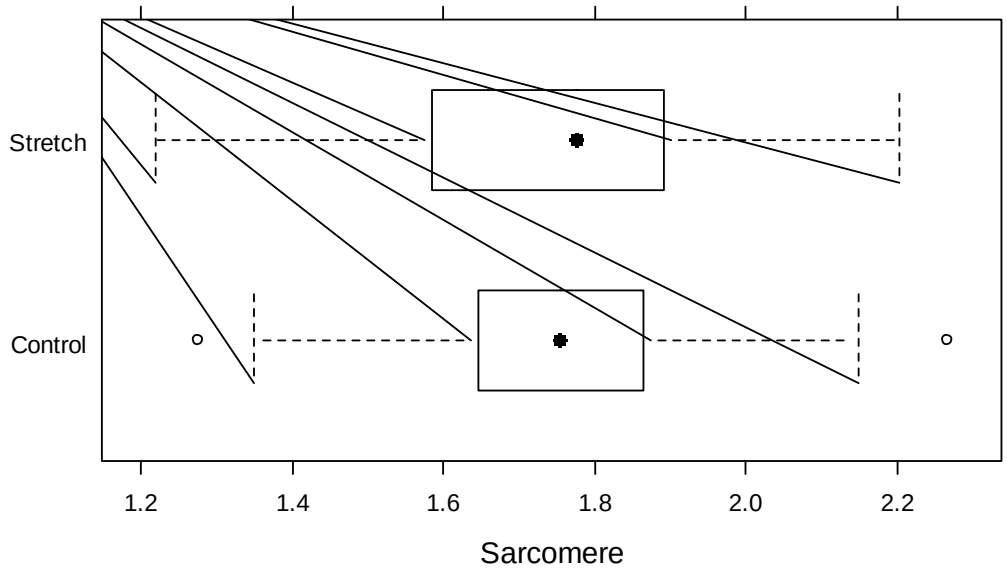

Figure 33: Box plot of sarcomere length for stretch and control treatments.

Shear force predicted means and standard errors are shown in Table 40, with initial pH as a significant covariate ($P < 0.05$) for 0 day aged samples. There was a significant reduction in shear force ($P < 0.05$) resulting from ageing. There was also a significant reduction in shear force ($P < 0.05$) due to stretching in the 0 day aged samples, but this effect had been nullified by ageing for 14 days although only just ($P = 0.07$). This result was similar to the results of Toohey, et al. (2009a) who found that shear force was significantly different between the control and stretched samples using the same technology at 0 days ageing, but not significantly different after 5 days ageing for *biceps* the m. *semimembranosus* in sheep (Section 2.1.1.2).

There was a tenderness benefit in unaged striploins resulting from stretching. Considering that the benefits from hot boning are based around the reduction in labour, time, storage space and turnover time of the product (Pisula & Tyburcy, 1996) this significant reduction in shear force gained from stretching may facilitate the marketing of this product. It should be noted though that the stretched product was still unacceptably tough after freezing on day 0. Perry, Thompson, Hwang, Butchers, & Egan (2001b) found that the relationship between tenderness and shear force tended to plateau at higher shear forces. Indeed Destefanis, Brugiapaglia, Barge, & Dal Molin (2008) suggested that a Warner-Bratzler shear force value exceeding 52.7N is unacceptable to consumers. Work done by Hopkins, Toohey, Kerr, & van de Ven (2011) suggested that the Warner-Bratzler shear force was ≈ 0.8 of the G2 Tenderometer shear force. Thus the figure suggested by Destefanis, et al. (2008) would equate to approximately 63N shear force as measured by the G2 Tenderometer. By comparison Rosenvold, et al. (2008) used a tenderometer value of 60N as the cut-off for consumer acceptability. In the current study ageing has reduced the shear force to a level that consumers would find partially acceptable, with a hint of stretching conferring a beneficial effect. In the previous work hot boned cube rolls after 14 days of ageing had shear force values less than 40N (Section 2.1.2.2; Table 29) and topsides after 7 days values around 50N (Section 2.1.2.1; Table 25) measured with a Lloyd Texture analyser so on the G2 scale the values would be 48 and 60N respectively and similar to those for the striploin in this study after 14 days of ageing. It is of interest that stretching did not result in a significant difference in sarcomere length, but there was some

indication that as the degree of stretch increased shear force declined for 0 day aged product (Figure 34).

Table 40: Predicted shear force means (N) and standard errors (s.e.) for stretch and ageing treatments using initial pH as a covariate (6.22).

Treatment	Shear force (N) G2 Tenderometer					
	0 day			14 day		
Control	98.8	*(6.3)*	c	56.5	*(3.6)*	a
Stretch	84.7	*(5.5)*	b	51.5	*(3.3)*	a

Means having a following letter different are significantly different ($P < 0.05$).

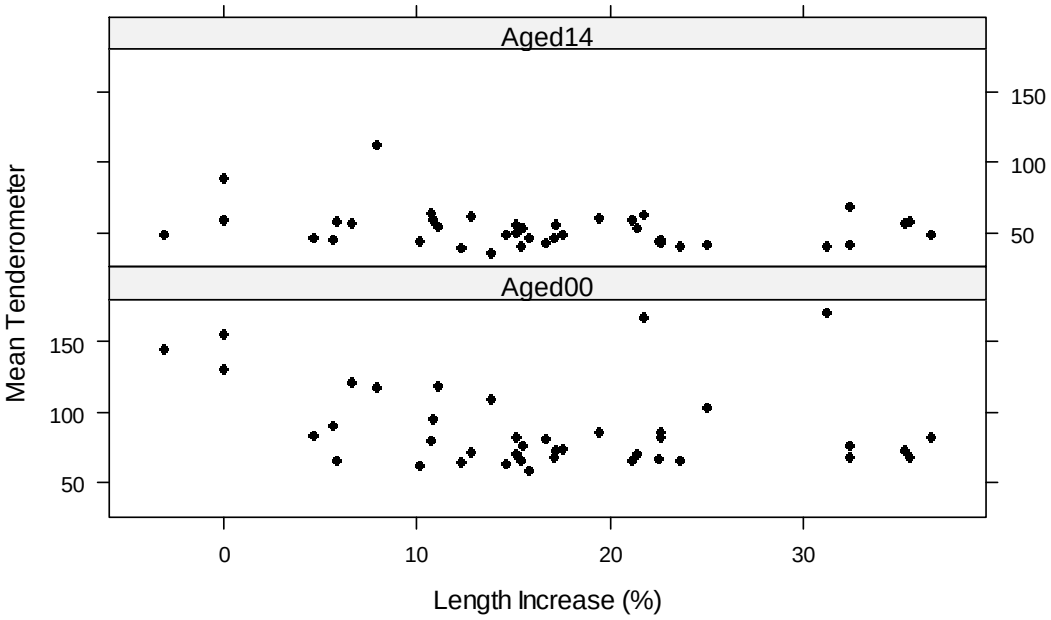

Figure 34. Plot of mean tenderometer results (N) against the change in length due to stretching according to ageing period.

Results for cooking and thaw loss are presented in Table 41. This shows that the cooking loss was significantly higher ($P < 0.001$) in the 14 day aged stretch treatment than the control. This is contrary to the results for the topside (Section 2.1.2.3) where stretching resulted in a significant reduction in cooking and thaw loss.

Table 41: Predicted cooking loss % and thaw loss % and standards errors (s.e.) for stretch and ageing treatments.

Treatment	Cooking loss %					
	0 day			14 day		
Control	22.1	*(0.81)*	ab	22.5	*(0.80)*	b
Stretch	21.0	*(0.81)*	a	24.6	*(0.80)*	c
	Thaw loss %					
Control	10.8	*(0.50)*				
Stretch	10.9	*(0.50)*				

Means having a following letter different within a test are significantly different ($P < 0.05$).

The predicted means and standard errors for fresh colour are presented in Table 42. In this study ageing had an effect on fresh colour traits, while stretching did not.

Table 42: Predicted means and standard errors (s.e.) for each stretch treatment of colour of a fresh surface on samples including L*, a* and b*.

Treatment	0 day				s.e.	14 day				s.e.
	Control		Stretch			Control		Stretch		
L*	37.8	a	38.3	ab	*(0.35)*	38.3	ab	38.5	b	*(0.34)*
a*	15.9	a	16.2	a	*(0.26)*	17.8	b	17.7	b	*(0.27)*
b*	-3.0	a	-2.7	a	*(0.23)*	-0.7	b	-1.0	b	*(0.22)*

Means having a following letter different within a colour parameter are significantly different ($P<0.05$)

The predicted means and standard errors for lightness (*L**), redness (*a**), yellowness (*b**) and brownness (ratio 630/580nm) are presented in Table 43. Lightness was significantly ($P < 0.05$) higher in 14 day aged samples after 3 days on retail display, regardless of stretch treatment as found in section 2.1.2.3. Redness was significantly ($P < 0.05$) reduced by stretching only in the 14 day aged samples after 3 days on retail display. Days on retail display significantly increased the brownness of the samples, more so in stretched meat after 3 days of display.

The decision by consumers to purchase meat is influenced by meat colour more than any other trait, because colour is considered an indicator of freshness (Mancini & Hunt, 2005). Meat on retail display will begin to brown within 1 – 7 days and retailers often price discount red meat after 2 days on display (Jacob, et al., 2007). This is at great cost to industry. Here ageing and time on display had a small effect the colour of the meat. Stretch treatment had a significant effect on the colour of aged meat, especially as the length of time on display increased. Khliji, et al. (2010) suggested that a 630/580 ratio of less than 3.3 means that meat is unacceptably brown to consumers, while a ratio of 6.3 is required to have 95% confidence that a randomly selected consumer will find the meat acceptable. With a ratio of 3.5 the 14 day aged stretch treatment would be considered unacceptably brown to most consumers, while the equivalent control would be considered acceptable to most consumers. It can be concluded that, in this study, stretching reduced the colour acceptability of the meat which is contrary to the previous results of other studies.

Table 43: Predicted means and standard errors (s.e.) for each stretch and ageing treatment over display time for colour samples including L*, a*, b* and ratio 630/580µm values.

Treatment	Time (hours)	0 day						14 day					
		Control			Stretch			Control			Stretch		
L*													
	0	28.6	*(0.97)*	a	29.1	*(0.97)*	ab	30.7	*(0.87)*	ab	31.2	*(0.87)*	b
	72	29.8	*(0.98)*	ab	30.1	*(0.98)*	ab	33.8	*(0.88)*	c	33.7	*(0.88)*	c
a*													
	0	18.7	*(1.51)*	abcd	19.3	*(1.51)*	abcd	22.1	*(1.50)*	d	21.4	*(1.51)*	cd
	72	17.0	*(1.58)*	ab	17.1	*(1.58)*	abc	20.7	*(1.58)*	bcd	15.6	*(1.57)*	a
b*													
	0	16.8	*(2.00)*	ab	16.9	*(2.00)*	ab	20.0	*(1.99)*	ab	20.0	*(1.99)*	ab
	72	18.2	*(2.01)*	ab	18.0	*(2.01)*	ab	18.1	*(2.01)*	b	15.7	*(2.00)*	a
Ratio 630/580nm													
	0	7.3	*(1.00)*	cd	7.3	*(1.00)*	cd	9.5	*(1.28)*	d	8.8	*(1.19)*	d
	72	4.4	*(0.64)*	ab	4.4	*(0.63)*	ab	5.8	*(0.83)*	bc	3.5	*(0.50)*	a

Means having a following letter different within a colour parameter are significantly different ($P < 0.05$).

2.1.2.5 Experiment 9: The effect of a meat stretching device on the tenderness of hot-boned beef topsides (m. semimembranosus) and rostbiffs (m. gluteus medius)

Introduction

Hot-boning of beef has many financial advantages to the beef processing industry. Savings can be made primarily by reduction in storage, refrigeration and transport costs as compared to cold-boned beef (Pisula & Tyburcy, 1996). There is however, a negative perception of hot-boning on the consumer acceptance of the product. White, et al. (2006) found that hot-boning of beef resulted in both higher shear force and poorer sensory tenderness scores. Stretching pre-*rigor* of hot-boned beef striploins (Toohey, et al., 2009b), sheep meat topsides (Toohey, et al., 2008c; Section 2.1.1.1) and sheep meat legs (Toohey, et al., 2009a; Section 2.1.1.2), using the same technology as this study in all cases, resulted in a significant reduction in shear force, suggesting that stretching of hot-boned primals results in improved tenderness. This tenderness assessment was based on the use of an objective measure using either the Tenderometer or the Lloyd, with no data from sensory testing. In this study tenderness and consumer acceptance of stretched and unstretched beef topsides and rostbiffs were compared using SmartStretch™ technology.

Materials and methods

Six female cattle with eight permanent incisors and with carcase weights between 175-265kg were used for the experiment. The carcases were hot-boned under the normal operations of the abattoir, involving electrical stimulation of the carcase after death and the hot-boning of the primals within an hour of death. Twelve topsides (Anonymous, 2005, HAM 2000) and 12 rostbiffs (Anonymous, 2005, HAM 2110) were removed on the chain and the fat, sinew and epimysium removed. The m. *adductor* was removed from the topside and discarded. The remaining m. *semimembranosus* was then trimmed to 17cm wide and the pairs of samples from each animal were allocated at random to two treatments: i) vacuum packed control or ii) SmartStretch™ and packaged into 95mm diameter (150mm layflat) packaging with a 105mm diameter unit ring. The rostbiffs were likewise allocated to

the control or SmartStretch™ treatments. The samples were frozen (~-22ºC in a plate freezer) within 2 hours of death and stored frozen until sampling.

Shearforce using the G2 Tenderometer was assessed. Refer to section 2.1.2.1 for the G2 shear force methodology.

Figure 6: Frozen stretched and control samples labeled at the cranial (G2 Tenderometer) and caudal (Sensory assessment) ends

The length of the topsides and the rostbiffs was measured and those that were stretched were re-measured after stretching. pH and temperature measurements were taken at the caudal end of each primal within 1.5 hours of death and prior to treatment. Muscle pH was measured as previously described (see Section 2.1.1.1).

The samples were split and the caudal portion of each sample used for sensory assessment in a method adapted from Gee & Ross (2006). The samples were defrosted in a refrigerator for 36 hours and three 15mm slices of each sample taken across the primal. Two sensory sessions, one for each cut (topside and rostbiff), were conducted on two consecutive days, with twenty tasters (n = 20) used for each session. Some of the tasters were common to both sessions. Each session was conducted over a 75 minute interval during which time each taster tasted six portions of meat, one from each of six cook batches. Each cook batch comprised five slices, one from each of five of the twelve samples. Slices were cooked at ~220ºC for between 5 and 6 minutes to a medium degree of doneness on a clam-grill. Following cooking each slice was cut into four portions and the twenty portions per cook batch were allocated to the 20 tasters for scoring, one portion per taster. Tasters scored each sample for tenderness, flavour and juiciness and provided an overall liking score, all on a 0-100 scale. Consumers were also asked to give a regard score for each sample – unsatisfactory, good every day, better than every day and premium quality. The allocation of samples to cook batch and subsequent allocation of portions to taster was designed to balance the treatments (Control and Stretched) and samples to cook batches and to tasters and also to balance any carry over treatment effects from the previous portion tasted. The design for each session was generated separately using DiGGer (Coombes, 2009).

Figure 36: One of the sensory testing participants at Orange Agricultural Institute.

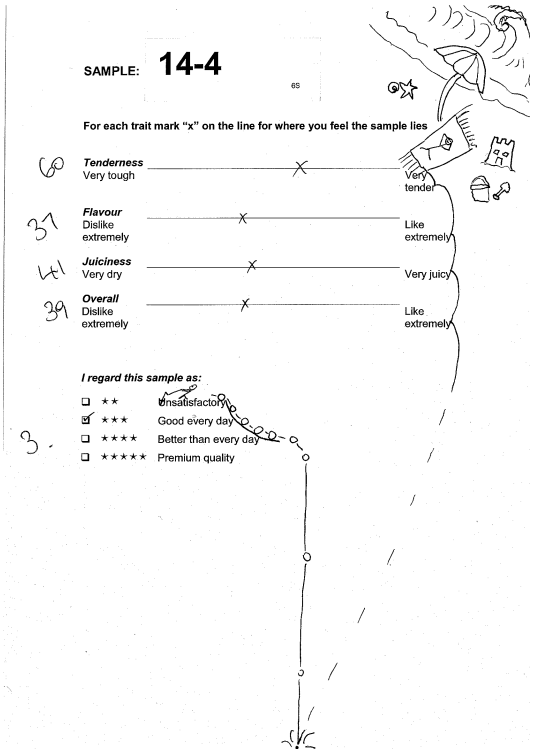

Figure 37: Completed sensory test survey sheet from a good humoured participant.

Statistical analysis

Linear mixed model methods were used to analyse, separately, the sensory data for the 2 primals. For analysis of each of response variables, tenderness, flavour, juiciness and overall liking, the model included as fixed effects the stretch treatment of the current and previous sample tasted and the interaction between these two factors. Animal, sample, cook batch, interaction between sample and cook batch, position on the grill during cooking and taster were included as random effects.

The model for shear force included the cooking loss, the primal, the stretch treatment and the interaction between the primal and stretch treatment as fixed effects and animal, interaction between animal and primal and samples within primal as random effects. Cooking loss was included as a co-variate. Differences between predicted means were based on the LSD. All models were fitted using the statistical package ASReml (Gilmour, et al., 2006), which uses REML based methods and incorporates adjusted Wald statistics (Kenward & Roger, 1997) to test significance of fixed effects under small sample interference.

Results and Discussion

There was no significant difference between the control and stretch treatment for either primal from the sensory analyses. The predicted means and average standard errors for each treatment on each muscle are given in Table 44. As expected for any tests involving people, the results were highly variable. Variation across samples and the taster were the two largest sources of variation, whilst cook batch and cooking position on the grill contributed little to the variation. There was a lot of unexplained variation in the responses.

On average, the initial pH of the samples collected was 5.7 at 36.9ºC, suggesting that the muscles were close to *rigor* at the time of stretching. Electrical stimulation is used to reduce pH rapidly during chilling, thereby reducing cold induced shortening, enabling the freezing of primals in a hot boning plant soon after boning (Hwang, et al., 2003a). Muscles close to *rigor* may not stretch significantly as actomyosin bonds that are formed at *rigor* prevent filament movement (Hopkins & Thompson, 2002). Despite this there was an average 21% increase in length achieved with stretching across primals.

Table 44: Predicted means (av s.e.) of tenderness, flavour, juiciness and overall scores for each treatment as related to the previous treatment.

		Topside							
Previous Treatment	**Treatment**	**Tenderness**		**Flavour**		**Juiciness**		**Overall**	
Control	Control	38.2	*(7.5)*	52.1	*(5.3)*	53.4	*(8.0)*	46.2	*(6.7)*
Control	Stretch	36.6	*(7.0)*	47.7	*(4.6)*	46.1	*(7.4)*	44.4	*(6.1)*
None	Control	19.9	*(9.3)*	42.6	*(6.9)*	48.3	*(10.9)*	22.2	*(8.4)*
None	Stretch	25.5	*(8.2)*	47.3	*(6.0)*	56.6	*(9.9)*	38.2	*(7.3)*
Stretch	Control	37.8	*(7.0)*	56.6	*(4.6)*	50.5	*(7.4)*	48.3	*(6.1)*
Stretch	Stretch	33.4	*(7.8)*	50.0	*(5.7)*	48.3	*(8.3)*	42.8	*(7.0)*
	Mean	31.9	*(7.8)*	49.4	*(5.5)*	50.5	*(8.6)*	40.3	*(6.9)*
					Rostbiff				
Control	Control	37.6	*(7.8)*	48.4	*(5.6)*	45.9	*(6.8)*	44.7	*(7.0)*
Control	Stretch	50.7	*(7.2)*	50.6	*(4.9)*	50.7	*(6.2)*	50.7	*(6.5)*
None	Control	33.2	*(10.4)*	37.5	*(7.2)*	36.8	*(10.1)*	34.3	*(8.7)*
None	Stretch	34.8	*(9.4)*	50.3	*(6.4)*	36.7	*(8.9)*	43.2	*(7.7)*
Stretch	Control	37.2	*(7.2)*	44.8	*(5.0)*	44.8	*(6.2)*	39.7	*(6.5)*
Stretch	Stretch	50.1	*(8.1)*	49.0	*(6.0)*	46.4	*(7.3)*	52.2	*(7.3)*
	Mean	40.6	*(8.3)*	46.7	*(5.8)*	43.6	*(7.6)*	44.1	*(7.3)*

There was no significant difference in the responses to the statement “I regard this sample as..”. The number of responses for each cut and treatment are presented in Table 45. Of interest are the absolute values for the rostbiff stretch samples with two thirds of the responses indicating that this cut was “good every day” and over eighty percent of responses being favourable. This is in stark contrast with the other three cuts and treatments where almost half of all responses regarded the sample as unsatisfactory. This suggests that there could be a sensory benefit in the rostbiff from stretching. This needs to be validated by further study and a larger sample set.

Table 45: Number of responses for each cut and treatment for “I regard this sample as..”

	Unsatisfactory	Good every day	Better than every day	Premium quality
Topside-Control	27	24	7	1
Topside-Stretch	26	27	6	0
Rostbiff-Control	28	25	7	0
Rostbiff-Stretch	11	39	8	1

The shear force results showed that there was no significant reduction in the shear force in the rostbiff resulting from the stretch treatment when cooking loss (average = 18.4%) was included as a covariate, although there was a large absolute difference in the predicted means. There was also no significant reduction in the shear force in the topside resulting from the same stretch treatment, as found in previously for hot boned beef (Toohey, et al., 2010f; Section 2.1.2.3). The predicted means and average standard errors for shear force are shown in Table 46.

Table 46: Predicted mean (av s.e.) shear force (N),

measured using the G2 Tenderometer, according to treatment.

Treatment	Topside			Rostbiff		
Control	67.3	*(2.6)*	ab	83.1	*(9.6)*	ab
Stretch	73.0	*(2.7)*	b	64.4	*(2.6)*	a

Means without a following letter in common are significantly different P = 0.05.

Perry, et al. (2001b) found that the relationship between tenderness and shear force tended to plateau at higher shear forces. Indeed Destefanis, et al. (2008) suggested that a Warner-Bratzler shear force value exceeding 52.7N is unacceptable to consumers. Work done by Hopkins, et al. (2011) suggests that the Warner-Bratzler shear force is ≈ 0.8 of the G2 Tenderometer shear force. This figure would equate to approximately 66N shear force as measured by the G2 Tenderometer. Rosenvold, et al. (2008) used a tenderometer value of 60N as the cutoff for consumer acceptability. It is, therefore, not surprising that there was no significant difference found in the sensory tenderness scores with the very tough samples used in this study, given the results of Perry, et al. (2001b) which suggest that with very tough meat sensory testers lose the powers of discrimination. In comparison shear force measurements do provide a higher level of discrimination. It is proposed that, based on the shear force results for the rostbiff, a larger sample size may have detected a significant difference between treatments and if samples from better quality cattle were used then this would bring tenderness levels back to a zone where consumer discrimination was more likely.

Thompson (2002) found that a benefit can be gained through stretching by a reduction in the variation in consumer sensory responses, suggesting a less variable product is gained from stretching. A significant ($P < 0.05$) reduction in the shear force variability was gained by stretching the rostbiff, with the variance component of shear force decreasing from 357.0 (s.e. ± 68.7) to 104.0

(s.e. ± 11.5) with stretching. This reduction in variance is presented in Figure 38. This shows that the range in shear force for the rostbiff has been halved by stretching. Such a reduction lessens the likelihood that consumers will be encounter very tough meat. Reducing variability in the muscle improves consumer confidence in the eating quality of the product.

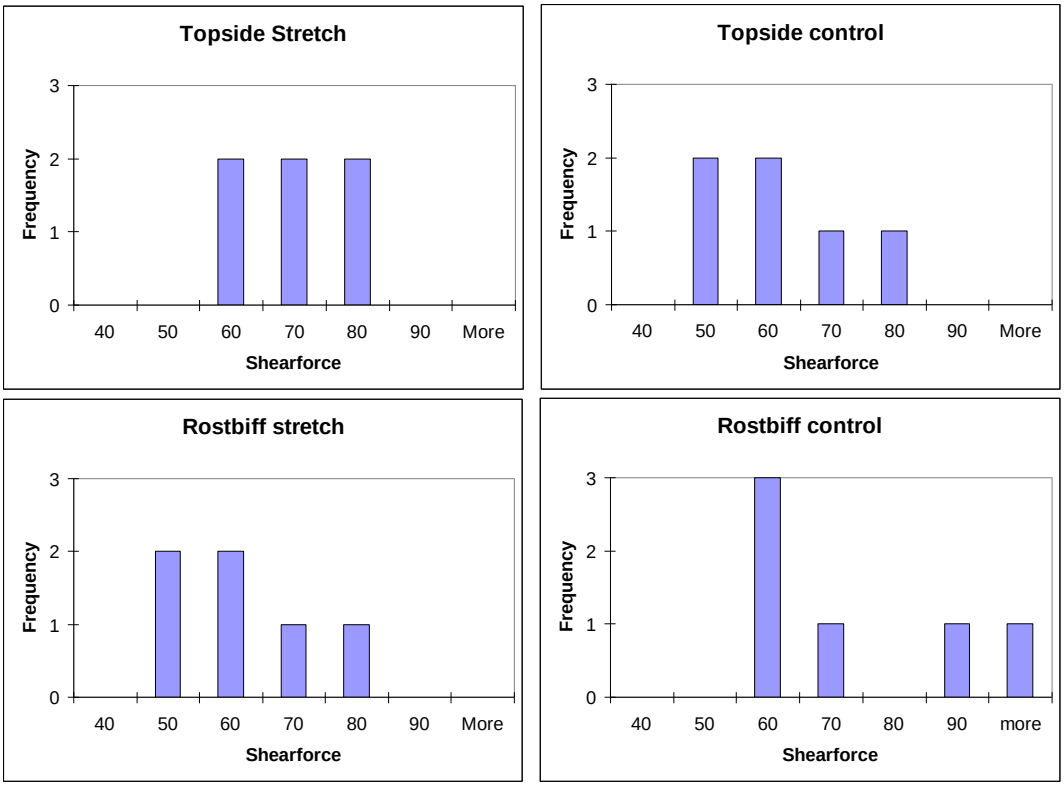

Figure 38: Stretch applied versus shear force measured with the G2 tenderometer for the topside (top) and rostbiff (above) for the control and stretched samples.

The spread of the data showed that there was a poor relationship between the increase in length of a cut and shear force particularly in the rostbiff, but there were too few data points for meaningful analysis of this relationship.

2.1.2.6 Experiment 10: The effect of SmartStretch™ on the tenderness of hot-boned beef rostbiffs (m. gluteus medius)

Introduction

Hot-boning of beef has many financial advantages to the beef processing industry. Savings can be made primarily by reduction in storage, refrigeration and transport costs as compared to cold-boned beef (Pisula & Tyburcy, 1996). There is however, a negative perception of hot-boning on the consumer acceptance of the product. White, et al. (2006) found that hot-boning of beef resulted in both higher shear force and poorer sensory tenderness scores. Stretching pre-*rigor* of hot-boned beef striploins (Toohey, et al., 2009b; Section 2.1.2.4), sheep meat topsides (Toohey, et al., 2008c; Sections 2.1.1.1) and section 2.1.1.4 and sheep meat legs (Toohey, et al., 2009a; Section 2.1.1.2), using the same SmartStretch™ technology (Taylor & Hopkins, 2011) in all cases, resulted in a significant reduction in shear force, suggesting that stretching of hot-boned primals can improve tenderness.

Experiments conducted on cast for age hot-boned beef (Sections 2.1.2.1 to 2.1.2.5) produced disappointing results. Initially the lack of a tenderness response resulting from stretching was attributed to the lack of a control in the experimental design (Section 2.1.2.1), but it became apparent that no tenderness benefit could be gained by stretching beef typically hot-boned in Australia. An early experiment by Geesink & Thompson (2008) found that SmartStretch™ (called the "Boa" at that time) compared favourably with Tenderstretch and Superstretch (Tenderstretch with weights added). That experiment had been conducted on cattle with a maximum dentition score of 2. In a previous study, Taylor, Hopkins, & van de Ven (2010) (Section 2.1.2.5) the tenderness of SmartStretch™ hot-boned topsides and rostbiffs from aged cattle was examined against an untreated control. Although the improved tenderness of the stretched rostbiff was not confirmed the results suggested that this cut was a candidate for improved tenderness when the technology's effectiveness was re-examined using younger animals as in Toohey, et al. (2009b) (Section 2.4.3), where the study was conducted on striploins from equally young animals.

This study was an assessment of SmartStretch™ technology and its impact on hot-boned rostbiff sourced from cattle with a maximum dentition score of 2.

Materials and methods

Experimental design

Hot-boned rostbiffs were taken from 40 beef cattle with an average carcase weight of 270kg (208-380) and maximum dentition score of 2 in a commercial abattoir. The left and right sides were randomly assigned to a control or a stretch treatment and each sliced to reduce their size, so those assigned to stretching could fit into the SmartStretch™ technology. The stretch treatment rostbiffs were, then stretched and packaged into 95mm diameter tubular (150mm layflat) packaging using SmartStretch™ technology (Taylor & Hopkins, 2011; Section 2.1.4) within 20 minutes of death. The control rostbiffs were vacuum packaged. The cranial and caudal ends of each rostbiff were randomly assigned to one of two ageing treatments – nil and 8 days.

Initial pH and temperature

The initial muscle pH was measured using a glass combination pH probe (potassium chloride) Ionode intermediate junction pH electrode, TPS Pty Ltd, Brisbane, Queensland) attached to a data recording pH meter (TPS WP-80). Muscle temperature was measured using an ACE-AI368 Pocket Thermometer.

Length and circumference measurements

Descriptive measurements were taken of each sample – length at 3 points and circumference at 3 points on each muscle prior to treatment. One length measurement and 3 circumference measurements were taken immediately after treatment for the stretched samples.

Sampling procedures

The nil day ageing treatments were kept in a chiller (5 - 7°C) until freezing within 12 hours of death (-27°C) and remained frozen until testing. The 8 day samples were kept at 7°C until the end of the working day and then chilled at 1-5°C until being cut into subsamples, which were then placed in a freezer set at -22°C until testing. Subsamples for testing of shear force and sarcomere length were cut from frozen for the 0 day aged samples. Subsamples for testing of shear force and fresh colour were cut from the fresh 8 day aged samples and the shear force samples held frozen at -22°C until laboratory testing.

Refer to section 2.1.2.1 for further detail on experimental methodology.

Statistical analyses

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) were used to analyse the data.

The model fitted for initial pH, initial temperature, sarcomere length and purge loss % was:

Y = constant + treatment + **animal** + **error**

Sarcomere length originally had initial pH included as a covariate in the model, although this was removed from the model when regressions on initial pH were not significant.

The model fitted for shear force was:

Y = constant + treatment + ageing + (treatment x ageing) + initial pH + (initial pH x treatment) + (initial pH x ageing) + (initial pH x treatment x ageing) + **animal** + **(animal x side)** + **cook batch** + **error**

The model fitted for cooking loss % was:

Y = constant + treatment + ageing + (treatment x ageing) + **animal** + **(animal x side)** + **cook batch** + **error**

The model fitted for fresh colour measurements taken with a Minolta CR400 using Illuminant D-65 (*L**, *a** and *b**) was:

Y = constant + treatment + average final pH + (treatment x average final pH) + **animal + error**

The terms in bold were fitted as independent random effects.

Results and Discussion

The predicted means and standard errors for initial pH, final pH, initial temperature, sarcomere length and the changes in length and circumference for the control and stretch samples are shown in Table 47. The initial pH and temperature reveal that the samples were on average pre-*rigor* at the time of stretching, although there was a range in values. The final pH reveals that by the time the 0 day samples were fully frozen they had attained their final pH.

Table 47: Predicted means (av s.e.) and ranges of initial pH, final pH, initial temperature, sarcomere length, % increase in length and % decrease in circumference for the stretch and control treatments.

Treatment	Control			Stretch		
	Mean	*SE*	Range	Mean	*SE*	Range
Initial pH	6.06	*0.03*	5.8-6.4	6.10	*0.03*	5.8-6.4
Final pH – 0 day	5.55	*0.01*	5.4-5.8	5.54	*0.01*	5.4-5.8
- 8 day	5.56	*0.01*	5.5-5.8	5.55	*0.01*	5.5-5.7
Initial temperature (°C)	39.8	*0.13*	38.4-41.0	39.7	*0.13*	36.2-40.9
Increase in length (%)				34%	*1.93*	
Decrease in circumference (%)				34%	*0.57*	
Sarcomere (μm)	1.70	*0.03* a	1.2-2.0	1.92	*0.03* b	1.3-2.4

Means having a following letter different in a row are significantly different (*P*<0.05).

A 34% (Table 47) increase in rostbiff length resulted in a significant ($P < 0.05$) increase in sarcomere length and a significant ($P < 0.05$) reduction (20%) in 0 day shear force (Table 48). This was nullified by ageing, with the stretch and control shear force after 8 days ageing being not significantly ($P > 0.05$) different from each other, although they were significantly less ($P < 0.05$) than the 0 day aged samples. This result is similar in context to that found in sections 2.1.1.1 and 2.1.1.2 in sheep meat after 5 days of ageing and section 2.1.2.4 in cast for age beef after 14 days of ageing. Destefanis, et al. (2008) suggested that a Warner-Bratzler shear force value exceeding 52.7N is unacceptable to consumers, meaning the tenderness improvement gained from stretching in this study was not enough for stretching to replace ageing as has been suggested previously (Section 2.1.1.1).

Table 48: Predicted shear force means (N) and standard errors (s.e.) for stretch and ageing treatments using initial pH (6.08) as a covariate at 0 days ageing only (P < 0.05).

Treatment	Shear force (N) Lloyd					
	0 day			8 day		
Control	66.4	*1.84*	c	35.8	*1.83*	a
Stretch	53.3	*1.83*	b	33.6	*1.83*	a

Means having a following letter different are significantly different (*P*<0.05).

The variation in shearforce for the stretching and ageing treatments is shown in Figure 39. This graph shows that not only has the mean shear force been reduced by stretching, but the variation in shear force has also been reduced. This result means that the meat is not only more tender at 0 days ageing, it is also has a more uniform shear force than the unstretched control.

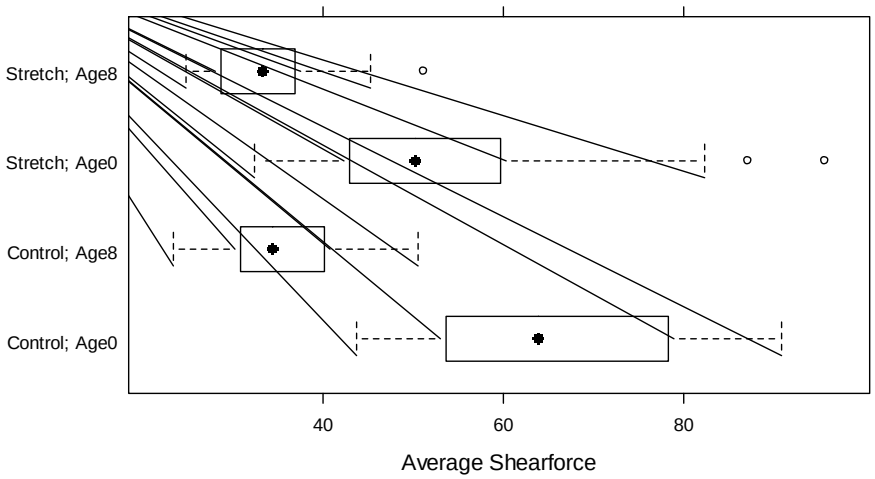

Figure 39: Variation in shear force (N) for stretch and control treatments and two ageing treatments.

Figure 40 is a plot of sarcomere versus the average shear force for the zero day aged samples. Adjusting for animal effects there is a significant negative correlation (r = -0.46, s.e. = 0.10) between sarcomere length and average shear force, meaning that as sarcomere length increases, shear force decreases.

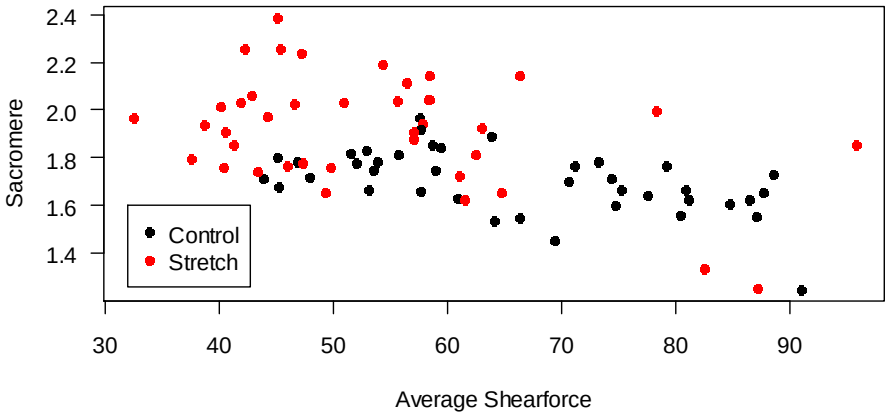

Figure 40: Sarcomere length (μm) versus average shear force (N) for rostbiff.

The predicted means for cooking loss and purge loss and their standard errors are shown in Table 49. Cooking loss was significantly ($P < 0.05$) reduced by stretching at 0 days ageing, although this positive result did not extend to the 8 day aged samples, where there was no significant ($P > 0.05$) difference in cooking loss between the control and stretched samples. In previous studies on sheep meat (Sections 2.1.1.1 and 2.1.1.3) and on beef (Section 2.1.2.3) stretch significantly ($P < 0.05$) reduced cooking loss at 0 days and after an ageing period. This is at odds with the results of Section 2.1.2.4 where cooking loss was significantly ($P < 0.05$) increased by stretching after 14 days ageing. Cooking loss is viewed unfavourably by consumers as it represents a loss of product content, juiciness and tenderness (Barbera & Tassone, 2006). Purge loss in this study was unaffected by stretching. Purge loss is important because it negatively affects the retail

presentation/purchaser acceptability of the product, by making the product unsightly and reducing saleable weight (Payne, et al., 1998).

Table 49: Predicted means for cooking loss % and purge loss % and standard errors (s.e.) for stretch and ageing treatments.

Treatment	Cooking loss %					
	0 day			8 day		
Control	21.0	0.40	b	23.2	0.40	c
Stretch	19.6	0.40	a	23.1	0.40	c
	Purge loss %					
Control				2.54	0.14	a
Stretch				2.23	0.14	a

Means having a following letter different within a test are significantly different (P<0.05).

Fresh colour, presented in Table 50, was measured on the 8 day aged samples. In this study stretching had no impact on the lightness (*L**), redness (*a**) or yellowness (*b**) of the rostbiffs. The lack of effect on fresh colour is unsurprising considering the lack of effect stretching has had on meat colour in previous beef experiments (Sections 2.1.2.1, 2.1.2.3 and 2.1.2.4).

Table 50: Predicted means and standard errors (s.e.) for each stretch treatment of colour of a fresh surface on samples including *L*, a and *b*.***

Treatment	8 day					
	Control		s.e.	Stretch		s.e.
L*	38.8	a	*0.25*	38.5	a	*0.25*
a*	22.1	a	*0.21*	22.0	a	*0.14*
b*	0.71	a	*0.24*	0.18	a	*0.23*

Means having a following letter different within a colour parameter are significantly different (P<0.05)

2.1.2.7 Overall discussion and conclusions

In Australia the hot-boning of beef is confined to the cast for age end of the market - older cows and bulls rather than the younger animals normally associated with table beef. There are only a small number of hot-boning beef plants. The experiments in this project were conducted in two hot-boning plants and in one cold-boning plant. Experiments 5, 7, and 8 were conducted at the EC Throsby plant in Singleton, NSW. HW Greenham and Sons plant at Tongala in Victoria was the location for Experiment 6 and for sample collection for Experiment 9. Finally Experiment 10 was conducted at the HW Greenham and Sons Pty Ltd plant at Smithton, Tasmania, where the Production Manager hot-boned the rostbiffs on the chain especially for this experiment.

In Experiment 5 (Section 2.1.2.1) it was found that increasing levels of stretch increased the length of the resultant primal significantly, but this had no significant effect on the sarcomere length, shear force, particle size or retail colour. With no baseline control to compare the results to, the minimum amount of stretch achieved (34%) was regarded as the upper limit for stretching, beyond which no further reductions in shear force would be achieved. No relationship was found between both the percentage increase in length and sarcomere length or shear force. Higher levels of stretch

resulted in less browning of the meat. It was concluded that SmartStretch™ technology had potential to improve the tenderness of hot boned SM and thus, add significant value to the topside. The evidence indicated that higher levels of stretch will produce meat that is more acceptable in terms of colour stability at least when initially displayed. This was considered an added bonus if the tenderness benefits of stretching cuts, like the topside could be validated.

This led to Experiment 6 (Section 2.1.2.2) involving the m. *longissimus lumborum* in the cube roll. Like Experiment 5 this involved using multiple levels of stretch, although one of those levels was a control. It was found that, although stretching increased the length of the primal significantly, increased levels of stretch did not result in commensurate reductions in shear force or differences in cooking loss, thaw loss or particle size. Based on the changes in circumference there were significant changes in form and function. However, given there was no difference between treatments for shear force, it indicated that a greater degree in stretch was required than what was achieved (8.5 – 9.3%) to improve meat tenderness. There were interesting treatment effects on colour values *L**, *a**, *b** and ratio, but inconsistencies were apparent between 0 and 14 day aged samples hence further validation was required before any real conclusions could be drawn. Further validation ensuring a greater degree of stretch was required to definitely determine whether the use of SmartStretch™ technology could improve meat quality traits of the cube roll. Based on the outcome of this study it could not be concluded that SmartStretch™ technology was able to guarantee improved meat quality for the cube roll.

Experiment 5 resulted in the belief that stretching cast for age beef topsides by more than 34% conferred benefits, but, because of the lack of a control, these could not be quantified. Experiment 6 found that stretching cast for age beef cuberolls by 9% did not confer any benefits, but suggested that an intermediate stretch could. What was apparent from the results was that the technology did produce a more acceptable product due to the shape and this led to keen interest in the technology for this purpose.

Experiment 7 (Section 2.1.2.3) built on the results of Experiment 5 and was a more comprehensive study to examine whether SmartStretch™ could be used to stretch and tenderise hot-boned topsides from cast for age cows. There was a stretch and a control treatment. The 40% increase in primal length resulted in a significant increase in the sarcomere length, but no significant improvement in tenderness at zero days ageing, which was unexpected and indeed after 14 days of ageing stretched topside was tougher than control topside. The reason for this and the lack of a significant effect for 0 day aged topside is not clear. Cooking loss and thaw loss percentages were reduced by stretching, but colour was unaffected.

Experiment 8 (Section 2.1.2.4) followed the earlier encouraging results from an experiment undertaken by UNE researchers using hot boned striploins from prime cattle. Thus an experiment was undertaken to examine whether these same benefits would flow to hot boned striploins from cull cows. Like Experiment 7 there was a stretch and a control treatment. A 17% increase in primal length with stretching resulted in a significant tenderness improvement at zero days ageing, although the meat was unacceptably tough. Sarcomere length and colour were not affected by stretching, nor were thaw loss or cooking loss at zero days ageing. There were no negative changes in meat quality resulting from the stretching of meat in this study. There was a positive effect of the stretching on tenderness in this study, but the level of improvement is unlikely to change the marketing options for hot boned striploins taken from old cows, but it may help to underpin existing markets.

In Experiment 9 (Section 2.1.2.5) the tenderness of stretched and control topsides and rostbiffs was assessed using both laboratory analysis and an untrained 20 person sensory panel. No significant difference in tenderness was found, although the increased tenderness of the rostbiff indicated that

this may be a promising cut for any further validation work. The conclusion was that SmartStretch™ technology had the potential to improve the tenderness of hot-boned rostbiffs and reduce variability, which would contribute the value of the cut. The low pH of the meat (due to very effective electrical stimulation) was also likely to have impacted on the effectiveness of the stretching technology and this is an important consideration. Although there were no significant differences found in the results the absolute values in the rostbiff for the stretched vs control suggested that this cut could benefit from stretching.

Taking stock of the unpromising results of stretching the hot-boned cast for age beef, combined with the more promising results of the sheep meat research and early work done by the University of New England (Geesink & Thompson, 2008), which found that stretching meat using Tenderstretch, Superstretch or SmartStretch™ conferred an equal tenderness benefit regardless of stretching techniques used, the decision was made to undertake a final validation experiment using hot-boned rostbiffs from cattle with a maximum dentition score of 2. The results of Experiment 10 (Section 2.1.2.6) indeed confirmed that the technology could improve tenderness in beef.

Significant improvements in the tenderness of hot-boned rostbiffs from cattle with a dentition score of 2 or less were made by stretching the muscle pre-*rigor*. In this case a 34% increase in length resulted in a 20% reduction in shear force at 0 days ageing. This positive impact on tenderness was nullified with ageing, but the tenderness improvement indicates that there may be scope for stretching to replace costly chilled storage. The tenderness improvements in this study were not enough to create a product that would be acceptable to consumers with 0 days of ageing, but indicates that stretching of muscles from younger animals is more promising than earlier work on beef from cast for age cattle. Presentation traits were either positively affected by stretching such as cooking loss, or unaffected by stretching – purge loss and colour. Sarcomere length was increased by stretching and this had a negative relationship with shear force, as sarcomere length increased shear force decreased.

Overall it was found that the SmartStretch™ technology could not confer any tenderness benefit on beef from cast for age cattle. Whether this result was based on the increased levels of connective tissue in older beef has not been explored. SmartStretch™ technology could confer improved tenderness on beef from cattle with a maximum dentition score of 2. There was no strong overall relationship between levels of stretch achieved and sarcomere length. Meat colour was unaffected by stretching, as was thaw and cooking loss. Particle size analysis revealed that stretching did not change the rate of proteolysis.

2.1.3 Shaping experiments on cold-boned beef

2.1.3.1 *Experiment 11: The effect of a kiwi fruit based solution on meat traits in beef m. semimembranosus*

Introduction

The active enzyme in the juice of kiwi fruit (Actinidia deliciosa) is actinidain (Barrett, Rawlings, & Woessner, 2004) and recent work published by Han, Morton, Bekhit, & Sedcole (2009) showed that lamb carcasses infused pre-*rigor* with a kiwi fruit juice extract produced more tender meat in the loin and hindleg region. Actindain is a cysteine protease and has been shown in a purified form to increase the solubility of collagen in the m. *semitendinosus* and reduce shear force, but also to alter the structure of actin and myosin filaments (Wada, Suzuki, Yaguti, & Hasegawa, 2002) and to increase protein solubility of beef meat (Aminlari, Shekarforoush, Gheisari, & Golestan, 2009). By contrast when Jorgensen, Christensen, & Ertbjerg (2005) injected porcine m. *biceps femoris* with a solution containing 0.075% kiwi fruit powder there was no significant reduction in shear force, compared to muscle injected with water. By contrast this same group of researchers subsequently

published results which showed that shear force could be reduced in porcine m. *biceps femoris* injected with a brine containing 2.8 g/L or more of a commercial kiwi fruit powder (Christensen et al., 2009) and that at 10 g/L there was a small increase in heat-soluble collagen. It is apparent that solutions based on kiwi fruit can lead to a reduction in toughness, but whether this only occurs through a reduction in connective tissue strength or through degradation of the myofibrillar component is less clear. If such a solution can improve the tenderness of the main muscle of the topside the m. *semimembranosus* (SM) this would be attractive given the poor eating quality of this muscle (Thompson, 2002). A major consideration for treatment of fresh meat with plant dervied enzymes is the effect on colour. Bekhit, Han, Morton, & Sedcole (2007) found that lamb carcases infused pre-*rigor* with a kiwi fruit juice extract produced meat with a similar colour shelf life to uninjected meat, but there was evidence of reduced lipid oxidation after meat had been aged for 21 days and then displayed. There does not appear to have been any studies on the colour stability of beef meat injected with a solution based on kiwi fruit. Given these facts and the fact that cold boned primals could be effectively shaped using SmartShape™ technology a study was undertaken to investigate the effectiveness of a kiwi fruit based solution for improving the tenderness of beef SM when injected and packaged cold and the impact of the solution on other meat traits, specifically colour.

Materials and methods

Eight female cattle with no permanent incisors and with a carcase weight between 230 and 250 kg were used for the experiment. The carcases were processed under normal conditions of the abattoir which meant that all carcases were head stunned, followed by low-voltage stimulation and the carcases were then tenderstretched. Both topsides (Anonymous, 2005; HAM 2001) from each carcase were removed the day after slaughter. The m. *adductor* was removed from the topside and discarded leaving the m. *semimembranosus* (SM) which was then split into two samples (equalling four samples/carcase). Each portion (n = 32) was allocated randomly, in a balanced manner within carcases, to one of three treatments: (i) injected with a kiwi fruit based solution, (ii) injected with water and (iii) non-injected (control).

Both “kiwi injected” and water injected treatments were injected at a rate of approximately 25% initial weight using a Fomaco machine (Copenhagen, Denmark) with 4-mm-thick needles. The “kiwi fruit based solution” was prepared according to the manufacturer's guidelines (Earlee Products Pty Ltd., Brisbane, Australia). After injection each sample, including the control, was packaged using a SmartShape™ prototype into 70mm diameter (110mm layflat) packaging using a 75mm diameter ring. For injected samples a pre-injection weight, post-injection weight and post-SmartShape™ weight were recorded. Each package was subsequently divided into sub-portions and one sub-portion of each portion was allocated, at random, to one of two ageing treatments, 1 or 14 days at 4°C. Following ageing samples were frozen and stored at −20°C until measurement.

Shear force (65 g) and compression (65 g) samples were cut from the frozen SM muscles using a band saw. Samples were cooked from frozen in plastic bags at 71°C for 35 min in a water bath, removed and cooled in cold water and stored chilled until testing. The samples were allocated in a balanced design to one of three cooking batches. Samples with a cross-sectional area of 1 cm² were prepared for shear force testing by cutting strips along the grain of the muscle, with 6 replicates tested per sample using a Lloyd Texture analyser as previously described (Hopkins, et al., 2010). Samples for measurement of compression were prepared by cutting strips as those for shear force, with a depth of 10 mm. Six replicates were tested using a rod 6.3 mm in diameter. The rod travels 8 mm into the meat sample for each compression as described by Perry, Shorthose, Ferguson, & Thompson (2001a). Samples used for shear force testing were also used to measure the amount of cooking loss. An initial weight was recorded prior to cooking and once the samples were cooled they were patted dry using paper towelling and re-weighed. The cooking loss percentage calculated as cooking loss (%) = 100 * (Initial weight − Final weight)/Initial weight.

Colour samples were cut from the frozen SM muscles 3 cm thick using a band saw, placed on trays and allowed to thaw overnight in a chiller set at 3–4 °C. The following day a fresh surface was cut on each sample and they were placed individually on black foam trays (13.5 cm × 13.5 cm) and over wrapped with PVC food film wrap (15 µm thickness). After a blooming period of 30–40 min, each sample was measured with a Hunter Lab Miniscan meter (Model 45/0-L) with an aperture size of 25 mm. The instrument was calibrated with black and white tiles using Illuminant D-65, with 10 degree standard observer. Samples were displayed in a chiller at 3–4°C under lighting (1000 lux) and measured over 4 days daily, in duplicate and results averaged on a daily basis.

Statistical Analyses

Data for each trait were analysed separately using linear mixed model (LMM) analysis. For shear force, where the replicate results for each sub-portion were included in the analysis, the model initially fitted included fixed effects for treatments (injection), ageing and an interaction between treatment and ageing. The random terms in the model were effects for cooking batch, carcase, side within carcase, portion within side, sub-portion within portion and finally random error. The random errors within treatments were fitted with different variances. For analysis of compression, where only the mean for replicates within sub-portion were analysed, the initial model was similar to that for shear force except for the exclusion of the random term sub-portion within portion, and here the random error variances were treated as homogeneous. The initial model for cooking loss (%), with only a single result for each sub-portion, was as for compression. Each of these models was subsequently simplified, including the removal of non significant fixed effect terms. Predicted means were then obtained and these were subsequently ranked based on pair-wise least significant differences.

Averages within sub-portions of the colour data *L**, *a** and 630 nm/580 nm ratio, recorded four times over a 72-hour period, were also analysed using LMM analyses. The initial model included as fixed effects separate linear regressions on time for each treatment by ageing combination. Random effects included terms for carcase, side within carcase, portion within side, interactions of each of these with linear time, deviations from linear time (i.e., time fitted as a factor with four levels), interactions of fixed effects with carcase, interactions of fixed effects and carcase with deviations from linear time, and finally a random error. Ratio was loge transformed prior to analysis. All models were fitted using the statistical package ASReml (Gilmour, et al., 2006) which uses REML based methods and incorporates adjusted Wald statistics (Kenward & Roger, 1997) to test significance of fixed effects under small sample inference.

Results

The SM's injected with kiwi fruit based solution and water increased in weight by an average of 23.5% and 19.9% respectively. After subjection to the SmartShape™ technology the increase in weight was 16.5% and 12.7%, respectively. There was a significant effect ($P < 0.001$) of the kiwi fruit based solution on shear force, with no difference between samples injected with water and the control which was not injected (Table 51). There was also a significant ($P < 0.05$) ageing effect with samples in all treatments exhibiting a decrease in shear force with ageing, but no significant interaction between treatment and ageing. There was no significant ($P > 0.05$) variation due to side within carcase or portion within side. There was variation due to cooking batch, across carcasses and the random variation for “kiwi injected” samples differed (was larger) than for the other two treatments which had similar error variance. For compression no fixed effects were significant ($P > 0.05$; Table 51), and of the random terms, carcase, side within carcase and portion within side contributed to the variance. Cooking loss of compression samples differed significantly across treatments ($P < 0.001$; Table 51), but not significantly ($P > 0.05$) across the two ageing levels, either on average or within a treatment.

Table 51: Predicted means (standard errors) for shear force and compression (Newtons) and cooking loss (%).

	Shear force (N)		Compression (N)		Cooking loss (%)
Treatment	**Aged 1 day**	**Aged 14 day**	**Aged 1 day**	**Aged 14 day**	
Kiwi	36.5 *(1.7)* b	32.9 *(1.7)* a	11.5 *(1.6)* a	13.2 *(1.6)* a	25.2 *(0.60)* a
Water	46.9 *(1.6)* de	43.3 *(1.7)* cd	12.7 *(1.5)* a	12.0 *(1.7)* a	27.0 *(0.60)* b
No injection	45.7 *(1.7)* e	42.0 *(1.6)* c	15.4 *(1.6)* a	13.7 *(1.5)* a	21.6 *(0.57)* c

Means (within each test) having a letter in common are not significantly different ($P = 0.05$)

The treatment of cold boned SM's with kiwi fruit based solution gave a clear improvement in tenderness of the order of 20% irrespective of ageing treatment (Table 51).

There was no significant effect ($P < 0.05$) of ageing or linear trend with time on L^* values, nor was the interaction between treatment and ageing significant. There was a significant ($P < 0.001$) overall treatment effect. Of the random terms, carcase and variation in the interaction effects between treatment and ageing across carcases, explained the most variation. Samples not injected (control) were the darkest (lowest L^* values) with a mean (± s.e.) of 37.0 ± 1.02 with no difference between samples injected with water (43.0 ± 1.02) and those injected with the kiwi fruit based solution (43.2 ± 1.02). For a^* values there was a significant interaction between treatment and ageing ($P < 0.05$) and a significant linear trend with time (days on display) ($P < 0.05$). The linear trend with time (decreasing) was consistent across treatment × ageing combinations. Hence, for example, non injected samples which had the highest values at time 0 also had the highest values after 4 days on display, irrespective of ageing level (Table 52). Of the random terms carcase × side × portion explained the most variation. The data for ratio at 630/580 nm were log transformed for analysis and both treatment and ageing had a significant effect ($P < 0.05$) on this trait as did time on display (Table 52). In general the samples not injected had higher ratio values indicating less formation of metmyoglobin.

Table 52: Effect of treatment, ageing and time on display (0 days or 3 days) for *a and ratio values.**

Treatment	Days aged	Mean *a**	Standard error	LSD	Mean ratio	Standard error	LSD
Time = 0 days							
Kiwi fruit	1	17.2	*0.70*	bc	3.82	*0.29*	bc
Water	1	16.1	*0.68*	b	3.61	*0.27*	c
No injection	1	18.2	*0.66*	c	4.52	*0.32*	d
Kiwi fruit	14	13.7	*0.70*	a	2.70	*0.21*	a
Water	14	15.0	*0.68*	a	3.20	*0.24*	b
No injection	14	17.0	*0.67*	b	4.00	*0.29*	c
Time = 3 days							
Kiwi fruit	1	15.33	*0.72*	bc	3.12	*0.25*	bc
Water	1	14.24	*0.69*	b	2.66	*0.20*	ab
No injection	1	16.25	*0.67*	c	3.33	*0.25*	c
Kiwi fruit	14	11.83	*0.72*	a	2.34	*0.19*	a
Water	14	13.04	*0.70*	a	2.51	*0.19*	a
No injection	14	15.06	*0.68*	b	3.15	*0.24*	bc

Means (within each time) having a letter in common are not significantly different (P = 0.05)

Discussion

Given there was no effect on shear force (tenderness) for samples injected with water compared to the control the improvement in tenderness in the samples injected with the kiwi fruit based solution can be attributed to an increase in proteolysis and thus protein degradation rather than to a physical effect associated with the injection process. Han, et al. (2009) clearly showed that when lamb carcases were infused with a kiwi fruit juice solution there was an increase in proteolytic activity with the more rapid disappearance of proteins like desmin and myosin light chain and Christensen, et al. (2009) also reported an increased disappearance of desmin at high concentrations of an injected brine solution. Wada, et al. (2002) reported that a kiwi fruit juice based solution did lead to disorganisation of myosin and actin filaments. Overall the absolute basal level of tenderness before treatment (46 N) indicated a relatively tender product to start with, reflecting the benefits of tender stretching employed by the company. The level was not dissimilar to the level reported by Geesink & Thompson (2008) for beef striploins at the same abattoir, whereas values around 70 N were reported when tender stretching was not used in beef striploins (Geesink & Thompson, 2008). However in the current study when a kiwi fruit based treatment was applied this further improved the product and after 14 days of ageing a very acceptable product was produced (based on the results reported by Thompson (2002) where 45 N was the level which equated to a maximum level for consumer acceptability of beef). There is some evidence that kiwi fruit juice may increase the solubilisation of collagen (Christensen, et al., 2009 and Wada, et al., 2002), but in the current study, the lack of effect on compression does not support this finding as this latter trait has been used to indicate the degree of toughness attributed to connective tissue (Lepetit, Salé, & Ouali, 1986). The absolute level for compression values in the current study was lower than those reported by Perry,

et al. (2001b) indicative of the young age of cattle used in the study. The explanation for the increase in tenderness attributed to myofibrillar degradation may rest with an elevation of calcuim levels in meat treated with kiwi fruit juice based solutions (Han, et al., 2009). This ion is required for activation of the calpains. Hopkins & Geesink (2009) and Han, et al. (2009) found increased autolysed m-calpain in lamb meat treated with a kiwi fruit juice based solution. These findings require further elucidation, but it is also conceded that the magnitude of improvements in tenderness will be driven by the concentration of the actinidain in the solution that is used as demonstrated by the results of Christensen, et al. (2009). As expected injection regardless of the composition of the solution led to greater loss of moisture during cooking, but the magnitude of the increase in the weight of the SM due to injection was such that a net benefit in weight was apparent for injected product.

The results of Bekhit, et al. (2007) showed that meat from lamb carcases infused with water had higher *L** values than those of meat from non-infused carcases or those infused with a kiwi fruit based solution in direct contrast to the results reported here where both infused groups showed higher *L** values and thus lighter meat. Increasing the water content of meat does potentially increase spacing between muscle fibres so a lighter coloured meat is to be expected. Further to this Bekhit, et al. (2007) reported some increase in *a** values for leg meat from kiwi infused carcases, but the opposite effect was found in the current study, with control (non-injected) meat showing the highest *a** values after 3 days on display and thus being more acceptable. Recent data in lamb (Khliji, et al., 2010) show that when the *a** value falls below 14.8 consumers will on average regard the meat as unacceptable. If the level is applicable to beef then 14-day aged meat injected with a kiwi fruit based solution would not be acceptable even at initial display.

In general the ratio (630/580 nm) values indicate that meat injected with a kiwi fruit based solution is less colour stable (lower values) hence having a shorter display life and would therefore be less acceptable at the retail counter especially when aged for 14 days, although water injection also reduced colour stability. The study of lamb by Khliji, et al. (2010) showed that when ratio values fall below 3.3 consumers will on average regard the meat as unacceptably brown (excessive metmyoglobin formation). If a kiwi fruit based solution was to offer an advantage for colour stability this would be likely due to the presence of antioxidants in the juice. However, the lack of positive effect on colour stability in the current study may well be due to the loss of the antioxidants during preparation filtration, whereas in the study of Bekhit, et al. (2007) the solution was not subjected to phases of filtration (Han, et al., 2009). Use of crude extracts of the juice could limit this discolouration effect and the results suggest that those developing methods to prepare kiwi fruit based products should consider these findings.

Conclusion

It can be concluded that injection of a kiwi fruit based solution will confer tenderness benefits, which appears to operate through the myofibrillar component of meat, but this requires confirmation. Despite improvements in meat tenderness gained by the kiwi fruit based solution the increased discolouration would limit the use of the treated product by the retail sector, whereas for the food service sector this is unlikely to be an issue.

2.1.3.2 Experiment 12: The appearance of shaped, portion controlled steaks for food service and retail customers

Introduction

Red meat competes for the food dollar with a variety of foods in both the retail and food service industries. Beef and other meats are losing market share to poultry, which is a different product now

compared to 20 years ago (Resurreccion, 2003) as that industry now focuses on the development of easy to prepare and cook value added products. The change in focus in the poultry industry occurred over a time when human health concerns about beef and pork (BSE, salmonella, dioxins) in some countries caused a drop in the consumption in beef and pork (Verbeke & Viaene, 2000). Although the human health concerns about beef and pork have reduced over time (Verbeke, Pérez-Cueto, Barcellos, Krystallis, & Grunert, 2010) society has changed and consumer demands for easy to use portions (Resurreccion, 2003) and value added products are now being met by the poultry industry (Martinez Michel, Punter, & Wismer, 2011). As a result the red meat industries need to become product marketers rather than traditional commodity sellers (Grunert, Bredahl, & Brunsø, 2004; Resurreccion, 2003). Marketing involves establishing consumer needs and wants and creating products to meet those needs and wants, whereas sellers create a product and then use a variety of selling techniques to bend the demand to that product, which is a less successful approach (Rix, 2004).

Shaped meat products have been available to the retail consumer and the food service industry for generations. These products have undergone extensive processing and can be viewed by the consumer as cheaper, lower quality alternatives to fresh meat (Martinez Michel, et al., 2011). There is a dearth of information about the impact of fresh meat shape on consumer purchase preferences or on the food processing industry. Preferences for steak cross-sectional area have been examined at the retail level (Leick, Behrends, Schmidt, & Schilling, 2011; Sweeter, Wulf, & Maddock, 2005) and for the food service sector (Dunn, Williams, Tatum, Bertrand, & Pringle, 2000). In an older study Hopkins (1995) found that shape had no impact on the prices that retailers set for lamb.

In terms of consumer preference for steak size both Leick, et al. (2011) and Sweeter, et al. (2005) conducted studies that involved establishing the consumer preference for weight portioned steaks sourced from different sized carcases, therefore with different cross-sectional areas. Both studies found that although all consumers have size preferences for steaks those preferences are not the same for all consumers. Dunn, et al. (2000) conducted a study to establish the optimal ribeye/cube roll cross-sectional area for the production of ribeye/cube roll and T-bone steaks for the "steakhouse" sector of the foodservice industry in the United States. The conclusion that the optimal cross-sectional area range was 77.4 to 96.6cm² was a compromise between tenderness and cooking times. The "steakhouse" sector of the foodservice industry was not consulted during this study.

In 2008 a novel processing technology for red meat was patented internationally (Pitt & Daly, 2008). This technology, registered as SmartShape™, can be used to shape cold-boned primals into an even form and package them so as to retain that form by applying air pressure (Taylor & Hopkins, 2011). An example of this is shown in Figure 41. Research involving the shaping of whole hot-boned lamb forequarters, with the aid of commercial binder, found that shape retention of the sheep meat after slicing frozen and cooking was very good (Toohey & Hopkins, 2009; Section 2.4.2). Anecdotal evidence has suggested that shaped fresh primals that could be sliced evenly into consistent portions would be of interest to both the food service and retail sectors.

This experiment was conducted to establish the optimal time period required for cold-boned primals to remain in the packaging between shaping and slicing to ensure that the slices retained their shape. This experiment was borne out of a question at a demonstration to Harvey Beef and WAMMCO in Western Australia that could not be answered, "How long does the product have to stay in the packaging for to retain its shape?. A suggestion, based on anecdotal evidence, of 2 to 3 days had always been given but this had never been quantified. This experiment was the response to the request for more information posed by industry.

Figure 41: Two halves of the same cube roll. Sample 1 (top) is the untreated control while Sample 2 (bottom) has undergone the SmartShape™ treatment.

Materials and methods

Left and right cold-boned cube rolls (Anonymous, 2005; HAM 2244) were taken from nine male bovine carcases with an average weight of 350kg (292 - 437) and dentition score ranging from 2 to 6 in a commercial abattoir. Each cube roll was split laterally with each half being randomly assigned to either the control or the shaping treatment. The shaped treatment samples were processed using the SmartShape™ technology and packaged into tubular packaging with a diameter of 95mm (150mm layflat). The control samples were placed in plastic bags. The length and circumference, were taken on each sample after splitting and this was repeated for shaped samples after the shaping treatment. The packaged samples were then randomly allocated to a 12 hour, 24 hour or 48 hour treatment and kept at 0-1°C for that period. After the allotted time each sample was sliced using a Sunbeam Café Series food slicer into 20mm thick portions along its length and three slices taken, the second slice in from either end and the slice closest to the middle. These slices were laid on a flat surface. The circumference of each slice, along with a long diameter and a short diameter, were recorded immediately on slicing and 2 hours after slicing. The middle slice of each sample was retained for cooking and the circumference and long and short diameter were recorded both immediately before and immediately after cooking in batches of 4 to ~220°C on a Cuisinart Griddler clam grill to a medium degree of doneness. Cooking occurred 12 hours after slicing for the 12 hour treatment samples and 24 hours after slicing for the 24 hour treatment samples. The 48 hour treatment samples were not cooked. A photograph of each slice was taken at each measurement time.

Statistical Analysis

Linear mixed models using restricted maximum likelihood (REML) with the statistical package ASReml (Gilmour, et al., 2006) were used to analyse the data. The model contained fixed effects for the interaction between measurement, treatment (shape or no shape) and time in packaging. Random terms used in the model were carcase, side within carcase, shape treatment within carcase x side and error. Trellis plots for the mean short diameter (*mean.sd*), mean long diameter (*mean.ld*) or mean circumference (*mean.circ*) for each trt × treatment period (12, 24 and 48 hours) combination were produced using the *lattice* package (Deepayan, 2008) in R (R Development Core Team, 2010). Each line on the trellis plot corresponds to a separate sample.

Results

Dimensional changes in slice diameters, or circumference were not significantly ($P > 0.05$) affected by the time the samples were retained in the packaging.

The predicted means and standard errors for short diameter, combined for all time in packaging treatments, are presented in Table 53. There was no significant ($P > 0.05$) change in the short diameter for the control samples until cooking, where the meat expanded. The short diameter of shaped slices increased gradually with increased resting time, becoming significant ($P < 0.05$) after more than 12 hours, but this was no longer significant ($P > 0.05$) after cooking. The short diameters for the control and shape slices were not significantly ($P > 0.05$) different from each other until the pre-cook measurement at which time the control short diameter was significantly ($P < 0.05$) shorter than the shape short diameter. This was no longer significant after cooking.

Table 53: Predicted means and standard errors (s.e.) for the short diameter (cm) of control and shaped steaks averaged over packaging times, but at measurement times

Measure	Control		
	Mean	*s.e.*	
Slice	9.0	*0.24*	a
Slice + 2 hours	8.9	*0.24*	a
Pre-cook (slice + >12h)	8.7	*0.30*	a
Cook	9.6	*0.30*	bc
	Shape		
	Mean	*s.e.*	
Slice	9.2	*0.12*	ac
Slice + 2 hours	9.2	*0.12*	ac
Pre-cook (slice + >12h)	9.6	*0.20*	b
Cook	9.3	*0.20*	ab

Means having a following letter different within a column are significantly different ($P < 0.05$).

The mean short diameter of slices immediately after slicing, 2 hours after slicing, immediately before cooking (> 12 hours after slicing) and immediately after cooking are graphed in Figure 42 for the control and shaped samples and for each time in packaging treatment. The variation in the short diameter of the slices was reduced by shaping. The reduction in variation is illustrated in Figure 43, which shows the equivalent control and shape slices for two cube rolls alongside each other. Note the consistent and even, almost circular, shape of the shaped slices.

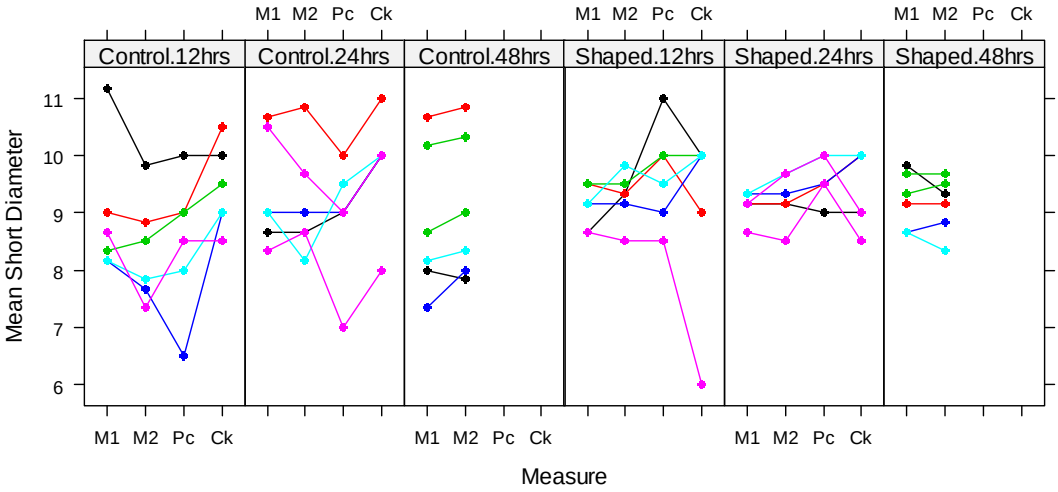

Figure 42: Mean short diameter of slices immediately after slicing (M1), 2 hours after slicing (M2), immediately before cooking (> 12 hours after slicing) (Pc) and immediately after cooking (Ck) for shaped and control samples retained in packaging for 12, 24 or 48 hours.

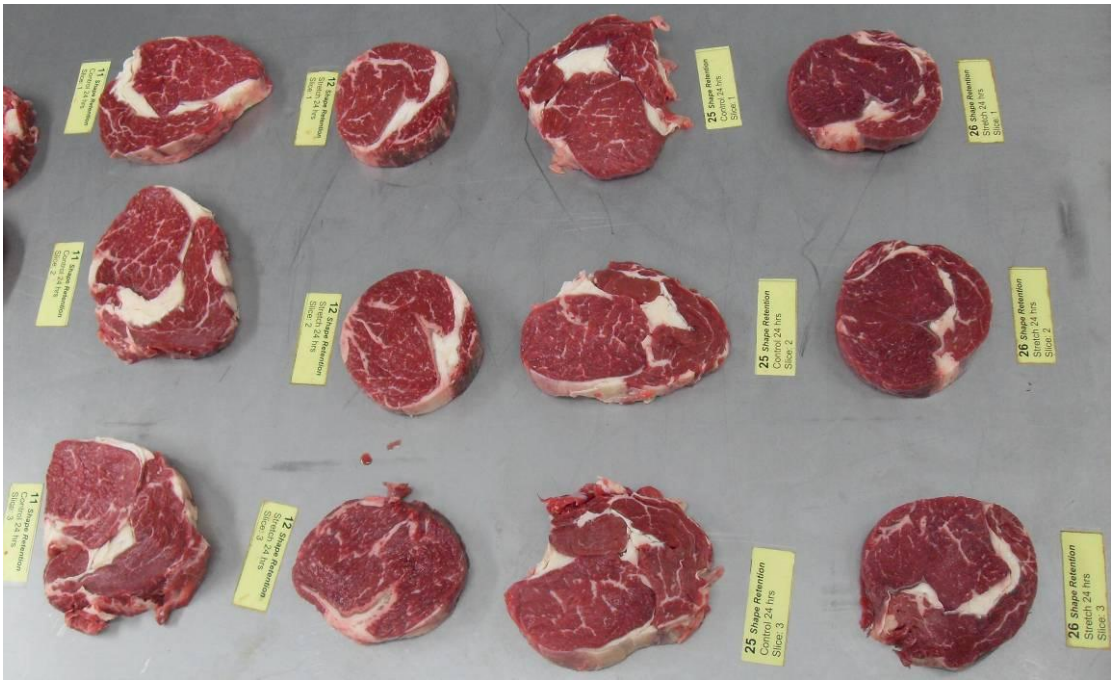

Figure 43: Shape of three slices from four samples, representing two cube rolls, after 24 hour treatment. Control 11 (far left) is the equivalent of shaped 12 (second from left) and control 25 (second from right) is the equivalent of shaped 26 (far right).

The predicted means and standard errors for long diameter, combined for all time in packaging treatments, are presented in Table 54. The long diameter for the control slices significantly (P < 0.05) increased after more than 12 hours resting time, but this significance was nullified by cooking.

The long diameter for the shaped slices gradually increased with resting time and became significantly ($P < 0.05$) longer with cooking.

Table 54: Predicted means and standard errors (s.e.) for the long diameter (cm) of control and shaped steaks averaged over packaging times, but at measurement times

Measure	Control		
	Mean	*s.e.*	
Slice	13.9	*0.33*	d
Slice + 2 hours	14.1	*0.33*	d
Pre-cook (slice + >12h)	14.6	*0.37*	e
Cook	14.2	*0.37*	de
	Shape		
	Mean	*s.e.*	
Slice	10.2	*0.10*	a
Slice + 2 hours	10.3	*0.10*	ab
Pre-cook (slice + >12h)	10.6	*0.15*	b
Cook	11.4	*0.16*	c

Means having a following letter different within a column are significantly different ($P < 0.05$).

The mean long diameter of slices immediately after slicing, 2 hours after slicing, immediately before cooking (> 12 hours after slicing) and immediately after cooking are graphed in Figure 44 for the control and shaped samples and for each time in the packaging treatment. As with the short diameter the variation in the long diameter was greatly reduced by the shaping treatment. There was an average 3.6cm difference in the long diameter between the control and the shaped slices. The shape treatment effectively reduced the long diameter of the slices.

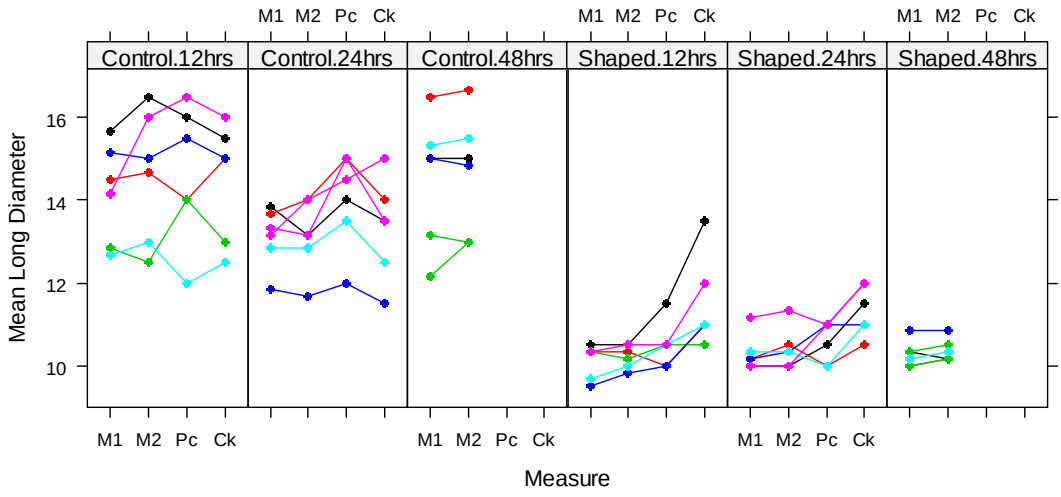

Figure 44: Long diameter of slices immediately after slicing (M1), 2 hours after slicing (M2), immediately before cooking (Pc) and immediately after cooking (Ck) for shaped and control samples retained in packaging for 12, 24 or 48 hours.

The predicted means and standard errors for the circumference for all time in packaging treatments combined for the control and shape treatments are presented in Table 55. The circumference of

the cube rolls before and after the SmartShape™ treatment are included, along with the combined circumference of the slices immediately after slicing, 2 hours after slicing, more than 12 hours after slicing and immediately after cooking. Significant ($P < 0.05$) differences in the original size of the cube roll between the control and shape treatments can be explained by small amounts of trimming required to allow the cube roll to undergo the shape treatment. As expected shaping had a significant ($P < 0.05$) impact on the circumference of the cube roll. The control samples increased in circumference with resting time, again significantly ($P < 0.05$) increasing with cooking. Shaped slice circumference gradually increased with increased resting time, with a significant ($P < 0.05$) increase resulting from cooking, which returned the slices on average to their pre-shape treatment circumference.

Table 55: Predicted means and standard errors (s.e.) for the circumference (cm) of control and shaped steaks averaged over packaging times, but at measurement times.

Measure	Control		
	Mean	*s.e.*	
Pre-shape treatment	37.9	*0.62*	d
Post-shape treatment			
Slice	39.2	*0.62*	e
Slice + 2 hours	39.7	*0.62*	e
Pre-cook (slice + >12h)	40.1	*0.74*	e
Cook	43.1	*0.74*	f
	Shape		
	Mean	*s.e.*	
Pre-shape treatment	35.2	*0.42*	c
Post-shape treatment	30.5	*0.37*	a
Slice	31.0	*0.40*	a
Slice + 2 hours	31.4	*0.47*	ab
Pre-cook (slice + >12h)	32.8	*0.60*	b
Cook	35.5	*0.46*	c

Means having a following letter different within a column are significantly different ($P < 0.05$).

As with the results for the short and long diameter, shaping was found to reduce the variability in circumference, although circumference did become more variable with cooking (Figure 45). Figure 46 illustrates the slices from Figure 43 following cooking. The shaped slices became less rigid and more natural in shape, closely resembling their untreated equivalents.

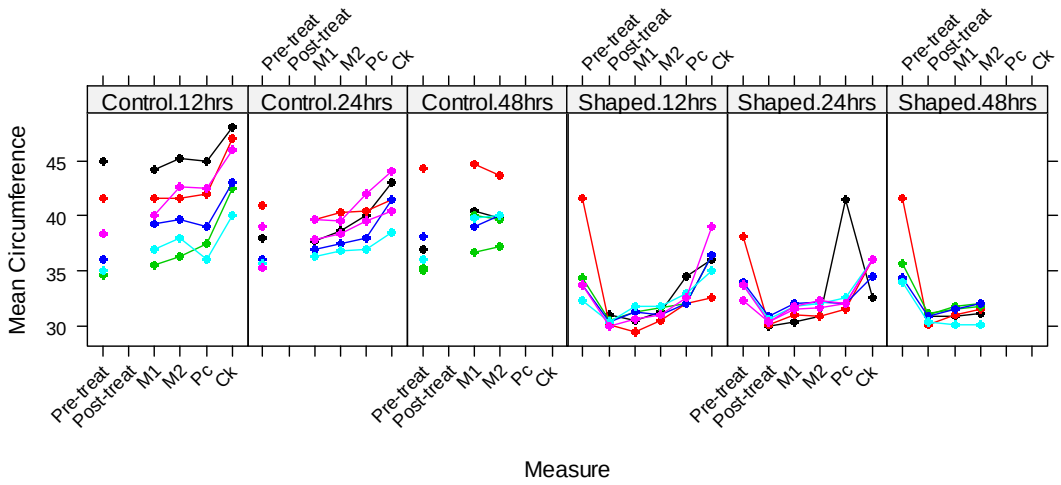

Figure 45: Circumference of samples before (Pre-treat) and after (Post-treat) shaping treatment and slices immediately after slicing (M1), 2 hours after slicing (M2), immediately before cooking (Pc) and immediately after cooking (Ck) for shaped and control samples retained in packaging for 12, 24 or 48 hours.

Figure 46: Cooked slices from two cube rolls. On the left are the shaped (12) and control (11) slices from one cube roll and on the right are the control (25) and shaped (26) slices of another cube roll. The uncooked slices are shown in Figure 43 above.

Discussion

The results revealed a shaped product that, within 12 hours of treatment, could be sliced evenly along its length into portions of consistent dimensions diameter and circumference, which would suggest that this product would be ideal for weight portioning. These dimensions will be for the most part retained until cooking, when the steaks will attain a more natural appearance. The natural appearance of the cooked product will appeal to consumers, although the processed appearance of the uncooked slices may cause some consumers to balk at purchasing this product (Verbeke, et al., 2010).

During the conduct of this experiment it was noted that the 24 hour and 48 hour samples were easier to slice than the 12 hour samples. It is unknown whether this is a function of increased time since the primals were excised from the carcase or increased time in packaging. It was also noted

that slice distortion increased with increased handling and this is an area that may need further investigation.

Marketing to the food service industry

Within the food service industry portion control is a major way of controlling costs. Setting portions and keeping to them results in small cost savings per portion, which accumulate into large savings for the business over time (Oros, 2008). Although the focus on portioning meat has largely been on processed, precooked and convenience foods (Petrak, 2006) those same principles should apply to portion controlled fresh meat. Institutional purchase of meat cuts is mainly on weight (Leick, et al., 2011), with constant weight steaks being sourced from different sized primals resulting in steaks of different thicknesses and differences in cooking times. The SmartShape™ product proposed here eliminates the size difference in primals, resulting in constant weight steaks being of the same thickness and thus providing similar cooking times.

Institutional food service is tightly controlled for financial reasons (Hartwell & Edwards, 2003). Institutional food wastage is an extremely important issue as increased waste leads to reduced profits. This issue has been extensively discussed (Dilly & Shanklin, 2003; Edwards & Hartwell, 2003; Williams, Kokkinakos, & Walton, 2003, and Williams, 2009) and studies have been conducted to examine the magnitude of the issue (Engström & Carlsson-Kanyama, 2004 and Hartwell & Edwards, 2003). The estimates of food wastage vary although the Engström & Carlsson-Kanyama (2004) study examining four Swedish institutions estimated total waste at 20% of all food delivered, half of which was preparation and serving waste and the other half was plate waste (food taken but not eaten and thrown away). Discussions of food wastage did not include information about the proportions of the types of food wasted, except for the Engström & Carlsson-Kanyama (2004) study, which found that starchy meal components, such as potatoes, rice and pasta, or vegetables accounted for the bulk of the plate waste while meat and fish were rarely wasted. As consumer behaviour is different in different markets and cultural groups (Martinez Michel, et al., 2011 and Reicks et al., 2011) the suggestion that meat is rarely wasted is heartening, but should not be accepted blindly. The advantage with the SmartShape™ product is that much of the slicing waste during preparation is eliminated as the shaped primal can be sliced evenly along its length. As the unnatural shape is not retained following cooking the impact of the primal shape should not affect institutional consumers any more or less than other foods and should not impact more or less on the level of plate wastage.

In this study we have covered one aspect of portioning shaped product that could be of interest to the food service industry – shape, slice and cook in that order. The other aspect that could be of great interest to the food service industry that needs to be explored experimentally is to shape, cook and then slice the primal. Commercial work undertaken has seen some success with a corned product, but a less attractive result with a cooked product Figure 47. More work needs to be done in this area.

Figure 47: Sliced and packaged corned beef that had been initially shaped using the SmartShape (left) and a less successful attempt to cook the shaped product in its packaging (right).

Marketing to the retail customer

Easy to prepare products are now essential to the retail consumer. Consumers don't plan meals anymore, often waiting until the end of the day to decide what to cook for dinner (Resurreccion, 2003). Consumers want access to healthy, easy to use and prepare products (Martinez Michel, et al., 2011). On that basis it could be assumed that the shaped and sliced product would be ideal. Cooking times for the steaks would be predictable and consistent and allow for a better home cooked product experience.

Marketing of meat to the retail customer is a complex field. Consumers at the point of purchase are affected by the shopping situation – available information, whether the purchases are planned or being made on impulse and the time pressure on the consumer at the point of purchase (Brunsø, Bredahl, Grunert, & Scholderer, 2005). Consumers also place a lot of faith in the retailers when selecting meat (Grunert, 1997), so much so that supermarkets are often regarded as the guardians of consumer interests (Duffy & Fearne, 2009). Retailers can influence the response to and use of a particular cut through the use of goal based displays, retailing products that are used alike alongside each other (Hoek, van Boekel, Voordouw, & Luning). Verbeke, et al. (2010) found that novel processing of beef was not necessarily accepted by consumers, who may view it with caution because of perceived risks coupled with little benefit. They found that unprocessed lean beef was considered healthiest, while the health value of meat decreased with the increased degree of processing. Resurreccion (2003) found that there was high acceptance of restructured meats created using binders that resemble intact cuts of meat. A study by Reicks et al. (2011) found that consumers placed more value on eating quality and price when purchasing beef than they did on product consistency and ease of preparation, although women did place more value on these characters than men did. These factors would suggest that the shaped raw steak may not be as acceptable to consumers as hoped, but displaying it at the point of purchase with other products of similar size and end use may assist with the shaped steak's acceptance.

Branding of shaped steak could be an attractive proposition because brands are a visual credence cue to assist the consumer with their purchases although, as consumers differ in their expectations, not all brands will interest all consumers (Brunsø, et al., 2005). Grunert, et al. (2004) found that consumers have very high expectations of branded products. Brands need to relate to specific and measurable characteristics that have relevance to the consumer. Brands also need to be consistent in their effect and thus trustworthy. Could the shaped steak be sold only on the advantages of consistency in portioning and cooking times or should it be linked to other important

characters, such as eating quality characteristics? A portion controlled product could be marketed to suit particular branded diets or to assist with consumers understanding appropriate portion sizes. A number of dietary recommendations are available for the consumption of red meat (American Cancer Society, 2011 and CSIRO, 2008) because the consumption of red meat is increasing (Wyness et al., 2011) and has been associated with chronic diseases and cancers (Verbeke, et al., 2010) although Verbeke, et al. (2010) and Wyness, et al. (2011) were unwilling to make recommendations for the consumption of meat on the basis of disease risk because it has been hard to find quantitative evidence of a direct link between moderate meat intake and disease risk. Obesity is also of concern to society (Edwards, Engström, & Hartwell, 2005).

Consumers are not very good at predicting eating quality of meat (Brunsø, et al., 2005). Consumers purchase meat based on search, experience and credence cues. Search cues are what the consumer can see when purchasing the meat, such as colour or fat, experience is the experience the consumer has when eating the meat and credence cues are aspects that are not seen or experienced in the purchase or consumption of meat, but affect purchase decisions, such as health concerns, animal welfare and product branding (Brunsø, et al., 2005). The search (visual) cues that consumers use when selecting fresh meat are either completely unrelated to eating quality (colour for example) or the consumer perception of that cue is at odds with eating quality, such as visible fat (Grunert, et al., 2004). Brunsø, et al. (2005) conducted a study of Danish consumers with increasing degrees of marbling. In that study consumers selected the meat with the least fat for purchase with the expectation that it will be best, but found that meat with the highest degree of marbling had better eating quality. It was concluded that consumers views on fat are dysfunctional – when they expect good eating quality it will be poor and vice versa. Eating quality is not visible and is highly variable and can be complicated by meal preparation, type of meal, time of day, consumer's mood and previous experience (Grunert, et al., 2004).

The consumer response to credence cues is also quite complex. In the late 1990s and early 2000s human health concerns surrounding beef and pork (BSE, salmonella, dioxins, etc) caused a drop in beef and pork consumption in many countries, although these concerns have now reduced in their impact on consumer purchases (Verbeke, et al., 2010). In 2000 Verbeke & Viaene (2000) considered animal welfare to be the "next big issue" facing consumer perceptions of beef and pork, although by 2010 Verbeke, et al. (2010) found that care needed to be taken about placing too much credit on personal views relating to meat production and animal welfare because, although people have views on these matters, they are not reflected in consumer purchasing patterns.

A number of factors affecting the red meat buying public have been presented here. These include the:

- want for easy to use and prepare consistent products,
- apparent mistrust of processed fresh meat,
- reliance on the retailer to assist with their purchases,
- use of brands to guarantee quality,
- perceived need for portion control in some sectors and
- inability to adequately guarantee their eating quality experience in their own retail selections.

As retail chains prefer to focus on in store branding, rather than industry level or processor level branding for meat (Duffy & Fearne, 2009) it could be suggested that selling the shaped steaks would be best as a niche supermarket branded product with very tight parameters relating to eating quality. This would allow for a consistent eating experience, coupled with the bonus of a portioned product, and will hopefully allay any concerns relating to the highly consistent and processed appearance of the uncooked steaks. Ultimately, though, it would be best to market the product to

consumers and establish the best sector of the community to target this product at through consumer research and subsequent product development.

Conclusions

Presented here is a novel processing technology, SmartShape™, which has the potential to meet requirements for portioning steaks for both the food service industry and retail consumers. The results show that the cold-boned primals could be sliced 12 hours after shaping without any loss of the benefits of shaping. Changes to the shape or size of the shaped steak do not occur until after cooking, meaning that the sliced product does not need to be used immediately, but can be left for 24 hours without the loss of shape. This suggests scope for flexibility in presentation (sliced and pre-packaged product) when introducing the shaped product to the marketplace. Gradual increases in the diameter measurements and circumference over time suggest that further work should be conducted to establish the time that must elapse before a shaped steak significantly changes shape insofar as to lose the benefits of shaping.

The food service industry should find this technology attractive as it allows for weight portioned steaks to have the same physical dimensions, thus consistent and predictable cooking times. Likewise the home consumer should also find the ability to prepare the resultant steaks with a consistent and predictable outcome attractive. As little previous work has been undertaken in establishing the consumer response to meat shape it would be valuable to undertake consumer, both food service and retail, based product development to ensure that the results of this technology are directed to the most appropriate consumer groups.

2.1.4 Review papers

One review paper was published (Appendix 8.6):

(Taylor & Hopkins, 2011) Taylor, J. M., & Hopkins, D. (2011). Patents for stretching and shaping meats. *Recent Patents on Food, Nutrition and Agriculture, 3*(2), 91-101.

2.2 Objective 2

Develop partnership relationships with sheep meat processors so as to expedite R&D adoption.

2.2.1 The success of collaborative partnerships with industry

The large number of demonstrations (n = 30; Section 2.5.1), the involvement in 4 MDC projects and the extensive experimentation that has been undertaken for this project demonstrate that the I&I NSW team was able to develop excellent working relationships with a range of processors. In the first phase of the project the focus was on sheep meat and 4 different experiments were undertaken at Fletchers International Exports Pty Ltd Dubbo plant over the life of the project. Edwina Toohey and David Hopkins have a long association with Fletchers due to previous R&D with the company and the value of this relationship can not be underestimated as it paved the way for work in the current project.

With a broadening in the scope of the project in 2009 to encompass beef due to a lack of progress in New Zealand the I&I NSW team established effective working relationships with Australian Country Choice (ACC), EC Throsby Pty Ltd and HW Greenham & Sons Pty Ltd and undertook 8 different experiments. This again was testament to the team's ability to conduct R&D in the commercial environment. The full listing of the companies with whom either experimentation or MDC projects were undertaken is as follows;

Experimentation

1. Fletchers International Exports Pty Ltd Dubbo – Sheep hot boning experiments and binding lamb and sheep forequarters.
2. Australian Country Choice (ACC) – Application of Kiwifruit based solution for improving the tenderness of cold boned beef. It should be noted that this came after Edwina Toohey assisted in the successful execution of Project RE-221941, run by UNE on behalf of Carne Technologies.
3. HW Greenham & Sons Pty Ltd – Beef hot boning experiments at both Tongala and Smithton including a sensory experiment at Tongala and a shape retention experiment at Smithton.
4. EC Throsby Pty Ltd - Beef hot boning experiments.

MDC Projects

1. Chefs Partner Pty Ltd
2. Gotzingers Smallgoods
3. HW Greenham and Sons Pty Ltd
4. Cargill Australia Beef

Of particular note in the relationships developed were those with HW Greenham & Sons Pty Ltd and Cargill Australia Beef as these involved a significant investment through the MDC projects.

2.2.2 HW Greenham and Sons Pty Ltd

A successful demonstration of the SmartStretch™ technology was conducted between 29th September and 2nd October 2009 at the HW Greenham and Sons Pty Ltd hot-boning plant at Tongala, Victoria. The primals assessed were the hot-boned cube roll, striploin and inside (cap off). The company felt that it would be difficult to improve the tenderness in beef from cull cattle, but believed benefits could be derived from shaping of hot-boned primals. The company proceeded to an MDC project.

An initial unsuccessful MDC project was conducted in March 2010. During the initial in house training period samples were collected for an experiment to assess the sensory and measured tenderness of stretched and unstretched rostbiffs and topsides (Section 2.1.2.5). Rubber and packaging breakage issues stalled Greenham's attempts to effectively assess the technology. These issues were resolved over the following 3 months. Rubber breakage issues were found to be a manufacturing quality control problem and new manufacturers were found and new rubbers supplied. The packaging breakage issues were partially resolved by sourcing a different brand of packaging and provision of a packaging head specific to that packaging.

A second, more successful MDC was undertaken in July 2010, where Greenhams had the SmartShape™/SmartStretch™ machine on site for 4 weeks. The intention of this period was two-fold – firstly to allow the company to produce samples for evaluation by clients and, secondly, to develop a clear picture of the types of product the company would like to produce and to record the primals dimensions in preparation for developing a Stage 2 machine. The overall response from Greenhams was that they liked the concept of the technology, but felt it was too slow for their purposes.

Greenhams undertook a 5 week trial period of the SmartShape™ technology at their cold-boning plant in Smithton, Tasmania in February and March 2010 after hosting two experiments. The first was a stretch validation experiment involving hot-boned rostbiffs from cattle with a maximum

dentition score of 2 (Section 2.1.2.6) and the second was to assess the ability of shaped steaks to retain their shape after slicing (Section 2.1.3.2). Negotiations with the owners of HW Greenham and Sons Pty Ltd for progression to a Stage 2 development phase are continuing.

This is evidence of the strong working relationship that has developed between HW Greenham and Sons Pty Ltd and the Industry & Investment NSW meat science research team. Regardless of problems that emerged during the initial phase of the MDC the company remained willing to accommodate our team for research and willing to continue to test the technology.

2.2.3 Cargill Australia Beef

A successful initial demonstration of the SmartShape™ technology was conducted in February 2010 at the Cargill Beef cold-boning plant in Wagga Wagga NSW. The primals assessed were beef topside, outside flat, knuckle and rostbiff. The company sought to improve yield, increase productivity and develop a retail ready product. The company proceeded to a MDC project.

A successful MDC project was undertaken in April and early May 2010. This involved two visits – the first to install the technology and a second visit to undertake urgent repairs following a rubber breakage. At that stage Cargills had two major clients interested in evaluating the technology. A structured test plan was also followed to assess shelf life and shape retention, as well as bound products. The company sought to value add to their cube roll, but was unable to effectively assess the technology because the machine was too small for the primal. Some concern was also expressed about the operational speed of the machine. Based on limited information recommendations were made for the sizes of the rubber and packaging unit for an upscaled machine that would be able to accommodate the cube rolls used by Cargills. The company proceeded to Stage 2.

A successful Stage 2 development meeting was undertaken in October 2010 to establish the requirements and the parameters of an upscaled SmartShape™ machine to better meet the specific needs of Cargills and their client. Updated recommendations for the sizes of the rubber and packaging unit were made based on more information on primal sizes provided by Cargills (Appendix 8.5). A list of OH&S changes were provided by the consulting OH&S engineer. The agreed engineering, production and packaging changes are listed below in Table 56.

Table 56: Agreed engineering, production and packaging changes for the development of the Cargill Beef Stage 2 SmartShape machine.

Item	**Issue**
	OHS
1	One point of isolation for both air and power required.
2	Fixed guard 600mm high to be installed around 3 sides of the machine
3	130mm minimum distance between packaging unit and guard to ensure that there is no pinch point
4	Light stream active across front of machine during packaging unit movement that will cause “Emergency Stop” if the beam is cut. Include an indicator light for when the light stream is deactivated.
5	Guard (no pinch point) or sensor linked to Emergency Stop to prevent overhead workers being trapped between moving packaging unit mast and low ceiling.
6	Rubber boot around packaging unit mast to prevent pinch point
7	Height adjustable unit for short operators
8	Computer unit to be fully sealed and watertight and accessible from the back of the machine.
9	Emergency stop prevents all functions on the machine from working

Item	**Issue**
10	Button panel to be yellow and Australian standard button colours (as advised by Roger Lim) for their functions to be used. Buttons to be further apart to reduce to chances that the wrong one is pressed.
11	Reduction in spinning force of packaging unit
12	Sound insulation for the air pump.
	Development
13	Arthur Pitt to visit the Cargill Beef abattoir at Wagga Wagga, NSW to see the line in operation and to see where the machine is to be placed on that line and refine machine development on that basis.
14	Mould for new 80cm long rubbers
15	Identifying marks (eg triangle) made on both rubber and machine to assist with aligning the sensors for automated operation following a rubber change.
16	Airbags within vacuum chamber mounted by lengthways elasticised attachments (as opposed to the current crossways elastic bands) and with the air hose attachments at the bottom of the chamber, rather than the top.
17	Rubbers to have the sensor magnets cast within the fabric of the rubber
18	Sensors for automated function to be more reliable and a quick check system to be created to assess sensor alignment and to fix alignment if necessary
19	All controls – computer and buttons – to be on a height adjustable floating arm attached to the right hand side of the machine.
20	Air pressure in the bottom of the rubber to facilitate ejection of product
	Operation
21	Rubber to be left in the expanded position at the end of the cycle to facilitate the start of the next cycle.
22	Multiple numbered packaging units with each 2 x 1 size and 1 x another size to fit the product specifications and the capacity to tell the machine which packaging unit is in place so that the sensors read sizes accordingly. Packaging unit to have a quick click on/ click off function to change it easily. Packaging unit to normally oscillate between the 2 heads of the one size with the option to select the second size.
23	Unloading tunnel for product post shaping.
24	Start button/flick switch to start each cycle.
25	Unit on wheels with effective brakes
26	Automatic function program cycle: • 5 secs – mast up (packaging unit up), rubber open • 10 secs – insert meat, hold meat • 7 secs – auto select size (packaging unit spins), mast down (packaging unit down) • 3 secs – squeeze meat, eject into packaging • 5 secs – rubber open, mast up • Total = 30 seconds per cycle
	Packaging
27	Packaging option – continuous roll of perforated packaging to be explored
28	Packaging spindles attached to the back of the machine with the capacity for at least 3 rolls of packaging
29	Packaging that is easily opened to be sourced
30	Guarded cutting blade for the slicing of the packaging on removal of shaped product

Item	**Issue**
	Further information required
31	Range of cube roll sizes across a range of lots within a day/days (preferably) of operation in the Cargill plant to allow the refinement of the size recommendations.
32	Assessment of drier product through the machine, straight off the line, rather than cryovaced and stored product,
	Future
	Increase the speed the machine operates from 2 cycles per minute to 3.5 cycles per minute
	Automatic loading and unloading of machine
	Multiple modular units
	Machine cycles automatically with no need to press start button
	Rubber texture changes to make it slipperier
	Fully automated unmanned machine

The machine was delivered to Cargills for a series of in house demonstrations to their clients in November 2010. Remote technical support was provided at that time as unexpectedly the machine was not operating correctly on the mornings of each demonstration. To facilitate Cargills further product development the company received the machine for the month of January 2010, but competing obligations meant that they did not undertake any work with the technology at that time. Delays in the signing of a Stage 2 development contract by Cargills have meant that the machine, which was originally timetabled for delivery in March 2011, will not be delivered until June 2011.

These developments are evidence of the partnership relationship that developed between Cargills and Industry & Investment NSW. Our ability to respond appropriately and quickly to any problems experienced with the technology facilitated the company's assessment of the technology. The company's needs were assessed effectively and appropriate recommendations were made for the upscaling of the machine to allow Cargills to meet the needs of their client.

2.3 Objective 3

Contribute to a research program to integrate stretching technology and electrical technologies with a focus on primal manipulation.

This objective was met through the design of the last sheep experiment undertaken which examined the interaction of electrical stimulation and stretching in hot boned topsides (see Section 2.1.1.4). No MLA programs were operative in which it was possible to examine the impact of direct stimulation of primals prior to stretching which was the intent of this objective when the project was originally designed.

2.4 Objective 4

Collaborate with other EQ programs (eg Joint MQST and Sheep CRC2 processing program) with a focus on pre-*rigor* stretching

2.4.1 The success of collaborative work with EQ programs

There were several activities that were undertaken as an adjunct to this project which relied on collaboration with the Sheep CRC and other MQST projects. Collaboration with the Sheep CRC was facilitated by David Hopkins, as he leads the Sheep CRC project – Application of meat processing technologies, which has undertaken a number of collaborative studies with MLA funded projects. Due to Edwina Toohey's experience in operating the machine she assisted in a project run by UNE on behalf of Carne Technologies and with out her involvement indications are that the project would not have succeeded. Overall the current project has enabled other work to be undertaken which has maximised the investment of R&D funds. The various collaborative projects are outlined below.

2.4.2 Experiment 13: Change in form and function of hot-boned sheepmeat forequarter

Introduction

The application of hot boning of sheep carcases for the retail market is not extensive (Waylan & Kastner, 2004). There are many economic benefits for using hot boning which include: increased meat yield, energy savings, chiller space minimisation, reduced labour and time (McPhail, 1995). The use of hot boning can have major constraints, such as an increased risk of shortening in muscles (Devine, et al., 2004), which can be minimised by the use of electrical stimulation.

Hot-boning allows each muscle to be separated from the carcase pre-*rigor* and treated optimally according to its intrinsic properties (White, et al., 2006). This process could also aid in the shaping of some cuts which add value and enhance eating quality of traditional hot-boned products.

In recent years consumers have become increasingly health conscious and there has been a large growth of 'healthier options' within the food industry (Desmond & Troy, 2004). The red meat industry is faced with the challenge of not only competing with other meat sources such as the chicken, pork and seafood, but also delivering convenient and healthy food products at competitive prices.

A recent survey of food service providers (MLA, 2009) highlighted that the food services industry has a demand for portion controlled products. This is largely driven by the need to reduce labour, improve time management, minimize wastage and improve the consistency of the product. One of the biggest demands was the ability to deliver consistent steaks. The capability to shape and portion meat gives the industry the tools to deliver a more consistent product for both cooked and raw meat and respond to changes in consumer demand.

The aim of this experiment was to evaluate the effect of a meat shaping device on the form and function of hot boned mutton and lamb forequarters and the use of a commercial protein binder. Additionally, a comparison was undertaken between a full forequarter excluding the shank, neck and trimmed fat (Anonymous, 2005; HAM 5280) and a partial forequarter (based on m. *supraspinatus,* m. *infraspinatus* and m. *biceps brachii*) which is currently used by the co-operating processor.

Materials and methods

Animals

Ten sheep and ten lamb carcases were randomly selected from the day's kill of a commercial processor. Only carcases with a fat score of 2 or less were selected, this fat score is based on the GR measurement (total tissue depth ≤ 10mm) which was measured with a GR knife. The sheep and lambs were from different consignments and hence were of varying backgrounds, to represent the variation of animals typically processed by the Australian abattoir.

Treatments and sampling

All forequarters were hot boned and the twenty mutton forequarters and twenty lamb forequarters were collected. Left and right sides were then randomly allocated to one of two treatments: 1) Full forequarter excluding the shank, neck and trimmed fat (Anonymous, 2005; HAM 5280) and; 2) Processor specification – a partial forequarter based on m. *supraspinatus,* m. *infraspinatus* and m. *biceps brachii* (Partial). All samples were given a light dusting of a commercial protein binder before been placed through the shaping device.

Measurements

The following was then recorded:

- Initial and final weight of sample
- Initial and final length of sample
- Initial and final circumference of sample
- A photo diary to record the change in form and function

Meat samples were placed through SmartShape prototype (licensed as SmartShape™) under development by Meat & Livestock Australia and Meat & Wool New Zealand. The prototype has a flexible inner sleeve and once the forequarters were placed in the flexible sleeve, air pressure was applied to stretch and shape the meat. Samples were ejected from the SmartShape machine into tubular packaging sleeve. Once the meat shaping process was complete the samples were frozen at -22º C.

Cooking methods

Samples were cut while frozen into both 15 mm and 2-3 mm wide slices. The 15 mm samples were cooked on a clam grill at 220ºC for 5 minutes and the 2-3 mm samples cooked at 220ºC for 1 minute. A photo diary of each sample was recorded (Figure 48 and Figure 49) to show the change in form and function and to demonstrate the usefulness of the commercial protein binder in this type of production using the SmartShape™ machine.

Statistical methods

A linear mixed model using restricted maximum likelihood (REML) within ASReml (Gilmour, et al., 2006) was used to analyse all data. The model contained fixed effects for forequarter type (full or partial).

Results and Discussion

The mean, standard deviation and range of carcase and mutton forequarter traits is shown in Table 57 and for lambs in Table 58. The mutton carcases were on average fat score 2 with a range from fat score 1-2 which were consistent with the aim to select leaner carcases that would require less trimming.

Table 57: Mean, standard deviation (SD) and range for GR and forequarter traits (mutton carcases).

Trait	Mean	SD	Range
GR (mm)	6.3	*1.59*	3-8
Initial weight (kg)	1.46	*0.20*	1.09-1.86
Final weight (kg)	0.91	*0.25*	0.57-1.30
Initial length (cm)	21.7	*4.19*	15-27
Final length (cm)	24.1	*6.03*	16-31
Initial circumference (cm)	22.5	*3.46*	17-28
Final circumference (cm)	20.9	*1.43*	18-22

In comparison to the mutton forequarter, the lamb forequarters were on average lighter and leaner, but were of similar dimensions before and after reforming.

Table 58: Mean, standard deviation (SD) and range for GR and forequarter traits (lamb carcases).

Trait	Mean	SD	Range
GR (mm)	4.1	*0.72*	3-5
Initial weight (kg)	1.34	*0.07*	1.24-1.49
Final weight (kg)	0.79	*0.30*	0.40-1.27
Initial length (cm)	22.7	*5.22*	16-34
Final length (cm)	24.9	*5.75*	17-35
Initial circumference (cm)	21.5	*3.43*	16-26
Final circumference (cm)	20.5	*1.99*	17-22

The partial mutton forequarters had significantly ($P < 0.05$) lighter weight and smaller circumference compared to the whole mutton forequarters. On average there was a significant percentage increase ($P < 0.05$) in length for both mutton forequarter cuts after stretching/shaping. The lamb forequarter partial cuts also had significantly ($P < 0.05$) lighter weight then the whole sample. However, there was no significant difference ($P > 0.05$) in length or circumference between the whole and partial cuts. This shows that for both the mutton and lamb forequarters the preparation of a partial cut as expected resulted in a lighter cut weight meaning that a larger proportion of the original forequarter is downgraded and goes into trim. However, the meat from the partial cut is leaner and thus more likely to attract a higher price, counteracting the downgrade of the extra trim. Overall, the change in length and circumference shows that there was a change in shape of the product tested.

Table 59: Predicted means (av. s.e.d.) as a percentage for a decrease in weight (relative to the untrimmed weight) and circumference, and increase in length for mutton and lamb forequarters.

	Full	Partial	*Ave s.e.d.*
Mutton			
Decrease in weight (%)	22.8a	52.6b	*2.2*
Increase in length (%)	16.5a	3.5b	*2.6*
Decrease in circumference (%)	13.8a	-2.2b	*2.2*
Lamb			
Decrease in weight (%)	21.2a	61.3b	*3.2*
Increase in length (%)	12.5a	7.9a	*4.2*
Decrease in circumference (%)	5.8a	0.60a	*4.3*

Means followed by a different letter in a row (a, b) are significantly different ($P < 0.05$).

In Figure 48 and Figure 49, images of the two types of forequarters are shown, along with slices from the forequarters after reforming using the shaping device.

Figure 48: Partial forequarter (left to right) boneless partial forequarter, after sample has been through SmartShape, sliced samples, cooked 15 mm samples and cooked 2 mm samples.

Figure 49: Whole forequarter (left to right) boneless full forequarter, after sample has been through SmartShape, sliced samples, cooked 15 mm samples and cooked 2 mm samples.

Observations from the photos recorded on all samples show that overall both the mutton and lamb forequarters held their shape relatively well. This indicates that once the meat has been frozen, the round shape given by the SmartShape™ machine is maintained. The middle image in Figure 47 and Figure 48 show that slices based on the partial forequarter contain less fat than those based on a full forequarter.

Observations on the effectiveness of the commercial protein binder showed that it was mostly successful in binding the forequarter muscles together. However, there was some variation and it is suspected that this was due to inconsistencies in the application of the protein binder due to the complexity of the arrangement of the forequarter muscles. Pre-experimentation studies indicated that forequarter muscles would not satisfactorily bind without the use of a protein binder

Conclusion

The SmartShape™ prototype is able to successfully reshape odd shaped sheepmeat primals such as the forequarter into a user friendly round shape. After freezing and slicing these samples are able to maintain the round shape. Observations from the use of a commercial protein binder in conjunction with the meat shaping device indicate that care needs to be taken in the application of the binder to ensure that the meat will bind successfully. This type of technology could prove to be invaluable to the processing industry as it is an effective way of reforming odd shaped pieces of meat into one uniform shaped product. This SmartShape™ machine has the potential to add value, control portion size and provide a consistent raw and cooked product for consumers which would be of benefit to both the food service and retail industries.

2.4.3 Experiment 14: Pre-*rigor* interventions: the effect on myofibrillar degradation and shear force

Note: this study was conducted in conjunction with Carne Technologies Project No RE-221941: Geesink, G. and Thompson, J. (2008). Utilising the "Boa" stretching technology to improve the quality of hot boned striploins.

Introduction

The ability to produce a tender product in a limited time while reducing inputs is a challenge for the processing industry. Meat tenderness is a function of production and processing factors (Thompson, 2002) and is an attribute that is highly valued by the consumer. Methods to improve the tenderness of meat can be utilised during either the pre-*rigor* or post-*rigor* phases (Hopkins, 2004) and large improvements in meat tenderness can be made through such interventions at the processing stage. One such method of intervention is tenderstretching (where carcases are suspended from the obturator foramen or the aitch bone) which can substantially improve the tenderness in many muscles including m. *longissimus lumborum* (Thompson, 2002). Superstretching is an adaption to the tenderstretch method where carcases are suspended from the obturator foramen and a pulley system is used to draw the tenderstretched hind quarter towards the forequarter. Similar techniques have been used in the past where weights have been used to increase the stretch of tenderstretched carcases (Hopkins, et al., 2000b) and the results have shown that there were additional benefits in shear force when compared to tenderstretched carcases.

The method of boning is another post-slaughter intervention which can have an impact on meat quality and processing speed. Carcases are most commonly boned cold, meaning they have been placed in a chiller for a period of time (usually around 24 hours) prior to boning. The process of hot boning is defined as the removal of muscles in a pre-*rigor* state shortly after slaughter (Sørheim & Hildrum, 2002). There are a small number of processors in Australia who do hot bone, despite the tendency to be associated with poorer quality meat by Australian processors. One of the major constraints of hot boning is that muscles are disconnected from the skeletal framework which increases the risk of cold shortening in muscles (White, et al., 2006). To ensure hot-boned muscles are as tender as possible, their contraction needs to be restricted (Sørheim & Hildrum, 2002).

The many economic benefits for using hot boning include: increased meat yield, energy savings, chiller space minimisation, reduced labour and faster processing (McPhail, 1995). In addition, hot boning allows each muscle to be separated from the carcase pre-*rigor* and treated optimally according to its intrinsic properties (White, et al., 2006), hence improving meat quality. Recent work has shown that if a combination of hot boning and a pre-*rigor* intervention (SmartStretch prototype) is used then tenderness could be improved by 46% at 0 days of ageing and 38% after 5 days of ageing (Toohey, et al., 2008c; Section 2.1.1.1).

The aim of this experiment was to evaluate the effect of different hanging methods Achilles tendon (AT), tenderstretched (TS), or superstretched (SS) and SmartStretch technology on myofibril degradation through Particle Size Analysis (PSA) and shear force and to examine the relationship between the two variables.

Materials and methods

Animals

The current study was based on 30 grain fed beef cattle. All the cattle were female, with a dentition score of 2 and originated from the same feedlot. Animals were slaughtered under the normal practices of the cooperating abattoir, which included head stunning followed by low voltage stimulation.

Treatments and sampling

There were five post-slaughter treatments applied. Three were variations in hanging method: Achilles tendon (AT), tenderstretched (TS, where carcases are suspended from the obturator foramen), or superstretched (SS, carcases are suspended from the obturator foramen using a pulley system to draw the tenderstretched hind quarter towards the forequarter) and two using a meat stretching device including: SmartStretch chilled (SS-Chill) or SmartStretch ice (SS-Ice). One side of each carcase was randomly assigned to a SmartStretch treatment and the other was then randomly assigned to one of the three hanging methods.

For both the SmartStretch treatments the m. *longissimus lumborum* (striploin) (Anonymous, 2005; HAM 2140) was removed from the hot carcase within 40 minutes post death. These samples were then trimmed of subcutaneous fat and processed through the SmartStretch prototype machine whilst still pre-*rigor*. The SmartStretch prototype (licensed as SmartStretch) under development by Meat & Livestock Australia and Meat & Wool New Zealand has a flexible inner sleeve. Once the striploins are placed in the sleeve, air pressure is applied to stretch and shape the meat. Samples were ejected from the SmartStretch machine into a tubular packaging sleeve. After this, samples were either wrapped in two layers of bubble wrap and chilled on a rack in the same chiller as the other carcases (SS-Chill) or placed in an ice bath until samples reached 4º C and then chilled on the same rack as the other samples (SS-Ice). All other carcase sides were held in the chiller for approximately 24 hours and then the striploins were removed.

All 60 striploin samples were cut into three 7 cm long samples, which were randomly allocated to one of three ageing treatments: 1, 7 or 21 days. Samples were frozen at -20º C after their respective ageing period. From these samples, a full range of meat quality traits were assessed including: pH and temperature, shear force, cooking loss, sarcomere length, colour stability, thaw loss and particle size analysis. However, the current study only reports results for shear force, particle size analysis and the relationship between the two.

Particle Size Analysis (PSA)

Particle size analysis was conducted on 2 g samples as previously described (Karumendu, et al., 2009).

Shear force

The Warner-Braztler shear force results were determined using an adapted method from that previously described (Perry, et al., 2001a). These modifications include the dimension size of samples (4x4x5 cm); cooking time (35 minutes) and samples were cooked from a frozen state.

Statistical methods

Analysis of the data was performed in two stages. For the first stage the results for shear force (SF), mean particle size (PS) and the 25% quartile for particle size (LT25) were analysed separately, using a linear mixed model (LMM). Models were fitted using ASREML (Gilmour, et al., 2006). The model contained fixed effects for stretch treatment at five levels (AT, SS-Chill, SS-Ice, SS and TS), ageing as a linear covariate, ageing as a factor with three levels (1, 7 and 21 days) and the interaction of treatment and ageing. Random terms used in the model were date of test, animal, side within animal and finally a random error. All random terms were included as uncorrelated effects. The variances of the random errors were initially allowed to differ across treatments.

The second stage of the analysis focused on estimation of the correlations between: SF and mean PS; and SF and log (LT25). Bi-variate analyses (LMM) were performed with the pairs of dependent variables, taking as PS results the average of the duplicate results of each sample. The bi-variate model included fixed effects for each combination of treatment and ageing for each trait. The random effects included: test date effect for each test; trait × animal effects (correlated across traits but uncorrelated across animals); uncorrelated animal × side effects for the SF trait; and residual effects which were correlated across traits but uncorrelated across samples. The variance–covariance matrix for the residuals was allowed to differ for treatment = AT, for treatment = SS-Chill & SS-Ice, and for treatment = SS & TS.

Results and discussion

The mean PS differed significantly ($P < 0.05$) across stretch treatments and across levels of ageing, with no significant interaction between the two factors. There was an estimated decline of 66.6 µm (se 5.44 µm) in mean PS for 7 day aged loin compared to 1 day aged loin. There was an estimated decline of 108.2 µm (se 5.39 µm) in mean PS for 21 day aged loin compared to 1 day aged loin. PS results may reflect increased fragility in the sarcomere due to increased sarcomere length and/or the degradation of myofibrillar proteins. However in a previous study (Toohey, et al., 2008c; Section 2.1.1.1) where a stretch treatment was compared to no stretch in sheep topsides, the PS results showed there was no difference between stretch treatments but there was an aging effect; the sarcomere length results showed that there was a significant difference between stretch treatments but no ageing effect. Based on this it could be concluded that the higher PS (i.e. larger particles) of the AT treatment in the current study could be due to the physical restraint and this may be better explained by the variance in sarcomere length which is not presented in the current findings. The ageing changes within treatments however are indicative of increased protein degradation (Table 60), an outcome supported by previous studies (Karumendu, et al., 2009). In addition Table 60 shows that at 1, 7 and 21 days of ageing, SS-Chill was not significantly different to any other treatment. However at 1, 7 and 21 days aged, SS-Ice had a significantly higher mean PS than TS and SS. The AT treatment also had a significantly higher PS than SS. This higher PS signifies that there was potentially less myofibrillar degradation and it could be concluded that the SS-Ice treatment resulted in a slower proteolysis rate due to the low temperature and/or shorter sarcomere length. Adjustment of PS results for sarcomere length across treatments would shed additional light on the important mechanism causing change in sarcomere structure.

Table 60: Predicted means, standard error (SE) and LSD ranking for mean PS (µm) and PS (LT25) for the various treatments.

Days Aged	AT Predicted value	AT LSD Rank	SS-Ice Predicted value	SS-Ice LSD Rank	SS-Chill Predicted value	SS-Chill LSD Rank	TS Predicted value	TS LSD Rank	SS Predicted value	SS LSD Rank
					PS Mean					
1	273*(7.5)*	i j	273*(6.7)*	j	262*(7.0)*	h i j	258*(7.8)*	h i	250*(7.7)*	h
7	206*(7.3)*	f g	206*(6.7)*	g	195*(6.6)*	e f g	192*(7.4)*	e f	184*(7.5)*	d e
21	165*(7.4)*	b c d	165*(6.8)*	c	154*(6.7)*	a b c	150*(7.6)*	a b	142*(7.4)*	a
					PS (LT25)					
1	79*(3.2)*	g h	84*(2.7)*	h	77*(2.8)*	g h	74*(3.8)*	d g f	73*(3.4)*	d e g
7	65*(3.0)*	b c e f	72*(2.6)*	d g	66*(2.5)*	c d	69*(3.1)*	c d	67*(3.1)*	c d
21	68*(3.0)*	c d	65*(2.8)*	b c e	64*(2.8)*	b c	58*(3.2)*	a b	51*(3.1)*	a

Means within a trait having no letter in common under LSD Rank are significantly different (*P* = 0.05).

Analysis of LT25 indicated a significant interaction (*P* = 0.03) between treatment and ageing (Table 60), whilst the variation of the random error was not significantly different across treatments. Hence mean PS differences between levels of ageing depends on treatment. For example, between 7 and 21 days of ageing there was no significant change for AT and SS-Chill treatments compared to the other treatments. Based on the mean PS results, SS-ice treatment in particular may also have been expected to show no difference.

The shear force results showed there was a significant difference across stretch treatments and a linear trend with the period of ageing as shown in Figure 50. From the coefficients SF declined by 0.47 Newton's (s.e. 0.09) for each day of ageing (up to 21 days).

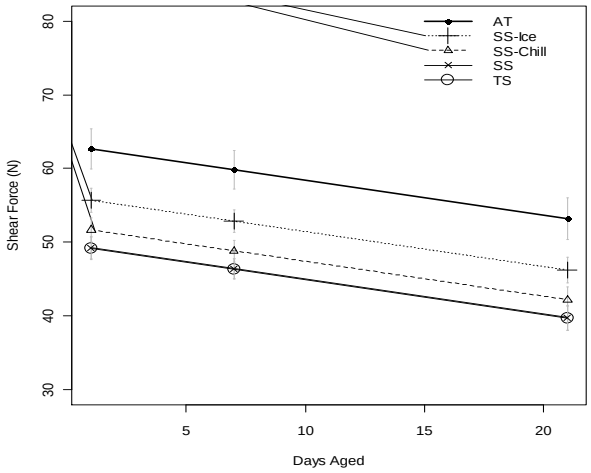

Figure 50: Predicted shear force (N) means with standard errors.

The significant difference between treatments was such that the AT had a significantly higher shear force value at 1, 7 and 21 days when compared to all other treatments. This result supports previous studies which have shown that carcases hung by the Achilles tendon have a significantly higher shear force when compared to tenderstretched and superstretched carcases (Hopkins, et al., 2000b). This result also indicates that hot boned samples were restrained and prevented to contract when treated through the SmartStretch prototype. This outcome is supported by previous work with the same prototype where mutton topsides had an improved shear force at both 0 and 5 days of ageing (Toohey, et al., 2008c; Section 2.1.1.1). The SS-Ice treatment had a significantly lower shear force than AT, but higher than all other treatments, indicating that during rapid chilling of the

muscles in an ice bath, the packaging did not completely prevent cold-shortening. Also, based on the mean PS results the muscle from the SS-ice treatment exhibited less myofibril degradation having higher absolute values than all other treatments except the AT treatment. There was no significant difference between SS-Chill, SS or TS at 1, 7 or 21 days aged and no significant ($P > 0.05$) interaction effect between ageing and treatments.

Table 61 reports the estimates of the correlations between SF and each of the two variables (PS Mean and LT25). These correlations are for a single result obtained for both the SF and the PS test, with the sample tested given the same treatment and aged for the same duration. The correlations are derived from samples within the same animal, but not necessarily the same side, nor necessarily tested on the same day. Estimates of the standard errors of the correlation estimates are also given and a 95% confidence interval provided for the estimate. The latter values were obtained using Monte Carlo simulation.

Table 61: Estimates of the correlations, standard error (SE) and 95% confidence interval (95% CI) between Shear Force and each of the two variables (PS Mean and LT25).

Traits	Treatment	Correlation	SE	95% CI
SF & PS Mean	AT	0.28	*0.16*	(-0.06, 0.54)
	SS - Ice	0.16	*0.09*	(-0.02, 0.32)
	SS - Chill	0.16	*0.09*	(-0.02, 0.32)
	TS	0.08	*0.12*	(-0.13, 0.30)
	SS	0.08	*0.12*	(-0.13, 0.30)
SF & LT25	AT	0.09	*0.17*	(-0.26, 0.40)
	SS - Ice	0.20	*0.08*	(0.03, 0.36)
	SS - Chill	0.20	*0.08*	(0.03, 0.36)
	TS	0.08	*0.11*	(-0.14, 0.30)
	SS	0.08	*0.11*	(-0.14, 0.30)

Shear force was positively correlated with the two PS traits (Mean and LT25), but the correlations are not strong (Table 61). These low correlations do not differ from recent studies where the correlation was examined between PS, LT25 and shear force (Karumendu, et al., 2009). This suggests that myofibril degradation does not describe well the variation in meat tenderness in the current study.

Conclusion

The pre-*rigor* interventions examined in the current study had a positive effect on meat tenderness, with traditionally hung AT carcases having a higher shear force when compared to all other treatments. The hot boned meat samples used for the SmartStretch prototype treatments, in particular the SS-Chill treatment, proved to be an acceptable alternative method of processing when compared to the conventionally chilled AT, SS and TS treatments. Particle size varied between the various processing interventions with AT and SS-Ice exhibiting a larger particle sizes than other

treatments and the lack of stretch and low temperature respectfully may have attributed to the lack of degradation. The weak correlations between shear force and each of the two variables (PS Mean and LT25) suggests that particle size did not describe the variation in meat tenderness well in the current study.

2.4.4 Experiment 15: Comparison of the G2 Tenderometer and the Lloyd Texture Analyser for measuring shear force in sheep and beef meats

Introduction

Several different instruments have been used to test aspects of meat toughness, but the best known is that based on the Warner–Bratzler (WB) shear (Bourne, 2002) providing objective measures of the shear force required to shear meat samples of specified dimensions in half. The stainless-steel blade of the device comes in various configurations and the application of the blade to the sample can be in either a tension mode (cutting up through the sample) or in a compression mode (cutting down through the sample). These variations are viewed by some as departures from the very specific definition of WB shear force (Wheeler et al., 1997), but as outlined by Purchas (2004) alternative forms of the basic system have been used to measure the toughness of cooked meat samples. An alternative machine, known as a Tenderometer, was developed by the Meat Industry Research Institute of New Zealand (MacFarlane & Marer, 1966) and it uses a blunt wedged-shaped 'tooth' to shear through the sample. The Tenderometer subsequently underwent further development such that the shearing action was controlled pneumatically, instead of by a carriage driven by an electric motor. The relationship between the data obtained from the Tenderometer and an Instron Materials Testing machine using a WB type shear was first established by Bouton & Harris (1972) who reported a high correlation (r = 0.94). Further work by Graafhuis, Honikel, Devine, & Chrystall (1991) using the upgraded version developed a linear model to relate data obtained by both machines:

WB Shear force (kg of force) = 0.63 x Tenderometer (kg of force) + 0.61

Further to this Peachey, Purchas, & Duizer (2002) also reported a high correlation (r = 0.93) between the Tenderometer and an unnamed device fitted with a WB type square blade shear when tested on meat from steers and bulls. Based on the relationship of Graafhuis, et al. (1991) WB values are ~64% of Tenderometer values and several studies in New Zealand have based their assessment of shear force on the Tenderometer (e.g. Rosenvold, et al., 2008). Knowing the difference between instruments is important when comparing absolute values across experiments as illustrated by Rosenvold, et al. (2008). Recently a new version of the Tenderometer has been developed called the G2. The intent is to provide the processing industry with a cheaper more, portable easily maintainable instrument for testing shear force than instruments that use a WB device such as the more versatile Lloyd Texture analyser. The G2 uses an electric linear motor to compress the sample under constant speed, but still retains the blunt wedge-shaped 'tooth' (Cummings, Pitt, Simmons, McGurk, & Daly, 2008) which has more of a biting action (Purchas, 2004) and like the Lloyd Texture analyser with a WB type blade fitted can provide a force deformation curve under constant displacement. In Australia numerous studies have been conducted using the Lloyd Texture analyser and objective measures of toughness obtained from this Lloyd instrument have been related to sensory assessments of both beef and sheep meat (e.g. Hopkins, et al., 2006 and Perry, et al., 2001a). This work has provided a guide which allows estimates of sensory toughness for sheep or beef meat without the high cost of undertaking sensory testing. Since at least one Australian processor has started to use the G2 for auditing their system they must know how data from this alternative instrument relates to other objective methods which

have been used to underpin previous measurements and thus indirectly indicate likely sensory results. Thus to facilitate the commercial application of the G2 a series of comparison studies were undertaken against a Lloyd Texture analyser using a type of WB shear. This paper reports on the results of those studies.

Materials and Methods

Samples and measurements – Experiment 1

The lumbar section of the *m. longissimus lumborum* (LL) was taken from one side of 26 sheep carcasses and divided into cranial and caudal samples with an average weight of 73 g (60–70 mm length, 40–50 mm width, 20–25 mm thick). Details of the processing of the carcasses were outlined elsewhere (Hopkins, Stanley, Martin, Toohey, & Gilmour, 2007), but they were aged for 7 days post-slaughter (4-5°C). Samples (cooking blocks) were cooked from frozen in plastic bags at 71°C for 35 min in a water bath, removed and cooled in water and stored chilled overnight (4-5°C) until testing based on the method developed by Hopkins & Thompson (2001). The samples were allocated in a balanced design to cooking batches (1 or 2) and instrument Lloyd (Model LRX, Lloyd Instruments, Hampshire, UK) or Tenderometer (Fix-All Services, Hamilton, New Zealand; Figure 51). The Lloyd instrument had a vee-shaped cutting blade that sheared down through the sample and the wedged-shaped 'tooth' of the Tenderometer was illustrated by Purchas (2004). Six sub-samples (replicates) from a cooked sample allocated to a particular instrument, with a cross-sectional area of 1 cm^2, were prepared for testing by cutting strips along the grain of the muscle. Such cuboidal sub-samples are a departure from the cylindrical samples used within the strict WB shear definition (Purchas, 2004), but such samples have been widely used in large Australian studies (Hopkins, et al., 2007 and Perry, et al., 2001a). Within this paper whenever the Lloyd instrument is mentioned this infers that the instrument was fitted with a WB type shear blade and for both instruments peak shear force values are reported.

Figure 51: Shows the shearing head on the Lloyd (left of picture) and the shearing head on the Tenderometer (right of picture).

Samples and measurements – Experiment 2

The lumbar section of the LL was taken from one side of 48 sheep carcasses which had been hot boned and divided into cranial and caudal samples with an average weight of 64 g (similar dimensions to Experiment 1). Half the samples (n = 48) were frozen at Day 0 and the other half (n = 48) aged for 5 days. Sample allocation to ageing was such that for 24 randomly selected carcasses one sample was allocated to each ageing period, for another 12 of the carcasses both samples were allocated to 0 days ageing and the samples for the remaining 12 carcasses were allocated to 5 days ageing. The samples (cooking blocks) were allocated to cooking batches (1 to 6) and instrument (Lloyd or Tenderometer) across ageing days. Cooking, sub-sampling and measurement procedures were the same as for Experiment 1.

Samples and measurements – Experiment 3

This experiment comprised a deeper nested structure than Experiments 1 and 2, and was designed to compare different levels of stretch (Stretch treatments 1, 2 and 3) and two ageing periods (aged 0 and 7 days). First, hot boned topsides (*m. semimembranosus*; SM) were removed from both sides of 24 cow carcasses and pairs of the three stretch treatments were allocated, in a balanced manner, to each carcass (one treatment to each SM). All topside's were stretched using SmartStretch™ technology (Toohey & Hopkins, 2009; Section 2.4.2) and ejected from the SmartStretch machine into packaging with a circumference of 24 cm (ring diameter 75mm, using 70mm diameter (110mm layflat) packaging). Each SM from each carcass was subsequently divided into two transverse halves and the two ageing periods (aged 0 and 7 days) randomly assigned to these halves within each SM. Each half (2 per SM) was subsequently split into two samples

(cooking blocks; 65 g) giving eight samples per carcass. Post cooking, three slices were taken from each sample (1 cm^2 cross-section) and one slice was assigned to one of the two shear force testing instruments and the other two slices to the second instrument, but constrained so that, for each half, three slices were assigned to each testing instrument. Each slice was tested in duplicate using two sub-samples of 1 cm^2 cross-section area from the same slice. Hence six results were obtained for each half by each instrument. Cooking and measurement procedures were the same as for Experiment 1, but with all samples from the same carcass cooked in the same cook batch, three carcasses per cook batch, and with carcasses assigned to batches so that each of the three stretch treatments occurred almost equally often in each cook batch.

Statistical analysis – Experiments 1 and 2

Given the sources of variation in the data (carcasses within experiment, samples within carcasses, cook batch within experiment, etc) linear mixed model (LMM) analysis was used to analyse the data, with analysis undertaken using the statistical package ASReml (Gilmour, et al., 2006). Prior to analyses individual shear force results for each replicate (sub-sample) were first natural log (log_e) transformed to improve variance homogeneity and these results were then modelled as.

log_e (shear force in newtons) = constant + experiment + at(Expt,1) : instrument + at(Expt,2) : (ageing + instrument + ageing x instrument) + *expt : cooking batch* + *expt : carcass* + *expt : carcass : sample* + *error*

The terms in italic were fitted as independent random effects and the *error* term corresponds to residuals within each sample (i.e. sub-samples with samples). The error variances were originally allowed to differ for each ageing × instrument combination. The fixed effects part of the model allowed for differences across experiments, differences across instruments within Experiment 1 and for differences across ageing × instrument combinations within Experiment 2.

Statistical analysis – Experiment 3

A similar statistical approach to analysis of data for Experiments 1 and 2 was used to analyse the data for Experiment 3. The following model was fitted:

log_e (shear force in newtons) = constant + treatment (stretch) + instrument + ageing + (treatment x instrument x ageing) + *random terms* + *error.*

The random terms consisted of effects for carcass, SM within carcasses, halves within SM, samples within halves, slices within samples, cook batch, interaction effects between ageing and the above random effects, and between instrument and these effects (excluding the confounded terms).

The error variation (i.e. variation for duplicate results within a slice) was allowed to differ for the two instruments (Lloyd and Tenderometer).

It should be noted that the error variance for Experiments 1 and 2 differed to that for Experiment 3. For the former it was the variation of individual test results across sub-samples within a sample whilst for Experiment 3, since tests were performed in duplicate on each slice, the error variance was the variation within sub-samples within slices within samples. Hence the former included variation across slices whilst this was separately extracted for Experiment 3.

Results

Experiments 1 and 2

On the log scale, the error variances in Experiment 2 were not significantly different ($P > 0.05$) across the four ageing × instrument combinations (Lloyd 0.013 *v*. Tenderometer 0.015), but did differ significantly ($P < 0.05$) to the error variances obtained in Experiment 1, wherein the error variances differed for the two instruments (Lloyd 0.024 *v*. Tenderometer 0.040). The error variation, still on the log scale, was larger for Experiment 1 (either instrument) than for Experiment 2, and in Experiment 1 the error variation was larger for the Tenderometer than for the Lloyd.

For the fixed effects, there was a significant difference ($P < 0.001$) between experiments for shear force (Figure 52). This is not surprising as this also encompasses an ageing comparison. Within Experiment 2 there was no significant ($P > 0.05$) interaction between instrument and ageing (0 and 5 days). Figure 52 presents box-plots of the mean $\log_e$ (shear force: SF) for each ageing × instrument combination, where the mean is based on six sub-samples within each sample (cooking block).

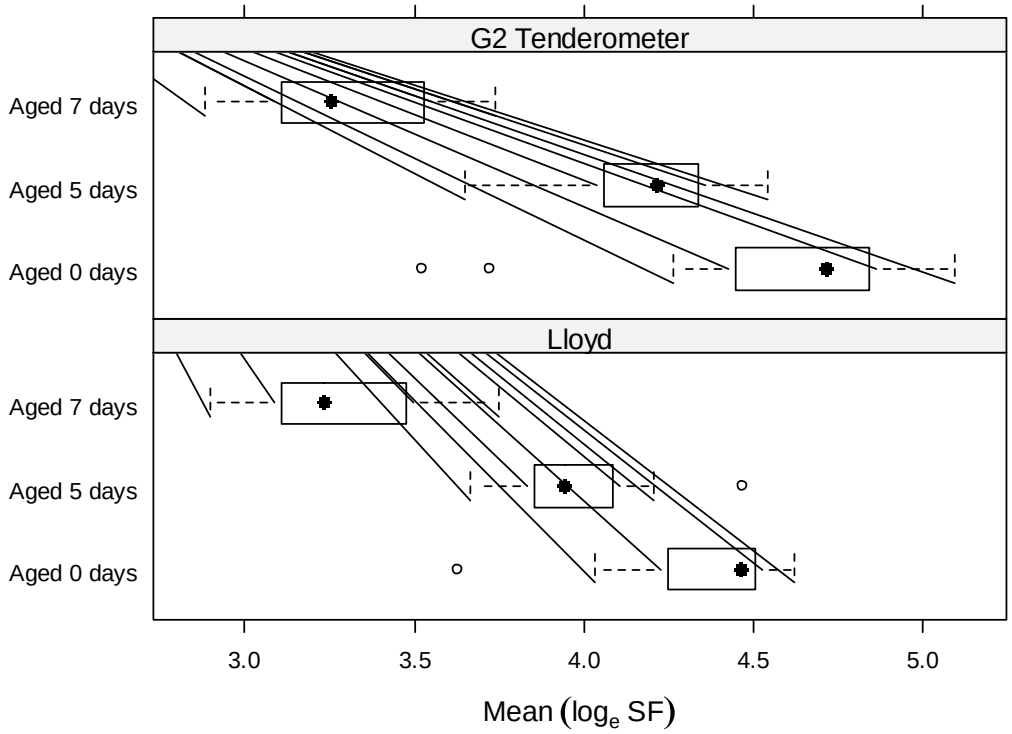

Figure 52: Box-plots of mean loge shear force (Newtons) results for samples within days aged for each instrument (Lloyd and G2 Tenderometer). Aged 7 refers to experiment 1 and aged 0 and 5 to experiment 2.

On the original scale (untransformed), for Experiment 2, the coefficient of variation (CV) for individual sub-sample results within a sample was estimated as 12.1% for both instruments, whereas for Experiment 1 this CV. was estimated to be 15.7% and 19.9% for the Lloyd and

Tenderometer instruments, respectively. These CV need to be multiplied by 0.41 (= $1/\sqrt{6}$) to calculate the corresponding CV for the means of six results (sub-samples) on the same sample.

There was a significant effect ($P < 0.001$) due to ageing and instrument within Experiment 2. The coefficient for instrument was 0.225 ± 0.040 on the $\log_e$ scale such that an average Tenderometer shear force result, on the $\log_e$ scale, was estimated to be 0.22 units higher (in absolute terms) than the corresponding result when using the Lloyd instrument. On the original scale, average Tenderometer shear force results are therefore estimated to be approximately $e^{0.22} = 1.25$ times those for the Lloyd. The predicted means and associated standard errors for shear force on the original scale across carcasses, for each experiment × ageing combination using each instrument are given in Table 62. Also given are pairwise least significant difference (l.s.d.) comparisons of these mean estimates.

Table 62: Predicted shear force (N) means across carcasses and standard errors (s.e.).

The comparison of instruments is given across experiments based on sheep and beef meat.

Experiments/ageing	Number of samples	Instrument	Predicted mean	s.e.	LSD Ranking*
		Sheep meat			
Experiment 1 (7 days aged)	26	Lloyd	28.2	1.4	a
	26	Tenderometer	28.4	1.4	a
Experiment 2 (0 days aged)	24	Lloyd	80.8	3.7	d
	24	Tenderometer	101.3	4.6	e
Experiment 2 (5 days aged)	24	Lloyd	56.2	2.6	b
	24	Tenderometer	70.4	3.2	c
		Beef meat			
Experiment 3 (0 days aged)	48	Lloyd	56.4	2.2	b
	48	Tenderometer	76.6	3.1	d
Experiment 3 (7 days aged)	48	Lloyd	52.3	2.1	a
	48	Tenderometer	71.0	2.8	c

*LSD ranking is applicable only within each meat type separately

The data in Table 62 show clearly that as the samples became tougher the differences in shear force between instruments increased and the Tenderometer produced significantly higher values than the Lloyd.

Experiment 3

The error variances, on the $\log_e$ scale, did not differ significantly for the two instruments. Of the fixed effects, the interaction effects were jointly non-significant ($P = 0.75$). Treatment effects, after adjusting for ageing and instrument effects, were also not significant ($P = 0.33$), whilst both ageing and instrument were significant after adjusting for the each other ($P = 0.002$ and $P < 0.001$ respectively). The coefficient for instrument was 0.306 ± 0.014 on the $\log_e$ scale indicating that an average Tenderometer shear force result, on the $\log_e$ scale, was estimated to be 0.30 units higher (in absolute terms) than the corresponding result when using the Lloyd instrument. On the original scale, average Tenderometer shear force results are therefore estimated to be approximately exp

(0.30) = 1.36 times those for Lloyd. The coefficient of variation for individual results from the same sample, thus including variation across sub-samples within a slice as well as variation across slices within a sample, was estimated to be 12%. This is the same for both instruments and agrees with the estimate obtained for Experiment 2.

Instrument comparison across experiments

A comparison of data obtained across carcasses was also undertaken to develop a model for predicting results for one instrument given the result on the other instrument. Figure 53 shows a plot of sample averages (across sub-samples) for the Lloyd versus the Tenderometer on the $\log_e$ transformed scale (i.e. log of the averages, not averages of the logs), where the points correspond to the comparable pairs of results within carcasses (i.e. same stretch treatment and/or ageing where applicable). Rather than simply regressing Lloyd on the Tenderometer values, which ignores error in both variates, a bivariates normal model (Chatfield & Collins, 1980) is fitted to the data and from this the conditional or expected mean of the Lloyd given the Tenderometer (or vice versa) can be estimated. The mean shear force from this analysis on a $\log_e$ scale for the Lloyd was 3.87 ± 0.03 and 4.11 ± 0.04 for the Tenderometer. The variances for the Lloyd and Tenderometer results across the carcasses were 0.12 and 0.21 respectively with a covariance of 0.15, or correlation equal to 0.93. From this the distribution of $\log_e$ (average Lloyd) given $\log_e$ (average Tenderometer) values was obtained. A (bias adjusted) back transformation was then used to estimate the mean and standard deviation of average Lloyd shear force given average Tenderometer shear force on the same carcass. This corresponds to Lloyd = 2.49 $\text{Tenderometer}^{0.72}$. Figure 53 shows the relationship between the expected value for the Lloyd given a value for the Tenderometer and the range ± one standard deviation around that line for actual values of Lloyd. There was a large variation associated with Lloyd results given a Tenderometer result Figure 54. Part of this variation arose because the results are being predicted on the same carcass, not the same sample within a carcass.

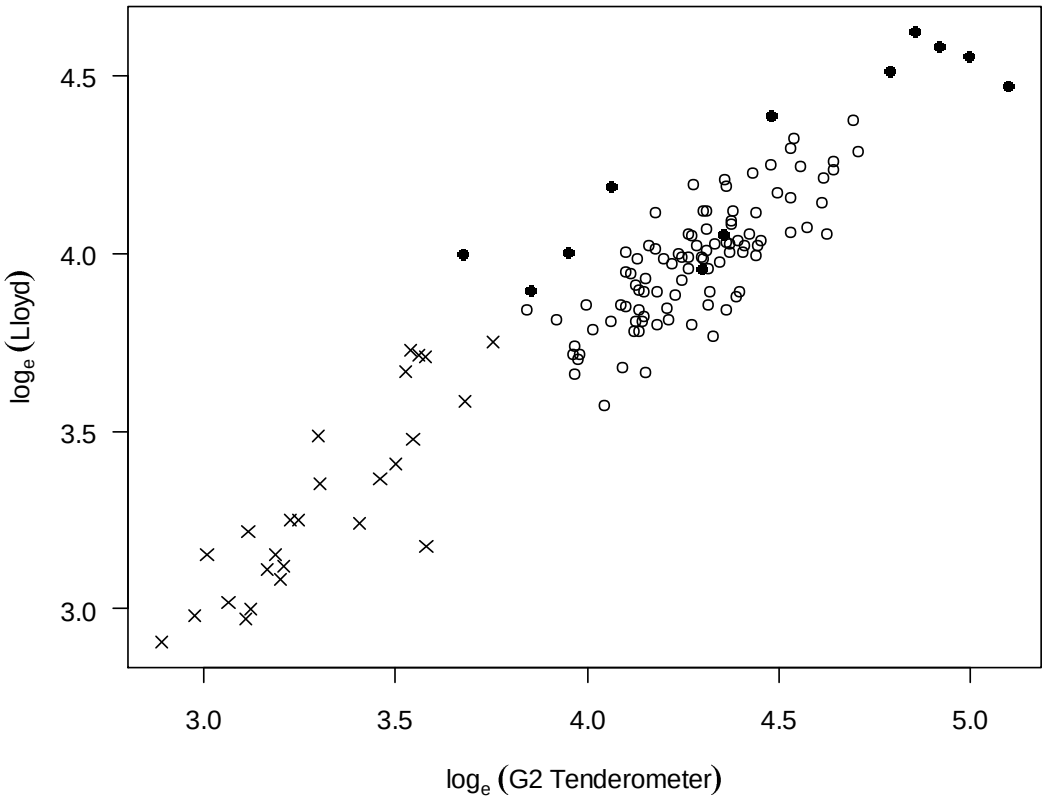

Figure 53: Lloyd versus G2 Tenderometer log^e sample mean shear force (Newtons) results for the same cut plotted on the loge scale (x = experiment 1; ● = experiment 2; ○ = experiment 3)

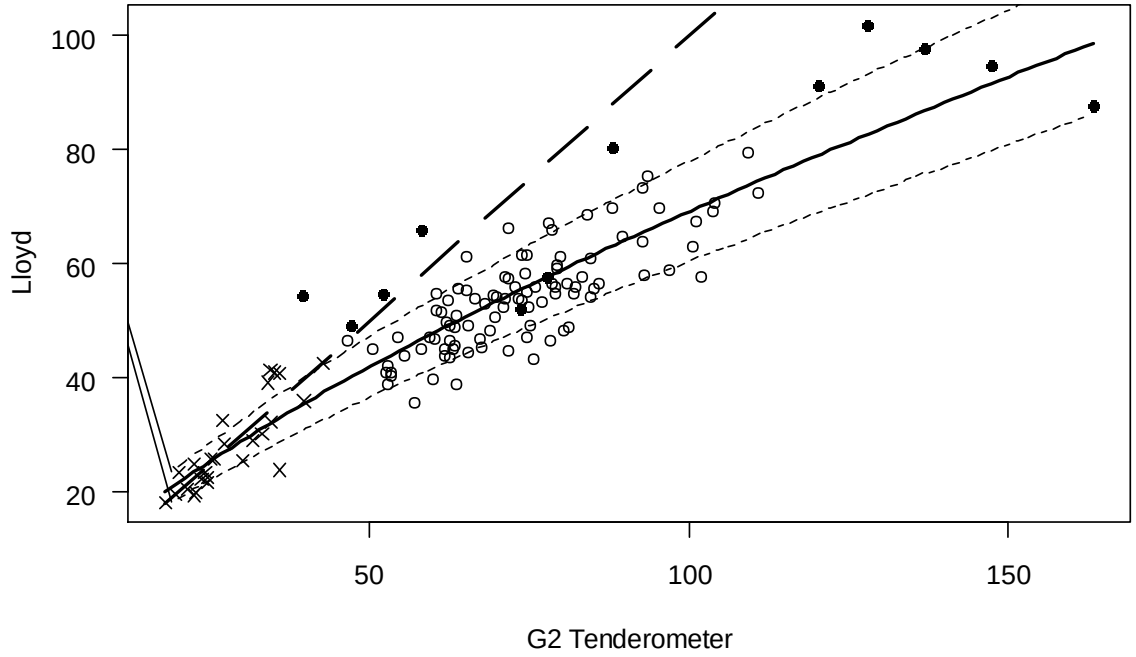

Figure 54: Lloyd and Tenderometer shear force results (Newtons) on the original scale; relationship for expected value for the Lloyd given a value for the Tenderometer (solid line, Lloyd = 2.49 × Tenderometer0.72) with ± one standard deviation bounds shown as the dashed lines (x = experiment 1; ● = experiment 2; ○ = experiment 3). The dashed line for comparison illustrates a 1:1 relationship.

Discussion

Several important observations emerged from the two experiments based on sheep samples. First, for tender meat (Experiment 1) there was no significant difference between the two instruments for the measurement of shear force. However, when tougher samples were compared the difference between the machines was evident and the difference increased as the meat became tougher. There was a 21-Newton difference for 0 day aged samples in Experiment 2, with the Tenderometer giving higher values. This increasing difference between instruments with increasingly tougher meat can also be seen in Figure 53 and Figure 54. Second, since the Tenderometer gives on average higher values than the Lloyd for tougher samples (~1.3 times on average over equivalent samples from Experiments 2 and 3) and since the CV of results on the same sample are approximately the same for both instruments with tougher samples (as shown for Experiments 2 and 3 with CV ~12%), this implies that the variability of results for the Tenderometer are necessarily higher than for the Lloyd on tougher samples. Hence, to have an equivalent standard error for sample mean differences for the two machines one would need $(1.3)^2$ times as many samples using a Tenderometer as a Lloyd. This finding from our study supports the need for 10 slices per cooking block as used by Graafhuis, et al. (1991) when testing meat with the Tenderometer, whereas six slices has been previously shown sufficient (Safari, Hopkins, Munro, Hall, & Thornberry, 2000) when using an instrument with a WB type shearing blade.

Based on the results from Experiments 2 and 3, the Lloyd measures a shear force ~75–80% of the Tenderometer. This is higher than the estimate found by Graafhuis, et al. (1991) when using an earlier version of the Tenderometer. Although Peachey, et al. (2002) reported a high correlation between an earlier version of the Tenderometer and an unnamed device fitted with a WB square blade the absolute difference between measures with the two instruments was not given. These workers claimed that the two instruments were measuring similar characteristics of the meat, but high correlations do not prove this is the case, whereas the comparison they provided between instruments and trained panellists for traits like toughness, chewiness, hardness and cohesiveness did suggest that the two instruments were measuring similar characteristics. The difference in absolute values between instruments may well be due to the shearing device, with the Lloyd having a sharper blade than the Tenderometer which has a much blunter shearing blade. Therefore, it is feasible that when confronted with tough samples this results in the recording of higher values by the Tenderometer. In their study it appears Graafhuis, et al. (1991) compared slices of cooked meat from within samples using the two different instruments, and applied regression analysis to the data. This approach is influenced by the variation in both variables in the regression model (i.e. errors in variables regression) and can lead to biased and inconsistent estimates. The approach adopted for the results from the three experiments in the current study, and presented in Figure 53 and Figure 54 overcomes this limitation to some degree.

In the study of Rosenvold, et al. (2008) a shear force threshold of 60 Newtons was used for consumer acceptability when analysing beef data based on measurement using the Tenderometer and this was extrapolated from Australian data that had related shear force data generated with a Lloyd to consumer acceptability. The exploration was based on the relationship between instruments published by Graafhuis, et al. (1991). Based on the results in the current study the threshold would change and for these purposes it is important to know what the relationship is in absolute terms. Ultimately for Australian processors the relationship between the Tenderometer and sensory data using the MSA system (Thompson, 2002) is required for the G2 to be a useful auditing tool. Until this is established the relationship established in this paper can be used to derive thresholds indirectly.

Conclusions

The G2 Tenderometer is a compact device that is suited for use as a quality assurance tool within a processing works. Data on shear force generated by the G2 are not equivalent to those generated by a Lloyd and use of the G2 will require more sub-samples (replicates) to be tested per sample to achieve an equivalent level of precision to that of a Lloyd texture analyser. As a guide only, a conversion of 0.75–0.80 for Tenderometer measured samples of average toughness (50–80 Newtons) could be applied in those cases where a comparison with Lloyd results was desired. Otherwise the model outlined in this paper can be used.

2.5 Objective 5

Deliver technical support for the running and maintenance of the Australian modified prototype unit during the full business development of phase 2 (12 months), specifically by providing technical input in a minimum of 6 plant demonstrations and/or technical trials.

A large number of successful demonstrations (Section 2.5.1) were undertaken (n = 30) from which 4 MDC projects emerged. Supporting this work was the development of a standard operating procedure (Appendix 8.3) for operating the machine along with a full operational manual (Appendix 8.2). From both demonstrations and the R&D program a series of suggestions were made which lead to significant modification of the machine over the life of the project. These have been used to assist in the construction of a specific machine for use by Cargill Australia Beef in their progression

into phase 2 of a MDC project and commercial application. The continuing interest from companies for further demonstrations to be under taken after this finalisation of this current project demonstrates that there is real potential for more wider spread adoption of the technology.

2.5.1 Demonstrations to industry

Industry & Investment NSW undertook 30 demonstrations (or site visits) with the machine to 23 companies in five states between September 2008 and April 2011. Four companies took the opportunity to further development products for their own clients and markets through MDC projects – Gotzingers, Chef's Partner, Cargill Australia Beef and HW Greenham and Sons Pty Ltd. One of these companies, Cargills, has proceeded to Stage 2 and has developed a machine to operate in their plant.

A summary of the demonstrations, feedback and results are presented below in Table 63.

Table 63: Demonstrations of the SmartShape/SmartStretch technology to industry.

Date	Company	Market	Demonstration	Feedback	Result
5th September 2008	Chef's Partners/Australian Agricultural Company, Brisbane Qld	One of Queensland's leading suppliers of premium quality portion controlled meats.	Injected beef topside.	Positive	Requested trial of machine
8th – 9th October 2008	Tabro and Yarra Foods, Victoria	Tabro Meats is an abattoir and Yarra Foods is a global food supplier to the food service industry.	Cold-boned injected beef striploins and hot-boned beef striploins.	Preference for a more automated system, with an automated loading device on top and automated ejection on bottom.	No further interest
16th October 2008	Teys Bros, Brisbane Qld (held at Earlee Products, Wynnum Central)	Beef processing and value adding company	Cold-boned injected beef.	A range of rubber and packaging sizes are needed.	A second demonstration. An intermediate ring size was developed.

Date	Company	Market	Demonstration	Feedback	Result
4th and 17th March 2009	Australian Country Choice, Brisbane Qld	Supplies beef and veal to Coles Supermarkets and export markets.	Cold-boned injected and fresh beef striploin, glued cold-boned beef tenderloin, Cold-boned injected topside, cold-boned injected rump centre, cold-boned injected rump eye. On the second visit – cold-boned beef cuts injected with kiwi fruit brine.	Could find no tenderness benefit for hot-boned beef over tenderstretching, but was interested in the shaping component and passed the samples to the marketing department. The kiwi brine injected samples produced at the second visit resulted in samples being evaluated by clients in Japan. Marketing aspects were also discussed.	No further interest.
5th March 2009	Chef's Partner, Brisbane Qld	One of Queensland's leading suppliers of premium quality portion controlled meats. Assessed: individually portioned rump pieces and thinly sliced chuck pieces	Cold-boned beef topside, rostbiff, glued tenderloin, injected outside flat.	The company was very impressed with the shape and could see the potential for market development. Product was taken for evaluation.	Proceeded to Stage 1 of an MDC project
5th and 24th March 2009	Gotzinger Smallgoods, Brisbane Qld	Premium smallgoods manufacturer Assessed: cooked silverside for the domestic market	Cold-boned injected beef outside for making silverside.	Impressed with shape and lack of wastage during slicing. Customer feedback was sought.	Proceeded to Stage 1 of an MDC project. Cost benefit analysis completed that showed that the company did not produce enough silverside to make this a viable product.

Date	Company	Market	Demonstration	Feedback	Result
5th and 25th March 2009	Topcut	Premium supplier of fresh meat and portion controlled and value-added products to the food service industry. Assessed: glued tenderloins.	Cold-boned glued beef tenderloins	Glued ends of the tenderloin did not remain in place.	No further interest
28th July 2009	EC Throsby, Singleton NSW	Hot-boning beef abattoir. Assessed: shaping of hot-boned beef.	Hot-boned beef topside and hot-boned beef cube roll.	Keen to try other cuts and requested cube rolls in packaging 95 – 105mm as an alternative to wrapping by hand.	The company liked the concept and were keen to support research, regardless of having no commercial interest in the technology.
3rd – 4th August 2009	Beak and Johnstone, Sydney NSW	Food supply company focussed on portion control. Assessed: improvement in yield and portion control for existing major hotel customer.	Cold-boned rostbiff and cold-boned glued beef tenderloin.	Concern over excess purge and yield losses. Bound tenderloin was unsuccessfully processed. Impressed with shaping capabilities.	Samples evaluated by overseas clients.

Date	Company	Market	Demonstration	Feedback	Result
4th -5th August 2009	AJ Bush and Sons, Sydney NSW	Meat proceesing company with a chain of retail outlets. Assessed: improved yield of existing roast beef and crumbed schnitzel from injected outside flats. Alternative to lamb shoulders currently being netted.	Cold-boned lamb forequarters and cold-boned injected beef outside flats.	Concerns at failure of injected outside flats to retain shape after ageing. Lamb shoulders were satisfactory, but no improvement on the current netted product.	No further interest.
12th August 2009	Sheep CRC Board of Directors, Cowra NSW	Sheep CRC co-funded work on reforming boned forequarter sheep meat.	Hot-boned sheep topsides.	Positive.	Not applicable.
29th September – 2nd October 2009	HW Greenham and Sons, Tongala Vic	Hot –boning beef abattoir with a cold-boning plant in Tasmania. Assessed: improved shape and portion control of hot and cold-boned beef. Development of new products for hot-boned cube roll and striploin in line with eating quality benefits of stretching.	Hot-boned cube roll, striploin and inside (cap off)	Very interested in the shaping benefit for hot-boned beef. Felt that it was difficult to improve tenderness in cull cattle.	Proceeded to a Stage 1 MDC project.

Date	Company	Market	Demonstration	Feedback	Result
4th November 2009	Teys Bros, Brisbane Qld	Beef processing and value adding company. Assessed: cooked value added products for the domestic and export markets. Seeking to compete with the cooked chicken market with small cooked beef roasts.	Cold-boned fresh and injected beef outside flat (10cm lengths), cold-boned fresh and injected beef cube roll (10cm lengths), cold-boned fresh and injected rostbiff and cold-boned fresh and injected beef rump.	Fresh and injected product did not present well after cooking. The product was odd-shaped following cooking and there were high cooking losses due to the small size of the cuts, amount of injection, poor sealing of the packaging and temperature of the ovens during cooking.	Agreed to another demonstration with presentation and cooking parameters changed. This demonstration did not occur because the company had a number of other development projects at that time.
5th November 2009	Beak and Johnstone, Sydney NSW	Food supply company focussed on portion control. Assessed: bound tenderloin currently being hand bon-bon wrapped	Bound tenderloins using a liquid glue.	Bound tenderloin (using a different binder to previous visit) was unsuccessfully processed due to inappropriate ring and bag sizes and the separation of the tenderloins during shaping. Liked the technology and its potential.	Not commercially viable.
8th December 2009	Fletcher International, Dubbo NSW	Hot and cold-boned sheep meat export abattoir. Assessed: package breast and flap for hotpot market.	Hot-boned sheep breast and flap, forequarter, short loin and rack	Investigation of breast and flap for hotpot market in China positive, although there were concerns overt the ability to compete with cheap Chinese labour.	No further interest.

Date	Company	Market	Demonstration	Feedback	Result
19th January 2010	OSI, Brisbane Qld	Small goods and portion controlled product supplier to the food service industry. Assessed: portion controlled steak for a new customer.	Cold-boned injected beef topside and eye round.	Samples collected of brine injected and tumbled beef topside and eye round for evaluation by customer.	No further interest.
20th January 2010	Chef's Partner, Brisbane Qld	Billed as one of Queensland's leading suppliers of premium quality portion controlled meats.	Cold-boned beef topside.	Although intended as a trial of the machine/MDC this did not go ahead because of staff changes and changed focus. Some product was produced for client evaluation.	No further interest.
9th February 2010	Cargills, Wagga Wagga NSW	Cold-boned beef processor. Assessed: improved yield and processing efficiency of products in development.	Cold-boned beef topside, outside flat, knuckle and rostbiff.	Positive for shaping in line with the company goals of improving yield, increasing productivity and producing retail ready product.	Proceeded to a Stage 1 MDC project which started 19th April 2010.
10th February 2010	Junee Abattoir, Junee NSW	Cold-boned sheepmeat processor. Assessed: rolled boneless legs and shoulders, topside miniroasts.	Cold-boned lamb forequarter, leg, topside and backstrap.	Liked the concept, but for their customers could not compete with the workable netting of legs and shoulders.	No further interest.

Date	Company	Market	Demonstration	Feedback	Result
10th and 11th March 2010 30th and 31st March 2010	HW Greenham and Sons, Tongala Vic P.PIP.0263	Hot –boning beef abattoir with a cold-boning plant in Tasmania.	Hot-boned beef rostbiff, cube roll, outside flat, knuckle, topside, inside meat. Cold-boned rostbiff, cube roll and outside flat.	Unsuccessful 3 week MDC due to equipment (rubber and packaging) failure.	Remained interested provided the packaging and rubber failure issues were addressed.
11th March 2010	Sealed Air, Tongala Vic	Food packaging supply company whose products include Cryovac.	Machine in operation in a commercial environment.	Discussed commercialising the machine. Positive about concept.	No further interest.
20th April 2010 and 5th May 2010	Cargills, Wagga Wagga NSW P.PIP.0253	Cold-boned beef processor	Cold-boned beef rostbiff, eye of rump, cube roll, outside flat, rump flat section of outside flat, knuckle cover, eye of knuckle, topside, chuck eye log, chuck, bolar blade.	MDC project for value adding to cold boned beef. Testing of shelf life and shape retention of product and evaluation of product by clients. Machine remained on site for 3 weeks. Needed the machine to be able to handle the grain fed cube roll produced by Cargills.	Proceeded to Stage 2 – purpose built machine in November 2010.
29th June – 1st July 2010	HW Greenham and Sons, Tongala Vic P.PIP.0263	Hot –boning beef abattoir with a cold-boning plant in Tasmania.	Hot-boned beef cube rolls. Fix of packaging and rubber breakage issues.	Second MDC project period following addressing of packaging and rubber failure issues. Machine remained on site for 4 weeks to generate samples for evaluation by clients.	Intention was to proceed to stage 2 after a trial of cold boned beef in Tasmanian plant early 2011.

Date	Company	Market	Demonstration	Feedback	Result
17th – 18th August 2010	DBC Meats, Bibra Lake WA	A meat processing company that also produced ready made meals. Assessed: cold-boned lamb legs and shoulders.	Cold-boned lamb shoulders, cold-boned trimmings, cold-boned beef topside and cold-boned injected beef rump.	Concept had been demonstrated by David Carew, therefore machine on site for 2 weeks for development of cold-boned product for evaluation by clients. Impressed with shape retention in the cold-boned beef primals. Disappointed that the machine had trouble ejecting cold-boned lamb into packaging.	Not currently interested, but would be if the machine could adequately shape cold-boned lamb.
31st August – 1st September 2010	V&V Walsh, Bunbury WA	Beef and sheep meat processor and exporter. Assessed: cold-boned lamb legs and shoulders.	Cold-boned lamb shoulders, cold-boned beef chuck roll, topsides and cube roll.	Concept had been demonstrated by David Carew, therefore machine on site for 2 weeks for development of cold-boned product for evaluation by clients. Disappointed that the machine had trouble ejecting cold-boned lamb into packaging.	Not currently interested, but would be if the machine could adequately shape cold-boned lamb.
9th September 2010	WAMMCO and Harvey Beef, Bunbury WA	WAMMCO is a sheep meat processing co-operative supplying export markets. Harvey beef is an export cold-boned beef abattoir.	Cold-boned lamb shoulders and legs, Cold-boned beef topside and rump.	Machine needs to be quicker and more automated. Need to clarify shape retention in cold-boned shaped product. How quickly can it come back out of the packaging?	No commitments, but interested in seeing where the machine goes from here.
21st October 2010	DMC, Dubbo NSW	Meat and seafood wholesaler and retailer	Cold-boned beef cube roll and cold-boned lamb leg	Could see a lot of potential for the machine. Discussed integrating the process into their current marinade lines.	Interest but no commitments.

Date	Company	Market	Demonstration	Feedback	Result
14th to 17th February 2011	HW Greenham and Sons, Smithton Tasmania	High quality branded table beef for domestic and export markets.	Cold-boned beef tenderloin and striploin	Successfully shaped tenderloin top to tail by folding it in half to prevent shearing of the muscles.	Continuing discussions with MLA to potentially move to Stage 2.
12th and 13th April 2011	CSIRO Food Technology, Coopers Plains, Brisbane	Research	Training in the use of the technology to facilitate bound product project	Initial concerns about the efficacy of the PearlE binder, which poorly bound lean red meat that was either shaped or not shaped. Binder issues to be fully addressed before experiments undertaken.	Demonstrations and training successful.

2.5.2 Machine Development

Patent
SmartShape™/SmartStretch™, originally called the “Boa”, was patented internationally, with patent WO 2008/123782 A1 being published on 16th October 2008 (Pitt & Daly, 2008).

The machine’s operation is based on an externally ribbed flexible sleeve surrounded by inflatable bladders that are housed within an airtight chamber (vacuum chamber) that air can be pumped into or out of. Air is pumped out of the chamber to create negative pressure which causes the sleeve to expand, allowing the meat to be inserted. Air is then pumped into the inflatable bladders causing the meat to be compressed by force perpendicular to the direction of the muscle fibres. This also applies peristaltic action, moving the meat towards the same end of the sleeve that it was inserted into. Positive pressure is then applied to the exterior of the sleeve by pumping air into the chamber, forcing the meat upwards and into packaging designed to prevent the subsequent contraction of the muscle placed at the top of the sleeve (Pitt & Daly, 2008).

Figures 1a to 1d (Figure 55) below show the original intent of the patent (Pitt & Daly, 2008). Figure 1a shows a flexible sleeve (rubber) (10) inside a vacuum chamber (12). Figure 1b shows that as air is pumped from the vacuum chamber the rubber expands (14) and a piece of meat (16) can be introduced. Figure 1c shows the meat being compressed as air is pumped into the vacuum chamber, while Figure 1d shows the shaped/stretched piece of meat being pushed through the bottom of the rubber using a piston.

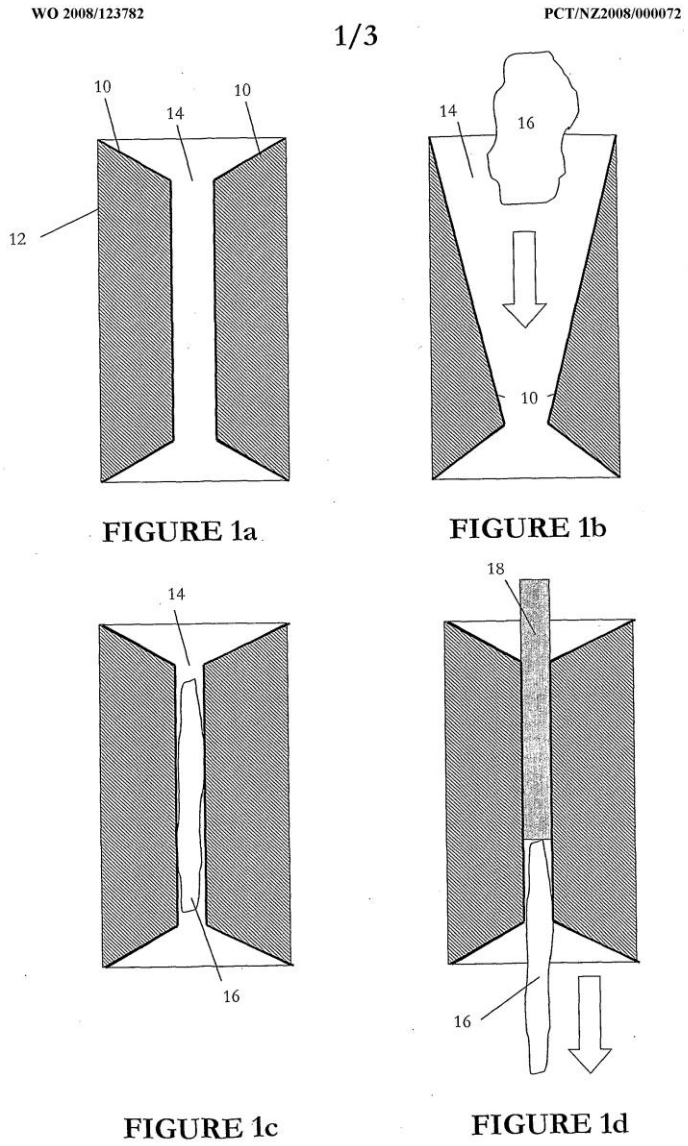

Figure 55: SmartShape/SmartStretch function

Figures 2a to 2d (Figure 56) below show the vacuum chamber in its housing (Pitt & Daly, 2008). This includes the piston (27) forcing the meat through the bottom of the rubber from above. This design also included a plate (29) attached to cylinders (25) that allowed the length of the rubber to be changed, which was intended to allow for some control over the extent of opening and closing of the rubber.

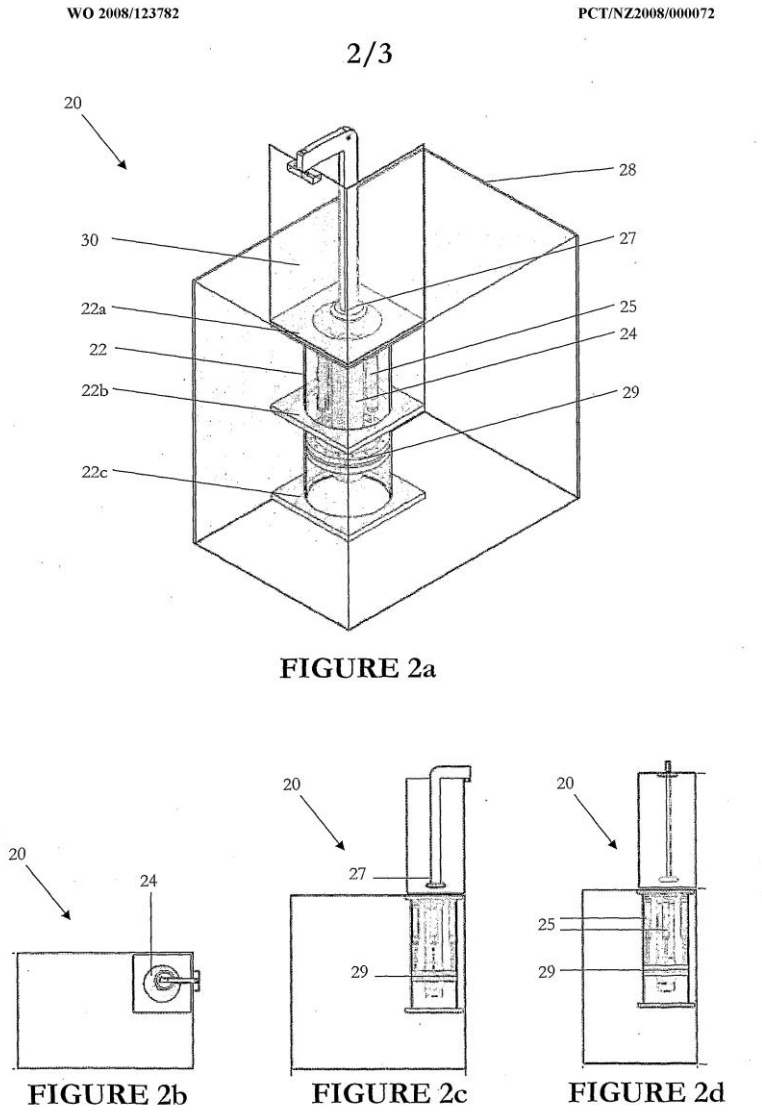

Figure 56: Vacuum chamber with piston

Figure 57 shows a ribbed rubber clamped at either end (320 and 325) contained within a vacuum chamber (335). Airbags (350, 355 and 360) are in place between the rubber ribs and are designed to expand only in the desired direction. Cylinders (370 and 375) are a feature of this design, allowing the rubber to be shortened, but in this case, for the purpose of changing the rubber. In this version peristaltic action was applied to push the shaped/stretched meat along the rubber and out the end, although a piston is also envisaged to assist. There is some mention of a packaging unit, but none was defined in the patent. The original New Zealand prototype is shown in Figure 58.

3/3

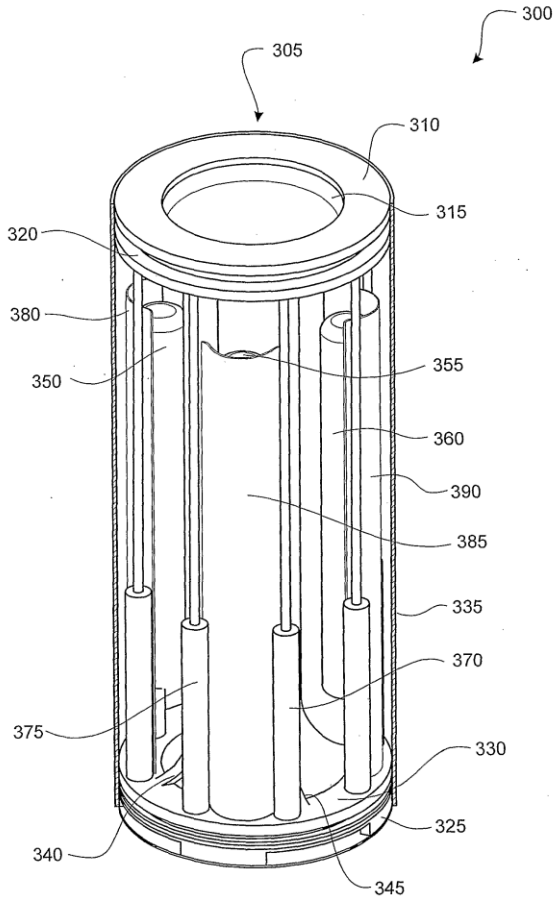

FIGURE 3

Figure 57: Externally ribbed rubber and airbags housed within the vacuum chamber.

Figure 58: Original New Zealand prototype.

Australian prototype

The Australian prototype, called the Boa, and significantly modified from the original design, arrived in Australia in November 2007. It was subsequently located at Fletchers International Exports Pty Ltd plant at Dubbo, NSW for testing. The initial pink rubber was rigid and relatively inflexible (Figure 59) and hence could not expand large enough to cope with larger sheep meat cuts such as whole boneless legs ((Anonymous, 2005), HAM 5060) and forequarters ((Anonymous, 2005), HAM 5047). There were also some issues in getting meat to eject efficiently into the packaging. This was mainly due to the amount of air pressure which had to be applied. To resolve this problem the air pressure in the chamber was increased and then food grade oil was used as a lubricant to aid the ejection of the first few cuts. The piston was used to force some cuts upward toward the packaging, but it did not extend the whole way and this would leave part of the cut hanging from the bottom of the packaging. Based on these initial observations it was considered that a more flexible rubber would be more effective to stretch larger cuts and alterations to the piston were required.

Arthur Pitt from Fix-All Services, along with a New Zealand company, developed a new rubber which was more flexible. The resting diameter was 60mm, which was the same as the initial rubber, but it was easier to fully expand to the required diameter of 150mm. In addition a longer piston was installed (Figure 59) which ensured the whole cut was able to be inserted into the packaging.

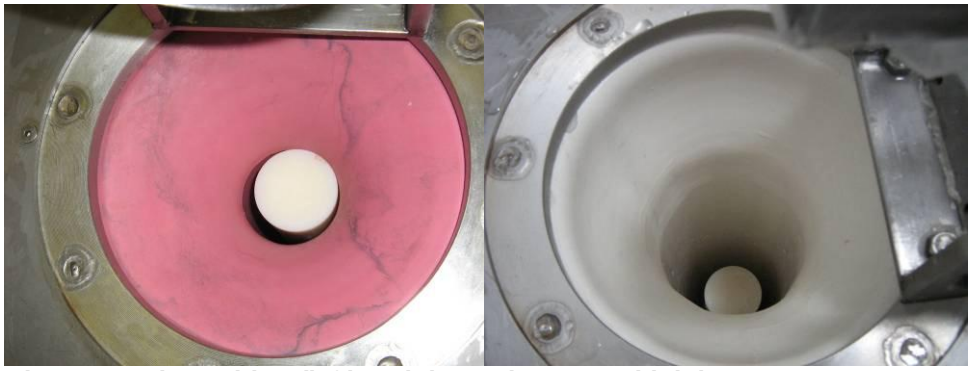

Figure 59: First rubber (left) and the replacement (right) January 2008.

In the early stages of the machine's development ejecting the meat cuts was not an easy task. The pressure required to eject product resulted in the first rubber bursting. This was attributed to be an operator error (ie trying to process a cut that was too large for the set packaging size) and wear and tear on the initial rubber. One of the biggest issues with the machine was that the product was unable to be stretched effectively. This was due to the excess space that the piston took up inside the rubber which inhibited the peristaltic action of the technology and restricted to movement of the meat upward inside the rubber. This caused the operator to rely on the piston to force the meat into the packaging. This would then cram the meat into the packaging and sometimes cause damage to cuts. The piston was subsequently removed which then allowed cuts to eject effectively into the packaging unit using a lower air pressure. Initial Standard Operating Procedures and Safe Work Method Statement were produced in early 2008. These are attached in Appendix 8.3.

Figure 60: Australian prototype in September 2008 (Version 1).

The initial Australian prototype (Figure 60) was in line with patent iteration 2a to 2d (Figure 56) above. A single size packaging unit was attached to the top of the machine. Changing packaging sizes meant unbolting the packaging unit and attaching a new one, which was a laborious and time consuming task.

In line with upgrades to the New Zealand prototype the Australian prototype underwent modifications in March 2009 (Figure 61) and was registered as SmartStretch™ and SmartShape™. These modifications consisted of stronger, longer and more durable airbags which were encased by sail cloth designed by Arthur Pitt, Fix-All Services. The new airbags were designed to prevent any air leaks and to be the same length as the rubber. In addition a new packaging unit was developed with three choices of size that could rotate to change size with the flick of a switch.

Figure 61: Machine upgrade March 2009 (Version 2).

Note the new packaging unit.

In November 2009 the machine underwent further upgrades. These consisted of installing a computer system with touchscreen interface as shown in Figure 62. The new airbags that were developed are shown in Figure 63. The vacuum chamber was also replaced with a newer unit designed to give more space within the chamber and also to allow housing of the new sensors which were installed to facilitate the new automated function of the machine (Figure 64).

The automated function relies on the computer settings that determine the length of time each function requires – expansion of the rubber, gripping meat, selecting the packaging size and

ejection. All of these functions are programmable. The advantage of this automated function is that it reduces the guess work required of the operator for selecting the correct packaging size. It also has the ability to streamline the process and allows the operator two free hands to handle the product.

The automated function relies on the ability of the four sensors in the chamber to align with the four magnets installed on the external ribs of the rubber (Figure 65). If the sensors are unable to locate a magnet then the automated function does not work for that sensor. When a new rubber is installed aligning the magnets to the sensors can be a time consuming task and is an issue that should be addressed in future models of the machine.

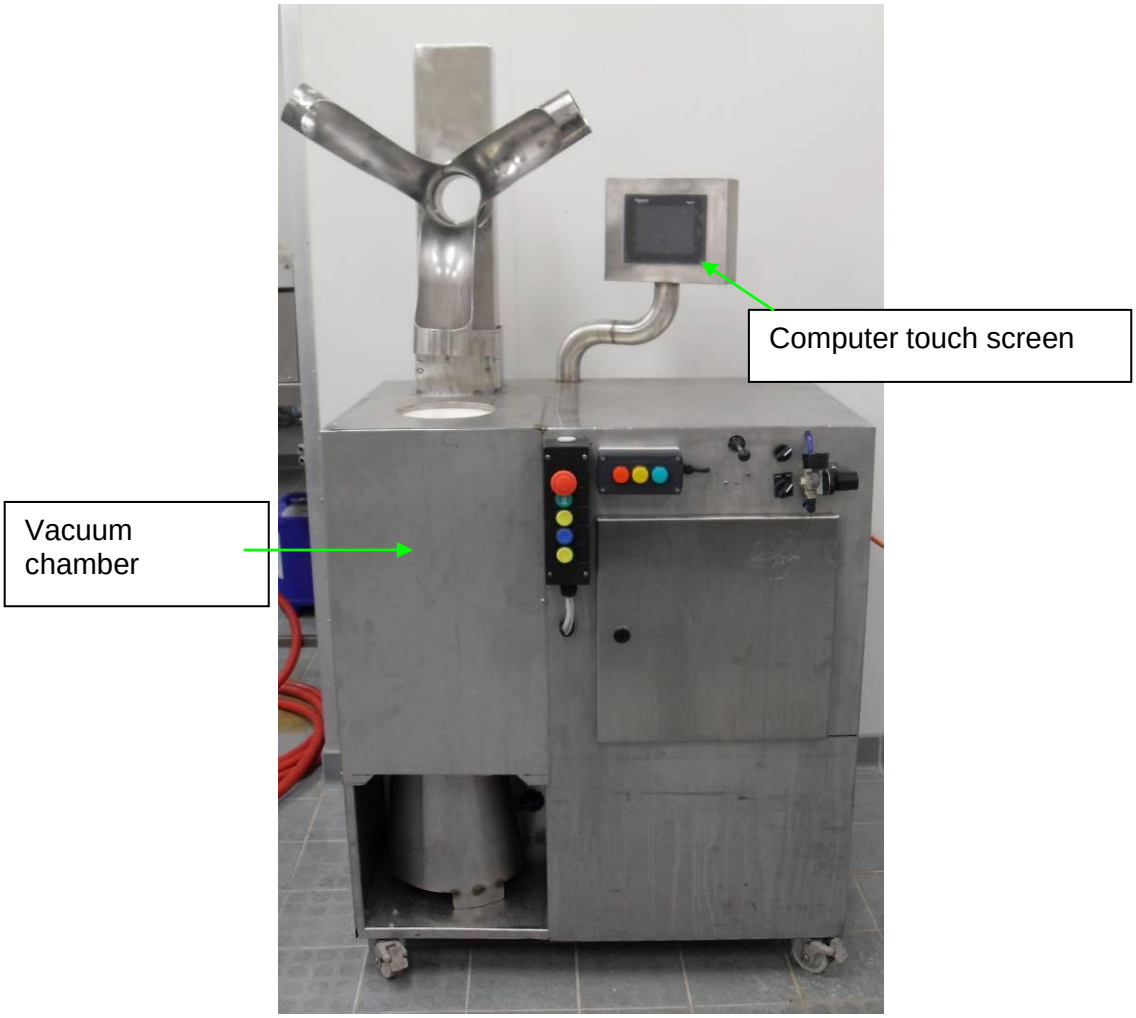

Figure 62: Machine upgrade November 2009 (Version 3). Note the new vacuum chamber and computer screen.

Figure 63: Airbags within the vacuum chamber installed in November 2009.

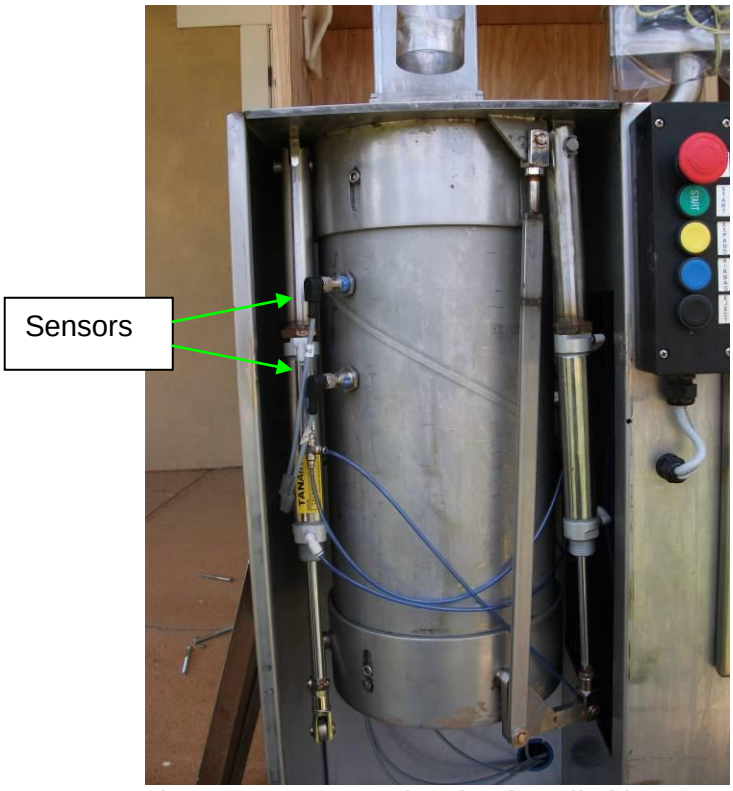

Figure 64: Vacuum chamber installed in November 2009 with sensors for the automated function.

Figure 65: Rubber showing magnets for automatic function sensors.

In February 2010 a “sheep” rubber was developed for the machine. This rubber had a resting diameter of approximately 25mm and was designed to examine the impact of SmartStretch™ on sheep loins initially and potentially beef tenderloins in the future. The external ribs present on the original rubber were removed from this rubber otherwise expansion of the rubber was restricted and it was placed in a PVC sleeve to assist it to maintain its integrity during the expansion phase (Figure 66). A 40mm diameter packaging unit was also developed so as to allow the impact of SmartStretch™ on single sheep loins to be tested. This was for research purposes only and is shown in Figure 67. Whilst undertaking the initial work with the “sheep” rubber problems were observed including the inability of the rubber to expand properly, making it difficult to insert the loins, and over compression of sections of the cuts, which resulted in tight gripping and tearing of meat on ejection. These issues may have been the result of the rubber’s uneven wall thickness, which was the consequence of the rough removal of the ribs. The maximum expansion of this rubber could not be determined because the uneven wall thickness caused uneven expansion along its length. Both sheep rubbers split during evaluation and have not been replaced. If future work were conducted using this “sheep” rubber on either for sheep loins or beef tenderloins a larger resting diameter should be considered.

Figure 66: Sheep rubber in PVC sleeve.

Figure 67: Sheep rubber and packaging unit.

An operating manual for the current version of the machine was produced in February 2010. A copy of this manual is attached in the Appendix 8.2.

Rubber integrity and alternative packaging head

Rubbers began to split and fail in early 2010 with extensive cracking around the top and bottom flanges of the rubbers (Figure 67). This was traced to a manufacturing fault which was rectified in July 2010. Rubber integrity has been maintained since.

Figure 68: Rubber cracking around the flange (left) and a complete breach of the rubber wall (right).

A new packaging unit head (Figure 69) was developed by Fix-All Services to accommodate a different brand of packaging (Globus). Regardless of the packaging brand used it is crucial that the packaging is protected from abrasion otherwise this leads to splitting and failure.

Figure 69: Globus packaging unit for use with Globus packaging.

Further Development

The development of a Stage 2 machine for Cargill Australia Beef was the goal of a meeting in late October 2010 between Industry & Investment NSW, Fix-All Services, MLA and Cargills. Roger Lim from Plant Safety Solutions provided OH&S technical advice about the requirements for upgrading the machine to satisfy OH&S requirements. The engineering changes agreed to for the machine are listed in Section 2.2.3. The recommended sizes of the new rubber, vacuum chamber and packaging unit are attached in the Appendix 8.5.

3 Success in meeting the objectives

The experimental work in this project commenced in 2008 after the development of a standard operating procedure for the SmartStretch™ machine. Initial R&D showed that tenderness of hot boned topsides could be significantly improved by use of the SmartStretch™ machine, such that after 0 days of ageing the stretching caused a 46% reduction in shear force with the benefits still evident even after 5 days of ageing, with a reduction in shear force of 38%. This effect was confirmed in subsequent experiments with hot boned hindlegs which focused on three key muscles

(m. s*emitendinosus,* m*. semimembranosus* and m. *biceps femoris*) to determine the impact of SmartStretch™ on meat tenderness. It was demonstrated that stretching hot boned sheep backstraps (loins) would require further development of a suitable rubber for the machine, but the investment was unlikely to make this worth pursuing. It was also successfully demonstrated that stretching of hot boned sheep sub-primals like the topside could be achieved without manipulation of existing electrical stimulation settings. The project has successfully demonstrated that SmartStretch™ technology could be used by the industry to improve the tenderness of hot boned sheep meat.

A series of experiments found that stretching hot boned beef primals such as the cuberoll and topside taken from cull cows had little impact on meat quality. However the SmartStretch™ technology successfully stretched hot boned topsides, but there was significant variation in the degree of stretch and unfortunately this did not translate into an effect on tenderness. By contrast there was an improvement in striploin tenderness with much less stretch (mean 16.5%), and the effect nearly persisted after 14 days of ageing. Experimentation on young prime cattle showed that stretching hot-boned rostbiffs could reduce shear force by 22% in product aged for 0 days verifying the value of the technology. In those cases where stretching conferred a benefit for both species, there was no indication that any detrimental effects on colour would arise.

The results of the various studies also showed that the requirement to achieve a minimum stretch of 20% before a beneficial effect is detected was not fully supported and indicated that this requirement may vary according to the primal. The wide variation in the level of stretch suggested that the technology needed to be up scaled to cope with the larger size of beef primals on the basis that this will increase the uniformity of the stretch. This recommendation was taken up by Cargills Australia Beef when ordering their own SmartStretch™/SmartShape™ machine. Of particular was the level of interest by beef processors in the ability of the technology to shape cold boned primals as a spin off of the R&D program. Added to this the positive improvement of topside tenderness from the injection with a kiwifruit based solution combined with shaping is more evidence that the project has exceeded all expectations for delivering scientifically credible R&D that has significant commercial potential.

This project also served as the basis of the Masters program for Edwina Toohey which is nearing completion and this has helped to develop her expertise and scientific creditability, with the publication so far of an impressive number of publications.

Overall the project also delivered a large number of demonstrations to industry from value adding companies to processors and this far exceeded the contracted requirements for the project. The success of this segment of the project is reflected in the number of subsequent MDC projects which were also undertaken in association with this project and the continuing requests for demonstrations. The contribution of Barry Lee and David Carew to this aspect of the project was also pivotal in the success of these demonstrations.

4 Impact on the meat and livestock industries

This project has shown that it is possible to achieve tenderness benefits in hot boned sheep meat and to a lesser extent in hot boned beef meat by using SmartStretch™ technology. For application of the technology in the sheep processing industry large, more automated versions of the technology would be required. Given that hot boned sheep meat is frozen and sold overseas in that form it is doubtful whether industry will consider it economical to invest in SmartStretch™ technology for improving tenderness. However there is definite scope for the technology to be used

to bind forequarter meat destined for markets that use 'hot pot' type products and for use to bind loins to increase slice area.

The project has demonstrated that SmartStretch™ technology could be used by beef processors to improve the tenderness of hot boned beef from prime cattle. This opens the way for the adoption of partial boning of lower value cuts to enhance value and may have specific application to carcases that are in the heat toughening zone where the fast rate of pH decline causes ageing to be reduced in the long term. Application of the technology by beef processors who hot bone cull cows is likely to be limited apart from the ability that the technology confers for improving shape. This area offers significant benefits for primals targeted at specific markets. Given that prime type cattle are hot boned routinely in New Zealand automated versions of the SmartStretch™ technology would be particularly relevant in that country.

The potential of the shaping capabilities of the technology (SmartShape™) particularly for beef primals are clearly evident from the results of the project and the interest by industry. Thus the progression of Cargills Australia Beef to the purchase of their own machine, designed specifically for beef is likely to be followed by other companies and this should move the technology to commercial application. There are numerous possibilities and assistance with product development will widen the application amongst companies.

5 Conclusions and recommendations

There is a definite need to undertake work to investigate the ability to bind hot boned sheep forequarters and loins and cold boned beef tenderloins using the SmartShape™ technology. This work is regarded as a high priority given the interest from demonstrations in the scope to improve the functionality of primals like sheep forequarters or beef tenderloins. The benefits to be derived from injecting primals particularly beef and then shaping them using the technology appear significant and further work should be undertaken which combines the use of different plant and bacterial based enzyme solutions and SmartShape™ technology.

This project has combined aspects of fundamental science, development and industry application and the next step is to capitalise on the interest generated in industry, especially amongst beef processors and value adders by seeing commercial units of the technology manufactured. This should include also further demonstration and promotion of the technology in combination with product development. However if the technology is applied for stretching meat then comprehensive research is required to establish the eating quality of such meat as no work has been undertaken in this project to quantify these benefits for primals from prime cattle.

Significant investment by both MLA and MWNZ in the technology has occurred in both countries, however only research undertaken in Australia has been subjected to scientific peer review (through publication) and there are a number of papers that are yet to be written and submitted for publication. Based at least on the Australian work is the potential to prepare industry articles to promote the results of the work and these should also be disseminated to New Zealand industry. Linked to this the scope to integrate the technology with the partial hot boning of other primals aside from the rostbiff from prime cattle is worthy of study and this will be particularly relevant to New Zealand.

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7 Bibliography

Aminlari, M., Shekarforoush, S. S., Gheisari, H. R., & Golestan, L. (2009). Effect of Actinidin on the Protein Solubility, Water Holding Capacity, Texture, Electrophoretic Pattern of Beef, and on the Quality Attributes of a Sausage Product. *Journal of Food Science, 74*(3), C221-C226.

Anonymous. (2003). Evaluation and future direction of innovative red meats, Food Service Providers, Report Project RMICMR.001. Sydney, Australia: Meat and Livestock Australia.

Anonymous. (2005). *Handbook of Australian Meat* (7th ed.): AUS-MEAT Limited.

American Cancer Society (2011) Retrieved 15th March 2011, 2011, from http://www.cancer.org/

Barbera, S., & Tassone, S. (2006). Meat cooking shrinkage: Measurement of a new meat quality parameter. *Meat Science 73*(3), 467-474.

Barrett, A. J., Rawlings, N. D., & Woessner, J. F. (2004). *Handbook of Proteolytic Enzymes* (Vol. 2). Amsterdam, Netherlands: Elsevier Academic Press.

Bekhit, A. D., Han, J., Morton, J. D., & Sedcole, J. R. (2007). *Effect of kiwifruit juice and water pre-rigor infusion on lamb quality*. Paper presented at the 53rd International Congress of Meat Science and Technology, Beijing, China. 377-378.

Bindon, B. M., & Jones, N. M. (2001). Cattle supply, production systems and markets for Australian beef. *Australian Journal of Experimental Agriculture, 41*(7), 861-877.

Bourne, M. (2002). *Food texture and viscosity: concept and measurement* (2nd ed.). San Diego, USA: Academic Press.

Bouton, P. E., Fisher, A. L., Harris, P. V., & Baxter, R. I. (1973a). A comparison of the effects of some post-slaughter treatments on the tenderness of beef. *International Journal of Food Science and Technology 8*(1), 39-49.

Bouton, P. E., & Harris, P. V. (1972). A comparison of some objective methods used to assess meat tenderness. *Journal of Food Science, 37*(2), 218-221.

Bouton, P. E., Harris, P. V., Ratcliff, D., & Roberts, D. W. (1978). Shear force measurements on cooked meat from sheep of various ages. *Journal of Food Science 43*, 1038–1039.

Bouton, P. E., Harris, P. V., & Shorthose, W. R. (1972). The effects of ultimate pH on ovine muscle: water-holding capacity. *Journal of Food Science, 37*(3), 351-355.

Bouton, P. E., Harris, P. V., Shorthose, W. R., & Baxter, R. I. (1973b). A comparison of the effects of aging, conditioning and skeletal restraint on the tenderness of mutton. *Journal of Food Science 38*(6), 932-937.

Brewer, M. S. (2004). Water holding capacity. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 242-249). Oxford: Elsevier.

Bruce, H. L., & Ball, R. O. (1990). Postmortem interactions of muscle temperature, pH and extension on beef quality. *Journal of Animal Science 68*(12), 4167-4175.

Brunsø, K., Bredahl, L., Grunert, K. G., & Scholderer, J. (2005). Consumer perception of the quality of beef resulting from various fattening regimes. *Livestock Production Science, 94*(1-2), 83-93.

Butler, D. (2009). ASReml: ASReml fits the linear mixed model.: R Package Version 3.00.

Chatfield, C., & Collins, A. J. (1980). *Introduction the multivariate analysis*. London: Chapman and Hall.

Christensen, M., Tørngren, M. A., Gunvig, A., Rozlosnik, N., Lametsch, R., Karlsson, A. H., & Ertbjerg, P. (2009). Injection of marinade with actinidin increases tenderness of porcine M.

biceps femoris and affects myofibrils and connective tissue. *Journal of the Science of Food and Agriculture, 89*(9), 1607-1614.

Coombes, N. (2009). DiGGer: DiGGer design generator under correlation and blocking. R package version 0.2-1., from http://www.austatgen.org/files/software/downloads

CSIRO. (2008). The CSIRO Total Wellbeing Diet Frequently Asked Questions. Retrieved from www.csiro.au

Culler, R. D., Jr, F. C. P., Smith, G. C., & Cross, H. R. (1978). Relationship of myofibril fragmentation index to certain chemical, physical and sensory characteristics of bovine longissimus muscle. *Journal of Food Science, 43*(4), 1177-1180.

Cummings, T., Pitt, A., Simmons, N. J., McGurk, J., & Daly, C. C. (2008). *A simple and portable electrical device to measure cooked meat tenderness.* Paper presented at the 54th International Congress of Meat Science and Technology, Cape Town, South Africa. Session 8.2.

Davey, C. L., Kuttel, H., & Gilbert, K. V. (1967). Shortening as a factor in meat ageing. *International Journal of Food Science & Technology, 2*(1), 53-56.

Davis, G. W., Smith, G. C., Carpenter, Z. L., Dutson, T. R., & Cross, H. R. (1979). Tenderness Variations among Beef Steaks from Carcasses of the Same USDA Quality Grade. *Journal of Animal Science, 49*(1), 103-114.

Deepayan, S. (2008). Lattice: Multivariate Data Visualisation with R. Springer, New York.

Desmond, E. M., & Troy, D. (2004). Nutrient claims on packaging. In W. Jensen, C. E. Devine & Dikemann (Eds.), *Encyclopedia of Meat Sciences* (Vol. 2, pp. 903-910): Elsevier Science.

Destefanis, G., Brugiapaglia, A., Barge, M. T., & Dal Molin, E. (2008). Relationship between beef consumer tenderness perception and Warner-Bratzler shear force. *Meat Science 78*(3), 153-156.

Devine, C. E., Hopkins, D., Hwang, I. H., Ferguson, D. M., & Richards, I. (2004). Electrical Stimulation. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (Vol. 2, pp. 413-423): Elsevier Science.

Devine, C. E., Payne, S. R., Peachey, B. M., Lowe, T. E., Ingram, J. R., & Cook, C. J. (2002a). High and low rigor temperature effects on sheep meat tenderness and ageing. *Meat Science, 60*(2), 141-146.

Devine, C. E., Payne, S. R., & Wells, R. W. (2002b). Effect of muscle restraint on sheep meat tenderness with *rigor mortis* at 18°C. *Meat Science 60*(2), 155-159.

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*. *Meat Science 51*(1), 61-72.

Dransfield, E., Etherington, D. J., & Taylor, M. A. J. (1992). Modelling post-mortem tenderisation--II: Enzyme changes during storage of electrically stimulated and non-stimulated beef. *Meat Science, 31*(1), 75-84.

Duffy, R., & Fearne, A. (2009). Value perceptions of farm assurance in the red meat supply chain. *British Food Journal, 111*(7), 669-685.

Dunn, J. L., Williams, S. E., Tatum, J. D., Bertrand, J. K., & Pringle, T. D. (2000). Identification of optimal ranges in ribeye area for portion cutting of beef steaks. *Journal of Animal Science, 78*(4), 966-975.

Edwards, J. S. A., Engström, K., & Hartwell, H. J. (2005). Overweight, obesity and the food service industry. *Food Service Technology, 5*(2-4), 85-94.

Egan, A. F., Ferguson, D. M., & Thompson, J. M. (2001). Consumer sensory requirements for beef and their implications for the Australian beef industry. *Australian Journal of Experimental Agriculture, 41*(7), 855-859.

Engström, R., & Carlsson-Kanyama, A. (2004). Food losses in food service institutions. Examples from Sweden. *Food Policy, 29*, 203-213.

Gee, A. M., & Ross, I. R. (2006). *Protocols for the preparation, fabrication, assembly, cooking, serving, sensory testing and scoring of commercial meat cuts from lamb, yearling and mutton.* Sawtell, New South Wales, Australia: Cosign Pty Ltd.

Geesink, G., & Thompson, J. (2008). Utilising the "Boa" stretching technology to improve the quality of hot boned striploins University of New England, School of Environmental and Rural Science. Retrieved from www.redmeatinnovation.com.au/innovation-areas/eating-quality/products/smartstretch/validation-trials

Geesink, G. H., Mareko, M. H. D., Morton, J. D., & Bickerstaffe, R. (2001). Electrical stimulation -- when more is less. *Meat Science, 57*(2), 145-151.

Gilmour, A. R., Gogel, B. J., Cullis, B. R., & Thompson, R. (2006). *ASReml User Guide Release 2.0*. Hemel Hampstead, HP1 1ES, UK: VSN International Ltd.

Graafhuis, A. E., Honikel, K. O., Devine, C. E., & Chrystall, B. B. (1991). *Meat tenderness of different muscles cooked to different temperatures and assessed by different methods*. Paper presented at the 37th International Congress of Meat Science and Technology, Kulmbach, Germany. 365-368.

Grunert, K. G. (1997). What's in a steak? A cross-cultural study on the quality perception of beef. *Food Quality and Preference, 8*(3), 157-174.

Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector--a review. *Meat Science, 66*(2), 259-272.

Han, J., Morton, J. D., Bekhit, A. E. D., & Sedcole, J. R. (2009). Pre-rigor infusion with kiwifruit juice improves lamb tenderness. *Meat Science, 82*(3), 324-330.

Hartwell, H. J., & Edwards, J. S. A. (2003). A comparative analysis of 'plated' and 'bulk trolley' hospital food service systems*. *Food Service Technology, 3*(3-4), 133-142.

Herring, H. K., Cassens, R. G., & Briskey, E. J. (1965). Further Studies on Bovine Muscle Tenderness as Influenced by Carcass Position, Sarcomere Length, and Fiber Diameter. *Journal of Food Science, 30*(6), 1049-1054.

Herring, H. K., Cassens, R. G., Suess, G. G., Brungardt, V. H., & Briskey, E. J. (1967). Tenderness and associated characteristics of stretched and contracted bovine muscles. *Journal of Food Science 32*(3), 317-323.

Hildrum, K. I., Anderson, T., Nilsen, B. J., & Wahlgren, N. M. (2000). *Improving beef tenderness by restricting rigor mortis contraction*. Paper presented at the 46th International Congress of Meat Science and Technology, Buenos Aires, Argentina. 444-445.

Hoek, A. C., van Boekel, M. A. J. S., Voordouw, J., & Luning, P. A. Identification of new food alternatives: How do consumers categorize meat and meat substitutes? *Food Quality and Preference, In Press, Corrected Proof*

Honikel, K. O. (2004). Conversion of muscle to meat. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 314-323). Oxford: Elsevier Science.

Honikel, K. O., Kim, C. J., Hamm, R., & Roncales, P. (1986). Sarcomere shortening of prerigor muscles and its influence on drip loss. *Meat Science 16*(4), 267-282.

Hopkins, D. (1995). Shape and size limitations for boneless lamb cuts. *Meat Focus International, November 1995*, 445-447.

Hopkins, D. (2004). Tenderizing mechanisms. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences.* (Vol. 3, pp. 1355-1363): Elsevier Science.

Hopkins, D., Garlick, P. R., & Thompson, J. (2000a). The effect on the sarcomere structure of super tenderstretching. *Asian-Australiasian Journal of Animal Science, 13, Supplement July 2000, Volume C.*, 233.

Hopkins, D., & Geesink, G. (2009). Protein degradation post mortem and tenderisation. In M. Ed Du & R. J. McCormick (Eds.), *Applied Muscle Biology and Meat Science* (pp. 149-173): CRC Press, Taylor and Francis Group, USA.

Hopkins, D., Littlefield, P. J., & Thompson, J. (2000b). The effect on tenderness of super tenderstretching. *Asian-Australiasian Journal of Animal Science, 13, Supplement July 2000, Volume C*, 240.

Hopkins, D., & Toohey, E. (2009). Critical adoption and R&D for joint MLA & MIRINZ Inc MQST program, Year 08/09 (Phase 2). Final Report for MLA project P.PSH.0482. (pp. 1-32).

Hopkins, D., Toohey, E., Kerr, M. J., & van de Ven, R. (2011). Comparison of two instruments (G2 Tenderometer and a Lloyd Texture analyser) for measuring the shear force of cooked meat. *Animal Production Science, 51*(1), 71-76.

Hopkins, D. L., Hegarty, R. S., Walker, P. J., & Pethick, D. W. (2006). Relationship between animal age, intramuscular fat, cooking loss, pH, shear force and eating quality of aged meat from sheep. *Australian Journal of Experimental Agriculture, 46*(7), 879-884.

Hopkins, D. L., Stanley, D. F., Martin, L. C., Toohey, E. S., & Gilmour, A. R. (2007). Genotype and age effects on sheep meat production 3. Meat quality. *Australian Journal of Experimental Agriculture, 47*(10), 1155-1164.

Hopkins, D. L., & Thompson, J. M. (2001). The relationship between tenderness, proteolysis, muscle contraction and dissociation of actomyosin. *Meat Science 57*(1), 1-12.

Hopkins, D. L., & Thompson, J. M. (2002). Factors contributing to proteolysis and disruption of myofibrillar proteins and the impact on tenderisation in beef and sheep meat. *Australian Journal of Agricultural Research 53*(2), 149-166.

Hopkins, D. L., & Toohey, E. S. (2006). Eating quality of conventionally chilled sheep meat. *Australian Journal of Experimental Agriculture 46*(7), 897-901.

Hopkins, D. L., Toohey, E. S., Warner, R. D., Kerr, M. J., & van de Ven, R. (2010). Measuring the shear force of lamb meat cooked from frozen samples: comparison of two laboratories. *Animal Production Science, 50*(6), 382-385.

Hopkins, D. L., Walker, P. J., Thompson, J. M., & Pethick, D. W. (2005). Effect of sheep type on meat and eating quality of sheep meat. *Australian Journal of Experimental Agriculture, 45*(5), 499-507.

Huff-Lonergan, E., & Lonergan, S. M. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. *Meat Science 71*(1), 194-204.

Hwang, I. H., Devine, C. E., & Hopkins, D. L. (2003a). The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. *Meat Science 65*(2), 677-691.

Hwang, I. H., Gee, A. M., Polkinghorne, R. J., & Thompson, J. (2002). *The effect of different pelvic hanging techniques on meat quality in beef.* Paper presented at the 48th International Congress of Meat Science and Technology, Rome, Italy. 220-221.

Hwang, I. H., Park, B. Y., Cho, S. H., & Lee, J. M. (2004). Effects of muscle shortening and proteolysis on Warner-Bratzler shear force in beef longissimus and semitendinosus. *Meat Science 68*(3), 497-505.

Hwang, I. H., Park, B. Y., Cho, S. H., Lee, J. M., Kim, Y. G., Kim, J. H., & Thompson, J. (2003b). *Relationships between WB-shear force and sensory tenderness scores for three muscles prepared using different cooking methods in tenderstretch and normally hung sides.* Paper presented at the 49th International Congress of Meat Science and Technology, Campinas, Brazil. 266-267.

Jacob, R. H., D'Antuono, M. F., Smith, G. M., Pethick, D. W., & Warner, R. D. (2007). Effect of lamb age and electrical stimulation on the colour stability of fresh lamb meat. *Australian Journal of Agricultural Research 58*(4), 374-382.

Jeacocke, R. E. (1984). The kinetics of rigor onset in beef muscle fibres. *Meat Science 11*(4), 237-251.

Jeremiah, L. E., Martin, A. H., & Murray, A. C. (1985). The effects of various post-mortem treatments on certain physical and sensory properties of three different bovine muscles. *Meat Science, 12*(3), 155-176.

Jorgensen, A. S., Christensen, M., & Ertbjerg, P. (2005). *Marination with kiwifruit powder followed by power ultrasound tenderizes porcine m. biceps femoris*. Paper presented at the 54th

International Congress of Meat Science and Technology, Capetown, South Africa. Session 7B, pp 1-3.
Karumendu, L. U., Ven, R. v. d., Kerr, M. J., Lanza, M., & Hopkins, D. L. (2009). Particle size analysis of lamb meat: Effect of homogenization speed, comparison with myofibrillar fragmentation index and its relationship with shear force. *Meat Science 82*(4), 425-431.
Kenward, M. G., & Roger, J. H. (1997). Small sample inferrence for fixed effects from restricted maximum likelihood. *Biometrics, 53*, 983-997.
Khliji, S., van de Ven, R., Lamb, T. A., Lanza, M., & Hopkins, D. L. (2010). Relationship between consumer ranking of lamb colour and objective measures of colour. *Meat Science 85*(2), 224-229.
Koohmaraie, M., Doumit, M. E., & Wheeler, T. L. (1996). Meat toughening does not occur when rigor shortening is prevented. *Journal of Animal Science, 74*(12), 2935-2942.
Koohmaraie, M., Shackelford, S. D., Wheeler, T. L., Lonergan, S. M., & Doumit, M. E. (1995). A muscle hypertrophy condition in lamb (callipyge): characterization of effects on muscle growth and meat quality traits. *Journal of Animal Science, 73*(12), 3596-3607.
Leick, C. M., Behrends, J. M., Schmidt, T. B., & Schilling, M. W. (2011). Consumer selection of constant-weight rib eye, top loin and sirloin steaks. *Meat Science, 87*, 66-72.
Lepetit, J., Salé, P., & Ouali, A. (1986). Post-mortem evolution of rheological properties of the myofibrillar structure. *Meat Science, 16*(3), 161-174.
Locker, R. H. (1960). Degree of muscular contraction as a factor in tenderness of beef. *Journal of Food Science 25*(2), 304-307.
Locker, R. H., & Hagyard, C. J. (1963). A cold shortening effect in beef muscles. *Journal of the Science of Food and Agriculture, 14*(11), 787-793.
Lorenzen, C. L., Miller, R. K., Taylor, J. F., Neely, T. R., Tatum, J. D., Wise, J. W., Buyck, M. J., Reagan, J. O., & Savell, J. W. (2003). Beef Customer Satisfaction: Trained sensory panel ratings and Warner-Bratzler shear force values. *Journal of Animal Science, 81*(1), 143-149.
Macfarlane, J. J., Harris, P. V., & Shorthose, W. R. (1974). *Manipulation of meat quality, particularly tenderness, by the processor.* Paper presented at the 10th Australian Society of Animal Production. 219-226.
MacFarlane, P. G., & Marer, J. M. (1966). An apparatus for determining the tenderness of meat. *Food Technology, 6*, 134-135.
Maltin, C., Balcerzak, D., Tilley, R., & Delday, M. (2003). Determinants of meat quality: tenderness. *Proceedings of the Nutrition Society, 62*(02), 337-347.
Mancini, R. A., & Hunt, M. C. (2005). Current research in meat color. *Meat Science 71*(1), 100-121
Marsh, B. B., & Leet, N. G. (1966). Studies in Meat Tenderness. III. The Effects of Cold Shortening on Tenderness. *Journal of Food Science, 31*(3), 450-459.
Martin, K. M., Hopkins, D. L., Gardner, G. E., & Thompson, J. M. (2006). Effects of stimulation on tenderness of lamb with a focus on protein degradation. *Australian Journal of Experimental Agriculture, 46*(7), 891-896.
Martinez Michel, L., Punter, P. H., & Wismer, W. V. (2011). Perceptual attitudes of poultry and other meat products: A repertory grid application. *Meat Science, 87*, 349-355.
McPhail, N. G. (1995). *Implementation of hot boning*. Paper presented at the Meat 95. The Australian Meat Industry Research Conference, Gold Coast, Australia. 5-6.
MLA. (2009), from http://www.mla.com.au/TopicHierarchy/InformationCentre/FoodQualitySafetyAndValueAdding/Valueadding/Market+Research.
Monin, G. (2004). Colour and texture deviations. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 323-329). Oxford: Elsevier.
Morrissey, E. R., Jacob, R., & Pluske, J. M. (2008). *Perception of red brown colour by consumers.* Paper presented at the 54th International Congress of Meat Science and Technology, Cape Town, South Africa. Session 9.7.

O'Sullivan, A., Korzeniowska, M., White, A., & Troy, D. J. (2003). *Using a novel intervention technique to reduce the variability and improve tenderness of beef longissimus dorsi*. Paper presented at the 49th International Congress of Meat Science and Technology Sao Paulo, Brazil 513 – 514.

Oros, B. (2008). 10 tips for more profitable portion control. *Food Management, 43,* 38, 40, 42-43.

Parrish, F. C., Vandell, C. J., & Culler, R. O. (1979). Effect of maturity and marbling on the myofibril fragmentation index of bovine longissimus muscle. *Journal of Food Science, 44*(6), 1669-1669.

Payne, S. R., Durham, C. J., Scott, S. M., & Devine, C. E. (1998). The effects of non-vacuum packaging systems on drip loss from chilled beef. *Meat Science 49*(3), 277-287.

Peachey, B. M., Purchas, R. W., & Duizer, L. M. (2002). Relationships between sensory and objective measures of meat tenderness of beef m. longissimus thoracis from bulls and steers. *Meat Science, 60*(3), 211-218.

Pearce, K. L., Hopkins, D. L., Williams, A., Jacob, R. H., Pethick, D. W., & Phillips, J. K. (2009). Alternating frequency to increase the response to stimulation from medium voltage electrical stimulation and the effect on objective meat quality. *Meat Science, 81*(1), 188-195.

Perry, D., Shorthose, W. R., Ferguson, D. M., & Thompson, J. M. (2001a). Methods used in the CRC program for the determination of carcass yield and beef quality. *Australian Journal of Experimental Agriculture, 41*(7), 953-957.

Perry, D., Thompson, J. M., Hwang, I. H., Butchers, A., & Egan, A. F. (2001b). Relationship between objective measurements and taste panel assessment of beef quality. *Australian Journal of Experimental Agriculture 41*(7), 981-989.

Pethick, D. W., Pleasants, A. B., Gee, A. M., Hopkins, D. L., & Ross, I. R. (2006). Eating quality of commercial meat cuts from Australian lambs and sheep. *New Zealand Society of Animal Production, 66*, 363-367.

Petrak, L. (2006). Portions of proteins. *National Provisioner: Portion Control Solutions, May 2006,* 22-24, 26.

Pisula, A., & Tyburcy, A. (1996). Hot processing of meat. *Meat Science 43*(Supplement 1), 125-134.

Pitt, A., & Daly, C. C. (2008). New Zealand Patent No. WO2008/123782. : W. I. P. Organisation.

Polkinghorne, R. J., Watson, R., Porter, M., Gee, A. M., Scott, A., & Thompson, J. (1999). *Meat Standards Australia, a 'PACCP' based beef grading scheme for consumers. 1. The use of consumer scores to set grade standards.* Paper presented at the 45th International Congress of Meat Science and Technology, Yokohama, Japan. 14-15.

Pringle, T. D., Johnson, L. P., Bernkopf, D. K., & Williams, S. E. (1996). Factors affecting purge losses in portion controlled steaks. *Foodservice Research International 9*(2), 93-105.

Purchas, R. W. (2004). Tenderness measurement. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 1370-1376). Oxford: Elsevier.

R Core Development Team (2010). R: A language and environment for statistical computing. Vienna, Austria: R foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Reicks, A. L., Brooks, J. C., Garmyn, A. J., Thompson, L. D., Lyford, C. L., & Miller, M. F. (2011). Demographics and beef preferences affect consumer motivation for purchasing fresh beef steaks and roasts. *Meat Science, 87*(4), 403-411.

Resurreccion, A. V. A. (2003). Sensory aspects of consumer choices for meat and meat products. *Meat Science, 66*, 11-20.

Rix, P. (2004). *Marketing: a practical approach.* (5th Edition ed.): McGraw-Hill Australia.

Rosenvold, K., North, M., Devine, C., Micklander, E., Hansen, P., Dobbie, P., & Wells, R. (2008). The protective effect of electrical stimulation and wrapping on beef tenderness at high pre-rigor temperatures. *Meat Science 79*(2), 299-306.

Safari, E., Hopkins, D., Munro, B. C., Hall, D. G., & Thornberry, K. J. (2000). The meat quality of a Branded lamb product compared to generic lamb product. *Asian-Australiasian Journal of Animal Science, 13, Suppliment July 2000, Volume B.*, 358-361.

Schall, R. (1991). Estimation in generalised linear models with random effects. . *Biometrika, 78*, 719-727.

Seideman, S. C., Koohmaraie, M., & Crouse, J. D. (1987). Factors associated with tenderness in young beef. *Meat Science, 20*(4), 281-291.

Shackelford, S. D., Koohmaraie, M., & Savell, J. W. (1994). Evaluation of Longissimus dorsi muscle pH at three hours Post mortem as a predictor of beef tenderness. *Meat Science, 37*(2), 195-204.

Simmons, N. J., Cairney, J. M., Auld, M. M., Nagle, T. A., & Mudford, C. R. (1999). *Effect of pre-rigor stretching of beef M. longissumus thoracis muscles on structural changes and key meat quality attributes*. Paper presented at the 45th International Congress of Meat Science and Technology Yokohama, Japan. 464-465.

Smith, G. C., Belk, K. E., Sofos, J. N., Tatum, J. D., & Williams, S. M. (2000). Economic implications of improved colour stability in beef. In E. A. Decker, C. Faustman & C. Lopez-Bote (Eds.), *Antioxidants in muscle foods: Nutritional strategies to improve quality* (pp. 397-426). New York: Wiley Interscience.

Smith, M. E., Kastner, C. L., Hunt, M. C., Kropf, O. H., & Allen, O. M. (1979). Elevated conditioning temperature effects on beef carcasses from four nutritional regimes. *Journal of Food Science, 44*(1), 158-163.

Smulders, F. J. M., Marsh, B. B., Swartz, D. R., Russell, R. L., & Hoenecke, M. E. (1990). Beef tenderness and sarcomere length. *Meat Science 28*(4), 349-363.

Sørheim, O., & Hildrum, K. I. (2002). Muscle stretching techniques for improving meat tenderness. *Trends in Food Science & Technology 13*(4), 127-135.

Spooncer, W. F. (1993). *Options for hot boning*. Paper presented at the Meat 93, The Australian meat industry research conference Gold Coast, Australia. 1-6.

Stevenson, B. J., Morton, J. D., Ilian, M. A., & Bickerstaffe, R. (2002). *Effect of muscle stretching on titin and calpain3: implications for tenderness*. Paper presented at the 48th International Congress of Meat Science and Technology, Rome, Italy. 598-599.

Suzuki, A., Yamadera, Y., Kido, K., & Watanabe, K. (1997). Sarcomere shortening and contraction nodes in stretched-restrained ovine myofibres during post mortem storage. *Meat Science, 46*(4), 339-348.

Sweeter, K. K., Wulf, D. M., & Maddock, R. J. (2005). Determining the optimum beef longissimus muscle size for retail consumers. *Journal of Animal Science, 83*(11), 2598-2604.

Tarrant, P. V. (1998). *Some recent advances and future priorities in research for the meat industry*. Paper presented at the 44th International Congress of Meat Science and Technology, Barcelona, Spain. 2-13.

Taylor, J. M., & Hopkins, D. (2011). Patents for stretching and shaping meats. *Recent Patents on Food, Nutrition and Agriculture, 3*(2), 91-101.

Taylor, J. M., Hopkins, D., & van de Ven, R. (2010). *The effect of a meat stretching device on the tenderness of hot-boned beef topsides and rostbiffs*. Paper presented at the 56th International Congress of Meat Science and Technology Jeju, Korea. E069.

Taylor, R. G., & Frylink, L. (2003). *Muscle structures which determine meat tenderness in South African and other beef breeds.* Paper presented at the 11th International Meat Symposium. 23-27.

Thompson, J. (2002). Managing meat tenderness. *Meat Science 62*(3), 295-308.

Thompson, J. M., Hopkins, D. L., D'Souza, D. N., Walker, P. J., Baud, S. R., & Pethick, D. W. (2005). The impact of processing on sensory and objective measurements of sheep meat eating quality. *Australian Journal of Experimental Agriculture 45*(5), 561-573.

Toohey, E., & Hopkins, D. (2007). *Does high frequency immobilisation of sheep post-death affect meat quality?* Paper presented at the 67th New Zealand Society of Animal Production, Wanaka, New Zealand. 420-425.

Toohey, E., & Hopkins, D. (2009). *Change in form and function of hot-boned sheepmeat forequarter*. Paper presented at the 55th International Congress of Meat Science and Technology Copenhagen, Denmark. PE4.13.

Toohey, E., Hopkins, D., & Lamb, T. A. (2008a). *Effects of moderate frequency immobilisation, low voltage electronic bleed and post-dressing medium voltage electrical stimulation (MVS) on sheep meat individually and in combination.* Paper presented at the Australian Society of Animal Production 27th Biennial Conference, Brisbane, Australia. 106.

Toohey, E., Hopkins, D., & Lamb, T. A. (2008b). *The impact of wrapping and ageing hot boned sheep meat on eating quality*. Paper presented at the 54th International Congress of Meat Science and Technology Capetown, South Africa. 7B.19.

Toohey, E., Hopkins, D., Lamb, T. A., Nielsen, S. G., & Gutzke, D. (2008c). *Accelerated tenderness of sheep topsides using a meat stretching device*. Paper presented at the 54th International Congress of Meat Science and Technology Capetown, South Africa. 7B.18.

Toohey, E., Hopkins, D., Nielsen, S., & Gutzke, D. (2009a). *Impact of a meat stretching device on sheep meat quality*. Paper presented at the 55th International Congress of Meat Science and Technology Copenhagen, Denmark. PE4.14.

Toohey, E., Hopkins, D., van de Ven, R., Thompson, J., & Geesink, G. (2009b). *Pre-rigor interventions: the effect on myofibrillar degradation and shear force*. Paper presented at the 55th International Congress of Meat Science and Technology Copenhagen, Denmark. PE4.15.

Toohey, E., & Hopkins, D. L. (2006). Eating quality of commercially processed hot boned sheep meat. *Meat Science 72*(4), 660-665.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010a). *The effect of "Kiwi Fruit solution" on colour stability of beef topside.* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 40.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010b). *The effect of "Kiwi Fruit solution" on meat traits in beef topside.* Paper presented at the 56th International Congress of Meat Science and Technology Jeju, Korea. D040.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010c). *The effect of "Kiwi Fruit solution" on the tenderness of beef topside.* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 39.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010d). *The effect of Smart Stretch technology on the tenderness of beef cube roll* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 47.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010e). *The effect of Smart Stretch technology on the tenderness of beef topside.* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 46.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010f). *The effect of SmartStretch technology on the tenderness of beef topsides and cube rolls*. Paper presented at the 56th International Congress of Meat Science and Technology Jeju, Korea. E072.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. L. (2011). The effect of a kiwi fruit based solution on meat traits in beef m. semimembranosus (topside). *Meat Science, 88*(3), 468-471.

Toohey, E. S., Hopkins, D. L., McLeod, B. M., & Nielsen, S. G. (2006). Quantifying the rate of pH and temperature decline in lamb carcasses at three abattoirs in New South Wales. *Australian Journal of Experimental Agriculture, 46*(7), 875-878.

Toohey, E. S., Kerr, M. J., de Ven, R. v., & Hopkins, D. L. (2011). The effect of a kiwi fruit based solution on meat traits in beef m. *semimembranous*. (topside). *Meat Science, 88,* 468-471.

Tornberg, E. (1996). Biophysical aspects of meat tenderness. *Meat Science 43*(Supplement 1), 175-191.

Troy, D. J. (2006). Hot-boning of meat: a new perspective. In L. M. L. Nollet & F. Toldra (Eds.), *Advanced technologies for meat processing* (pp. 74 - 83): CRC Press, Taylor and Francis Group.

Verbeke, W., Pérez-Cueto, F. J. A., Barcellos, M. D. d., Krystallis, A., & Grunert, K. G. (2010). European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science, 84*(2), 284-292.

Verbeke, W., & Viaene, J. (2000). Ethical challenges for livestock production: meeting consumer concerns about meat safety and animal welfare. *Journal of Agricultural and Environmental Ethics, 12*, 141-151.

Wada, M., Suzuki, T., Yaguti, Y., & Hasegawa, T. (2002). The effects of pressure treatments with kiwi fruit protease on adult cattle semitendinosus muscle. *Food Chemistry, 78*(2), 167-171.

Wahlgren, N. M., Goransson, M., Linden, H., & Willhammar, O. (2002). *Reducing the influence of animal variation and ageing on beef tenderness*. Paper presented at the 48th International Congress of Meat Science and Technology, Rome, Italy. 240-241.

Watson, R., Gee, A., Polkinghorne, R., & Porter, M. (2008). Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. *Australian Journal of Experimental Agriculture, 48*(11), 1360-1367.

Waylan, A. T., & Kastner, C. L. (2004). Hot boning and chilling. In W. Jensen, C. E. Devine & M. E. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (Vol. 2, pp. 606-613): Elsevier Science.

Wheeler, T. L., Shackelford, S. D., Johnson, L. P., Miller, M. F., Miller, R. K., & Koohmaraie, M. (1997). A comparison of Warner-Bratzler shear force assessment within and among institutions. *J. Anim Sci., 75*(9), 2423-2432.

White, A., O'Sullivan, A., Troy, D. J., & O'Neill, E. E. (2006). Effects of electrical stimulation, chilling temperature and hot-boning on the tenderness of bovine muscles. *Meat Science 73*(2), 196-203.

Williams, P. G. (2009). Foodservice perpective in institutions 2009. Retrieved from http://ro.uow.edu.au/hbspapers/109

Wyness, L., Weichselbaum, E., O'Connor, A., Williams, E. B., Benelam, B., Riley, H., & Stanner, S. (2011). Red meat in the diet: an update. *Nutrition Bulletin, 36*(1), 34-77.

8 Appendices

8.1 Research Summary

A number of research projects were undertaken to validate the stretching component of the technology. Below in Table 64 is a summary of SmartStretch™ research completed to date. "Version" is the version of the machine used to complete the research experiment. Following the table is list of all the published papers for this project.

Table 64: Summary of research for the project in chronological order.

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
1	January 2008	1	Evaluate effect of stretching and ageing on hot-boned sheep meat topsides from 40 Merino carcasses of similar age.	Stretch vs no stretch Ageing – 0 vs 5 days	24% increase in muscle length and 27% decrease in muscle circumference from stretching. Significant tenderness gains resulted from both stretching and ageing. Stretching resulted in a significant reduction in cooking loss % and a significant increase in sarcomere length.	The technology has potential to improve sheep meat eating quality.	(Toohey, et al., 2008c) Proposed paper for Meat Science.
2	May 2008	1	Evaluate effect of stretching and ageing on hot-boned sheep meat whole tunnel boned legs from 40 Merino carcasses of similar age.	Stretch vs no stretch Ageing – 0 vs 5 days	14% increase in leg length and 45% decrease in leg circumference from stretching. Significant tenderness gains resulted from both stretching and ageing, although the benefits of stretching disappeared with ageing. Stretching resulted in a significant increase in sarcomere length. Stretching has no effect on myofibrillar degradation.	The technology has the potential to improve sheep meat eating quality. Tenderness gains diminish with ageing. Stretching physically disrupts the fibres, but does not cause accelerated proteolysis.	(Toohey, et al., 2009a) Proposed paper for Meat Science.

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
3	September 2008	1	Evaluate the effect of stretching on the form and function of 10 hot-boned mutton forequarters and 10 hot-boned lamb forequarters.	Full forequarter vs trimmed forequarter. All forequarters treated with powder protein binder.	Mutton and lamb forequarters held shape well. Inconsistencies in binding of the muscles were attributed to inconsistencies in binder application.	SmartShape technology has the capacity to reshape odd shaped pieces of meat and, with the aid of binder, retain that shape and increasing the potential uses of the piece of meat.	(Toohey & Hopkins, 2009)
4	October 2008	1	The effect of stretching method on tenderness and myofibril degradation on the striploin from 30 grainfed heifers.	Achilles hung vs Tenderstretch vs Superstretch vs SmartShape + ice vs SmartShape + chilled Ageing – 1 vs 7 vs 21 days	Particle size and shearforce decreased with ageing across all treatments. All stretch treatments produced more tender meat than the traditional Achilles tendon hung animals. There was a poor correlation between shearforce and particle size for all stretch treatments.	Particle size is a poor measure of meat tenderness in stretching studies. SmartShape proved to be an acceptable alternative to Tendertretching or Superstretching.	(Toohey, et al., 2009b)
5	2008 to 2009	1	Comparison of the G2 Tenderometer and the Lloyd Texture Analyser for measuring the shear force of cooked meat	Experiment 1: G2 vs Lloyd on M. longissimus lumborum in 26 sheep; Experiment 2: G2 vs Lloyd on M. longissimus lumborum in 48 sheep; Experiment 3: G2 vs Lloyd on SmartStretch™ M. semimembranosus in 24 cattle.	Where meat is tender there is little difference between the G2 Tenderometer and the Lloyd texture analyser. Tougher meat will measure 75 – 80% lower shearforce values on the Lloyd as on the G2 Tenderometer.	Need to know which machine tenderness is measured on before attempting to compare results.	(Hopkins, Toohey, Kerr, & van de Ven, 2011)

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
6	March 2009	2	The effect of Kiwi brine on the quality of beef topsides from heifers.	Injected with brine Injected with water Non-injected Ageing – 1 vs 14 days All samples SmartShaped	Kiwi brine significantly improved tenderness at 1 and 14 days ageing. Injection of water and no injection resulted in no tenderness improvement. Meat injected with the kiwi brine was less colour stable than non-injected meat.	Kiwi brine created more tender meat, but the low colour acceptability to consumers could limit retail sales.	(Toohey, Kerr, van de Ven, & Hopkins, 2010a, 2010b, 2010c; Toohey, Kerr, van de Ven, & Hopkins, 2011; Toohey, Kerr, de Ven, & Hopkins, 2011)
7	July 2009	2	Evaluate the effect of stretching and ageing on hot-boned beef topside from 24 aged cow carcasses.	3 stretch treatments (52%, 41% and 34%) Ageing – 0 vs 7 days	Each stretch treatment resulted in a significant increase in length and decrease in circumference. Different stretch treatments had no effect on tenderness or sarcomere length. Ageing significantly improved tenderness. Stretching has no effect on myofibrillar degradation. Stretching, and increased levels of stretching, produced meat of a colour more acceptable to consumers than unstretched and lesser stretched meat.	The maximum tenderness benefit was reached with the lowest level of stretch (34%) gained in this experiment.	(Toohey, Kerr, van de Ven, & Hopkins, 2010e; Toohey, et al., 2010f)

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
8	September 2009	2	Evaluate the effect of stretching and ageing on hot-boned beef cube roll from 24 aged cow carcasses.	Two stretch treatments (8% & 9%) vs no stretch. Ageing – 0 vs 14 days.	Increasing levels of stretch resulted in no significant increases in length, while significantly reducing circumference. Stretching did not increase sarcomere length. Stretching had no effect on tenderness. Ageing improved tenderness. Ageing significantly reduced thaw loss and particle size, while stretching had no effect on these traits. Stretching produced meat of a colour more acceptable to consumers than unstretched meat.	More stretch is required for there to be a tenderness benefit resulting from stretching.	(Toohey, Kerr, van de Ven, & Hopkins, 2010d; Toohey, et al., 2010f)
9	February 2010	3	Evaluate the effect of stretching and ageing on hot-boned beef topside from 32 aged cow carcasses.	Stretch vs no stretch Ageing – 0 vs 14 days.	Stretching resulted in a 40% increase in muscle length and a significant increase in sarcomere length. At 0 days ageing stretching had no effect on tenderness. At 14 days ageing stretching had a significantly negative effect on tenderness. Thaw and cooking loss % were significantly reduced by stretching. Cooking loss % was significantly increased by ageing. Stretching had no significant impact on colour parameters, although ageing did.	Tougher meat was suggested after stretching and ageing. No other impacts resulting from stretching were found; therefore any commercial benefits will be the result of shaping.	Proposed paper for Meat Science.

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
10	February 2010	3	Evaluate the effect of stretching and ageing on hot-boned beef striploin from 40 aged cow carcasses.	Stretch vs no stretch Ageing – 0 vs 14 days.	Stretching resulted in a 17% increase in muscle length, but no significant increase in sarcomere length. Stretching resulted in a significant improvement in tenderness at 0 days ageing, which was no longer evident after 14 days ageing. Ageing caused a significant improvement in tenderness. Cooking loss % was significantly higher after stretching and ageing. The meat was unacceptably brown to retail consumers after ageing and stretching.	Considering the end use of product from hot-boned aged cows the results of this study does not change the way that it is marketed. Any improvement in tenderness was not enough to change the market and an increase in brownness has no affect on meat that is not displayed for retail sale.	Proposed paper for Meat Science.
11	April 2010	3	Evaluate the effect of stretching on the tenderness and eating quality of hot-boned beef topsides and rostbiffs from 6 aged cow carcasses.	Stretch vs no stretch	Stretching resulted in a 21% increase in muscle length. There was no significant improvement in sensory panel evaluation or measured tenderness resulting from stretching, although the results suggest that there might be an improvement found in the rostbiff if a larger sample size is used. An overall reduction in the variability of tenderness results was gained from stretching.	Further work on the impact of stretching the rostbiff should be done to validate these results.	(Taylor, et al., 2010)

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
12	September 2010	3	Evaluate the effect of stretching and ageing on hot-boned sheep loins from 27 adult sheep carcasses.	Stretch vs no stretch Ageing – 0 vs 5 days	Stretching (7%) significantly improved the tenderness but only for the aged samples. Cooking loss was reduced by stretching and ageing. Purge loss was increased by stretching. Colour was unaffected. Uneven rubber walls meant that the rubber did not expand or contract evenly, causing problems with inserting and ejecting the meat.	The improved shear force with ageing is at odds with previous experiments where the shearforce improvements were nullified by ageing. Problems with the rubber and with the resultant small sample suggest that assessing the sheep loin with this rubber should not be revisited.	Abstract has been submitted for ICoMST 2011.
13	October 2010	3	Review Paper: Patents for stretching and shaping meats			The second time that SmartShape™/SmartStretch™ has appeared in a review paper in a refereed journal. The first was Simmons et al (2006). Integrated technologies to enhance meat quality – an Australiasian perspective. Meat Sci. 74:172-9.	(Taylor & Hopkins, 2011)

No	Date	Version	Aim	Treatments	Results	Conclusions	Publications
14	December 2010	3	Evaluate the effect of stretching, electrical stimulation and ageing on hot-boned sheep topsides from 80 adult sheep carcasses.	Stretch vs no stretch Electrical Stimulation vs none Ageing – 0 vs 5 days	A 30% increase in length in stretched topsides resulted in a significant improvement in initial tenderness (37%) and following a 5 day ageing period (16%). Tenderness achieved by stretching was equal to 5 days ageing. Stimulation had no effect on tenderness, but it did affect pH. Cooking loss was significantly reduced by stretching.	The tenderness of the sheep topside was improved by stretching. Electrical stimulation had no effect on meat tenderness.	Proposed paper for Meat Science.
15	February 2011	3	Evaluate the effect of stretching and ageing on hot-boned beef rostbiff from 40 beef carcasses with a maximum dentition score of 2.	Stretch vs no stretch Ageing – 0 vs 8 days	A 34% increase in length in stretched rostbiffs resulted in a significant improvement in initial tenderness (20%), which was nullified by ageing. Cooking loss was significantly reduced by stretching.	The tenderness of the beef rostbiff was improved by stretching.	Proposed paper for Meat Science.
16	February 2011	3	Evaluate the length of time that cold-boned shaped primals must be packaged for to retain their shape.	Stretch vs no stretch Time in packaging treatments – 12, 24 and 48 hour Measurements after slicing over time	No significant difference in shape of sliced primals between 12 hour and longer treatments. The longer the slices were left the more they relaxed out. Shaped slices closely resembled their preshaping counterparts following cooking.	Shaped cold-boned primals can be sliced after 12 hours. Slices attain a “natural” shape similar to unshaped primals with cooking.	Proposed paper for Meat Science

8.1.1 Papers published

Hopkins, D., Toohey, E., Kerr, M. J., & van de Ven, R. (2011). Comparison of two instruments (G2 Tenderometer and a Lloyd Texture analyser) for measuring the shear force of cooked meat. *Animal Production Science, 51*(1), 71-76.

Taylor, J. M., & Hopkins, D. (2011). Patents for stretching and shaping meats. *Recent Patents on Food, Nutrition and Agriculture, 3*(2), 91-101.

Taylor, J. M., Hopkins, D., & van de Ven, R. (2010). *The effect of a meat stretching device on the tenderness of hot-boned beef topsides and rostbiffs*. Paper presented at the 56th International Congress of Meat Science and Technology Jeju, Korea. E069.

Toohey, E., & Hopkins, D. (2009). *Change in form and function of hot-boned sheepmeat forequarter*. Paper presented at the 55th International Congress of Meat Science and Technology Copenhagen, Denmark. PE4.13.

Toohey, E., Hopkins, D., & Lamb, T. A. (2008b). *The impact of wrapping and ageing hot boned sheep meat on eating quality*. Paper presented at the 54th International Congress of Meat Science and Technology Capetown, South Africa. 7B.19.

Toohey, E., Hopkins, D., Lamb, T. A., Nielsen, S. G., & Gutzke, D. (2008c). *Accelerated tenderness of sheep topsides using a meat stretching device*. Paper presented at the 54th International Congress of Meat Science and Technology Capetown, South Africa. 7B.18.

Toohey, E., Hopkins, D., Nielsen, S., & Gutzke, D. (2009a). *Impact of a meat stretching device on sheep meat quality*. Paper presented at the 55th International Congress of Meat Science and Technology Copenhagen, Denmark. PE4.14.

Toohey, E., Hopkins, D., van de Ven, R., Thompson, J., & Geesink, G. (2009b). *Pre-rigor interventions: the effect on myofibrillar degradation and shear force*. Paper presented at the 55th International Congress of Meat Science and Technology Copenhagen, Denmark. PE4.15.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010a). *The effect of "Kiwi Fruit solution" on colour stability of beef topside.* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 40.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010b). *The effect of "Kiwi Fruit solution" on meat traits in beef topside.* Paper presented at the 56th International Congress of Meat Science and Technology Jeju, Korea. D040.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010c). *The effect of "Kiwi Fruit solution" on the tenderness of beef topside.* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 39.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010d). *The effect of Smart Stretch technology on the tenderness of beef cube roll* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 47.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010e). *The effect of Smart Stretch technology on the tenderness of beef topside.* Paper presented at the Australian Society of Animal Production 2010 Armidale, NSW. 46.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. (2010f). *The effect of SmartStretch technology on the tenderness of beef topsides and cube rolls*. Paper presented at the 56th International Congress of Meat Science and Technology Jeju, Korea. E072.

Toohey, E., Kerr, M. J., van de Ven, R., & Hopkins, D. L. (2011). The effect of a kiwi fruit based solution on meat traits in beef m. semimembranosus (topside). *Meat Science, 88*(3), 468-471.

8.2 Operating Manual

The Operating Manual is attached as file –
Operating manual - SmartShape Version 1.4 27-08-10.pdf

8.3 Safe Work Method Statements And Initial Standard Operating Procedures

NSW DEPARTMENT OF PRIMARY INDUSTRIES

OHS UNIT
Locked Bag 21, Orange NSW 2800
Tel: (02) 6391 3585 Fax: (02) 6391 3329

SAFE WORK METHOD STATEMENT

Assessment no.	**Dub 1**
Version no.	**3**

☐**Entered on register**

Job Task: **8.3.1 Operation of SmartShape – automated function**	**Branch** Centre for Sheep Meat Development
	Unit Animal Production Research
	Location Various

RISK IDENTIFICATION AND CONTROLS

Please include all discrete steps involved in the performance of the task **must be listed as per MSDS**

NOTE: The PPE required must be listed and for chemicals the PPE

R1 Risk without controls

R2 Risk with controls

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
Ensure machine is set to manual mode	Moving parts which could injure operator	L	Manual and auto switch on the right hand side of the machine	L
Stop button in Ensure packaging unit is in the upright position Ensure air pressure is turned off	Moving parts which could injure operator	L	Red emergency stop button	L
Plug in and turn on at wall Connect air at the rear of the machine	Possible damage to power cord Possible damage to air connection	L	Check power cord before use Check Air connection before use (located at the rear of the machine)	L

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
Reset machine	N/A	L	Pull out red emergency stop button	L
Set machine to Automatic Mode	Moving parts which could injure operator	L	Manual and auto switch on the right hand side of the machine.	L
Start cycle	Moving parts which could injure operator	L	Press green start button Ensure hands and other objects other than meat are kept clear	L
Place meat in expanded rubber and wait for rubber to grab	Potential muscle strain	L	Use correct lifting procedures	L
Wait for automatic size selection – flashing light will appear, packaging unit propeller may turn	Moving parts which could injure operator	L	Ensure hands and other objects are keep clear	L
Lower packaging unit into place	Moving parts which could injure operator	L	Ensure hands and other objects other than meat are keep clear Pull lever downward	L
Wait for cycle to complete and until meat is ejected	Moving parts which could injure operator	L	Ensure hands and other objects other than meat are keep clear	L
Lift packaging unit and remove meat from packaging head	Potential muscle strain	L	Pull lever upward position to maximum upper level	L
Reload packaging on to packaging head	Potential muscle strain	L		
Push start button to complete the cycle		L	Green start button	L

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
When finished all operation switch to manual mode, switch packaging unit selection to small and press the emergency stop button.	Moving parts which could injure operator	L	Manual and auto switch on the right hand side of the Machine, packaging unit selection switch on right hand side of machine	L
	Overall risk rating	L	**Overall risk rating**	L

RISK RATING GUIDE

☐ Continuation sheet attached

		Consequence			
		Death Catastrophic Illness/Injury	Major Extensive Injuries	Moderate Medical treatment required	Minor No injuries
Likelihood	**Almost certain** Occurred before/expected	H	H	S	S
	Likely Probably will occur	H	S	S	S
	Moderate May occur at some time	H	S	L	L
	Unlikely Unusual or rare situation	S	L	L	L

High (H) – cease exposure immediately until protection, approved at senior mgt level, implemented.

Significant (S) – procedures alone may not be enough, senior management attention required.

Low (L) – may be managed by routine procedures, some risks in this category may be acceptable.

SPECIFIC TASK REQUIREMENTS

Qualifications or experience • Instruction By an Experienced operator
Training • Read and understand the relevant risk assessment and safe work method statement • Instruction By an Experienced operator
Engineering details, certificates, WorkCover approvals
Relevant codes of practice, legislation or standards In accordance with launch & Retrieve document OH&S regulation 2001 and OH&S Act
Plant/equipment Tube packaging, compressed air, single phase power, PPE (lab coat, protective eyewear, protective footwear)
Maintenance checks, site/workplace inspections As per Smart Shape/Smart Stretch operational Manual

Suggested improvements (in order or priority)

Additional comments

Assessment dates

Initial assessment date: 13/11/2007	Current assessment date 25/2/2009	Reassessment due date

Assessors

Name	Signature	Date
▪ Edwina Toohey	▪	
▪ Johanne Taylor	▪	
▪	▪	

Recommendation (Section Leader/Supervisor) ☐ Follow up required

Name	Signature	Date
▪ David Hopkins	▪	

Approval (Manager, Officer-in-Charge/TM4)

Name	Signature	Date
▪ Terry Coates	▪	

I have read and understand this Safe Work Method Statement

Name	Signature	Date

Name	Signature	Date

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

OHS UNIT
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Tel: (02) 6391 3585 Fax: (02) 6391 3329

SAFE WORK METHOD STATEMENT

Assessment no.	
Version no.	**1**

☐**Entered on register**

Job Task: **8.3.2 Operation of SmartShape – manual function**	**Branch** Centre for Sheep Meat Development
	Unit Animal Production Research
	Location Various

RISK IDENTIFICATION AND CONTROLS

Please include all discrete steps involved in the performance of the task **must be listed as per MSDS**

NOTE: The PPE required must be listed and for chemicals the PPE

R1 Risk without controls

R2 Risk with controls

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
Ensure machine is set to manual mode	Moving parts which could injure operator	L	Manual and auto switch on the right hand side of the machine	L
Stop button in Ensure packaging unit is in the upright position Ensure air pressure is turned off	Moving parts which could injure operator	L	Red emergency stop button	L
Plug in and turn on at wall Connect air at the rear of the machine	Possible damage to power cord Possible damage to air connection	L	Check power cord before use Check Air connection before use (located at the rear of the machine)	L
Reset machine	N/A	L	Pull out red emergency stop button	L

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
Select packaging size, packaging unit propeller may turn	Moving parts which could injure operator	L	Packaging unit selection switch is on the right hand side of the machine. Ensure hands and other objects are keep clear	L
Start cycle	Moving parts which could injure operator	L	Press yellow expand start button Ensure hands and other objects other than meat are kept clear	L
Place meat in expanded rubber and wait for rubber to grab	Potential muscle strain	L	Use correct lifting procedures	L
Lower packaging unit into place	Moving parts which could injure operator	L	Ensure hands and other objects other than meat are keep clear Pull lever downward	L
Shape meat and eject into packaging	Moving parts which could injure operator	L	Use blue airbag and black eject buttons. Ensure hands and other objects other than meat are keep clear	L
Raise packaging unit	Moving parts which could injure operator	L	Ensure hands and other objects other than meat are keep clear	L
Remove meat from packaging head	Potential muscle strain	L	Pull lever upward position to maximum upper level	L
Reload packaging onto packaging head	Potential muscle strain	L		
When finished all operation switch to manual mode, switch packaging unit selection to small and press the emergency stop button.	Moving parts which could injure operator	L	Manual and auto switch on the right hand side of the machine, packaging unit selection switch on right hand side of machine	L
	Overall risk rating	L	**Overall risk rating**	L

RISK RATING GUIDE

☐ Continuation sheet attached

		Consequence			
		Death Catastrophic Illness/Injury	Major Extensive Injuries	Moderate Medical treatment required	Minor No injuries
Likelihood	**Almost certain** Occurred before/expected	H	H	S	S
	Likely Probably will occur	H	S	S	S
	Moderate May occur at some time	H	S	L	L
	Unlikely Unusual or rare situation	S	L	L	L

High (H) – cease exposure immediately until protection, approved at senior mgt level, implemented.

Significant (S) – procedures alone may not be enough, senior management attention required.

Low (L) – may be managed by routine procedures, some risks in this category may be acceptable.

SPECIFIC TASK REQUIREMENTS

Qualifications or experience

- Instruction By an Experienced operator

Training

- Read and understand the relevant risk assessment and safe work method statement
- Instruction By an Experienced operator

Engineering details, certificates, WorkCover approvals
Relevant codes of practice, legislation or standards In accordance with launch & Retrieve document OH&S regulation 2001 and OH&S Act
Plant/equipment Tube packaging, compressed air, single phase power, PPE (lab coat, protective eyewear, protective footwear)
Maintenance checks, site/workplace inspections As per Smart Shape/Smart Stretch operational Manual

Suggested improvements (in order or priority)

Additional comments

Assessment dates

Initial assessment date: 13/11/2007	**Current assessment date 25/2/2010**	**Reassessment due date**

Assessors

Name	Signature	Date
▪ Edwina Toohey	▪	
▪ Johanne Taylor	▪	
▪	▪	

Recommendation (Section Leader/Supervisor) ☐ Follow up required

Name	Signature	Date
▪ David Hopkins	▪	

Approval (Manager, Officer-in-Charge/TM4)

Name	Signature	Date
▪ Terry Coates	▪	

I have read and understand this Safe Work Method Statement

Name	Signature	Date

Name	Signature	Date

NSW DEPARTMENT OF
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SAFE WORK METHOD STATEMENT

Assessment no.	
Version no.	**1**

☐**Entered on register**

Job Task: **8.3.3 SmartShape/SmartStretch machine transport**	**Branch** Centre for Sheep Meat Development
	Unit Animal Production Research
	Location Various

RISK IDENTIFICATION AND CONTROLS

Please include all discrete steps involved in the performance of the task **must be listed as per MSDS**

NOTE: The PPE required must be listed and for chemicals the PPE

R1 Risk without controls

R2 Risk with controls

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
Move machine to desired location	Potential for stress fractures and muscle strains, lacerations and abrasions from slips, trips and falls. Fatigue and stress.	S	Refer to SWMS 02/2009 – Manual handling - general	L
Front panel and top are put on crate and bolted into place	Potential for stress fractures and muscle strains, lacerations and abrasions from slips, trips and falls. Fatigue and stress.	S	Refer to SWMS 02/2009 – Manual handling - general	L
Loading and unloading crate/machine.	Forklift	S	Forklift operation by certified person only	L
Crate/machine is secured using tie down straps	Potential for stress fractures and muscle strains, lacerations and abrasions from slips, trips and falls. Fatigue and stress.	S	Refer to SWMS 02/2009 – Manual handling - general	L

Procedural step(s)	Possible hazard(s)	R1	Safety control(s)	R2
Ute is driven to the new location	Driving Tie down straps coming loose or breaking	S	Only licensed drivers may operate a vehicle Driver to stop after 10 minutes to check the load security and then at each rest break	L

RISK RATING GUIDE

☐ Continuation sheet attached

		Consequence			
		Death Catastrophic Illness/Injury	Major Extensive Injuries	Moderate Medical treatment required	Minor No injuries
Likelihood	**Almost certain** Occurred before/expected	H	H	S	S
	Likely Probably will occur	H	S	S	S
	Moderate May occur at some time	H	S	L	L
	Unlikely Unusual or rare situation	S	L	L	L

High (H) – cease exposure immediately until protection, approved at senior mgt level, implemented.

Significant (S) – procedures alone may not be enough, senior management attention required.

Low (L) – may be managed by routine procedures, some risks in this category may be acceptable.

SPECIFIC TASK REQUIREMENTS

Qualifications or experience

- Instruction By an Experienced operator

Training

- Read and understand the relevant risk assessment and safe work method statement
- Instruction By an Experienced operator

Engineering details, certificates, WorkCover approvals
Relevant codes of practice, legislation or standards In accordance with launch & Retrieve document OH&S regulation 2001 and OH&S Act
Plant/equipment Forklift, spanners for undoing bolts, ute, tiedown straps, PPE (protective footwear)
Maintenance checks, site/workplace inspections Check that the crate is in good order, normal scheduled maintenance of forklift and ute.

Suggested improvements (in order or priority)

Additional comments

Assessment dates

Initial assessment date: 5/3/2010	**Current assessment date 5/3/2010**	**Reassessment due date**

Assessors

Name	Signature	Date
▪ Edwina Toohey	▪	
▪ Johanne Taylor	▪	
▪	▪	

Recommendation (Section Leader/Supervisor) ☐ Follow up required

Name	Signature	Date
▪ David Hopkins	▪	

Approval (Manager, Officer-in-Charge/TM4)

Name	Signature	Date
▪ Terry Coates	▪	

I have read and understand this Safe Work Method Statement

Name	Signature	Date

Name	Signature	Date

8.3.4 Standard Operating Procedure – SmartShape – Manual Mode – November 2009

1. Ensure machine is set to Manual mode
2. Ensure emergency stop button is pressed in
3. Ensure packaging unit is in the upright position
4. Ensure air pressure is turned off
5. Plug in and turn on at wall
6. Connect air at the rear of the machine
7. Set to manual mode
8. Release emergency stop button
9. Expand white lady – hold in top yellow button
10. Place meat in expanded white lady - release top yellow button
11. Select appropriate packaging head size – turn black switch
12. Lower packaging unit into place - Pull lever downward
13. Apply both airbag and white lady pressure – press Blue and bottom Yellow buttons till meat ejected – approx 10 seconds

    Trouble shoot - If product still won't eject may need to reconsider packaging size or trim meat slightly.

14. Lift packaging unit up – pull lever upward
15. Remove meat from packaging unit
16. Reload packaging on to packaging head
17. To start cycle again - hold in top yellow button

8.3.5 Standard Operating Procedure – SmartShape – Automatic Mode – November 2009

1. Ensure machine is set to Manual mode
2. Ensure emergency stop button is pressed in
3. Ensure packaging unit is in the upright position
4. Ensure air pressure is turned off
5. Plug in and turn on at wall
6. Connect air at the rear of the machine
7. Release emergency stop button
8. Set to auto mode
9. Start cycle - Press green start button
10. Place meat in expanded white lady and wait for white lady to grab
11. Wait for automatic size selection – light will flash
12. Lower packaging unit into place - Pull lever downward
13. Wait for cycle to complete and till meat is ejected – if meat does not automatically eject please refer to manual mode SOP
14. Lift packaging unit up – pull lever upward
15. Remove meat from packaging unit
16. Reload packaging on to packaging head
17. Push start button to start the cycle again

8.4 Media

Presentation by Drs Dean Gutzke and David Hopkins and Edwina Toohey to staff of Fletcher's International Exports Pty Ltd, Dubbo, titled **MQST** May 2007.

Improving sheepmeat tenderness, function, Agriculture Today, October 2007, p.13.

Presentation by Drs Dean Gutzke, David Hopkins and Edwina Toohey to the staff of Fletcher's International Exports Pty Ltd, Dubbo – titled **Update,** September, 2008.

Presentation by Dr David Hopkins to the NSW Farmers Sheepmeats Committee, titled **Some important changes in the Australian sheep meat processing industry**, September, 2008.

Demonstration of the SS technology by Edwina Toohey at the Sheep CRC Information Nucleus Open day, April 2009, Cowra AR&AS – to 250 people including James Griffiths from Oberon abattoir. Included some results from the use of the SS for forming sheep forequarters in a paper titled **Can the 'Sunday roast" be improved?** by Dr David Hopkins pp-15-21.

Dr David Hopkins and Edwina Toohey presented 6 papers at the 55th International Congress of Meat Science and Technology held in Copenhagen, Denmark. As part of the congress the International Meat Secretariat awards a prize to the top judged paper from an author who must be aged under 40 and Edwina Toohey was selected in the top 6 of the candidates for her work on Smart Shaping (Paper titled Change in the form and function of hot-boned sheepmeat forequarter) based on work funded by Sheep CRC2 and MLA, August 2009.

Article by Dr David Hopkins, **Application of meat processing technologies**, for The Muster, No. 76, August. pp. 11&15.

Presentation by Dr David Hopkins to visiting scientists and government officials from the Gansu Xinjiang pastoral development project (China) titled **Some important changes in the Australian sheep meat processing industry**, October, 2009.

Presentation by Dr David Hopkins to sheep breeders as part of a Sheep CRC2 workshop, Cowra AR&AS titled **Preliminary results from the Meat program: - Health aspects of lamb and more!** November 2009.

Serving up what the customer wants: I&I NSW's sheep meat research – October 2009.

Presentation by Dr David Hopkins to abattoir meat managers as part of a MINTRAC network meeting titled **Lamb Eating Quality & Methods to Improve Quality,** Wagga (April) and Singleton (June), 2010.

Dr David Hopkins presented 4 papers at the 28th Biennial Conference of the Australian Society of Animal Production on results from the SmartShape/SmartStretch™ technology, July 2010.

Dr David Hopkins conducted a radio interview with 2EL on the work on SmartShape/SmartStretch™ technology, following a press release – **Perfect portions of steak shaped satisfaction** (5/8/2010).

Perfect portions of steak shaped satisfaction, Agriculture Today, 5/8/2010, p5, Forbes Advocate p9, Quirindi Advocate p9, The Rural News Wagga and Country News. Additionally a news item featured Johanne Taylor WIN Orange (27/08), WIN Wollongong and Canberra (30/08) and WIN Riverina (02/09),

Dr David Hopkins conducted a radio interview with the Orange ABC central west rural reporter on the **Perfect portions of steak shaped satisfaction** press release which was aired across the network - Western Plains, Riverina and New England, 5/8/2010. Johanne Taylor conducted radio interviews with 2UE and 2TM 5/8/2010.

Shaping the 'perfect' steak, The Land, 12/8/2010, p76.

Dr David Hopkins presented 3 papers at the 56th International Congress of Meat Science and Technology held in Jeju, South Korea. For the Process Technology session 76 papers were submitted and as part of the congress the best 3 papers per session were selected for an oral presentation. The paper Toohey, E.S., Kerr, M.J., van de Ven, R. and Hopkins, D.L. (2010). The effect of SmartStretch™ technology on the tenderness of beef topsides and cube rolls. *Proc. 56th International Congress of Meat Science and Technology.* Session E, pp 1-4, Jeju, South Korea was selected for presentation and was presented by Dr David Hopkins on behalf of the co-authors, August 2010.

Dr David Hopkins presented an invited paper - Technology supporting the development of a product – the case of Australian Sheep meat at the 14th AAAP Animal Science Congress, held at the National Pingtung University of Science & Technology, Pingtung, Taiwan, August 2010**.**

Stretch and squeeze 'perfect' steak is no devon, Quirindi Advocate, 1/9/2010, 9.

Dr David Hopkins, by invitation gave a presentation at the MINTRAC National Meat Inspection & Quality Assurance Conference titled "**Stretching and shaping - a new approach to packing meat cuts",** September 2010, with approximately 100 industry attendee's.

Johanne Taylor gave a presentation at the I&I NSW Beef & Sheep Conference titled "**Progress of the SmartShape™/SmartStretch™ Meat Science Project – April 2007 to June 2011",** November 2010.

Dr David Hopkins conducted a radio interview with Orange ABC central west, 2EL, 2SM and the ARC network and a TV interview with WIN on the work on SmartShape/SmartStretch™ technology, an article appeared in the Casino Times, Narrabri Courier, Weekly Times and the Muster following a press release – **Fruit infused melt in the mouth meat** (11/3/2011).

Kiwi fruit makes meat more tender, Agriculture Today, 3/3/2011, p3.

Fruit infused melt in the mouth meat, Cowra Guardian, 21/3/2011, p3.

8.5 Recommendations For Stage 2 Machine – Cargill Beef

The original recommendation in Milestone 1 for project P.PIP.0253 for Cargills SmartShape™/SmartStretch™ machine size was 40% larger than the current demonstration model.

Cube roll diameter

Minimum = 100mm
Maximum = 147mm
Maximum diameter difference within a primal = 20mm

Ring sizes

The range of diameters of the Cargills cube rolls is shown in Figure 70. The bulk of the cube roll measurements fall into the 120mm to 135mm range, with a number being smaller or larger. It was important to ensure that the ring sizes selected were consistent with the most common cube roll sizes, rather than the outliers, while still trying to adequately process all of the primals.

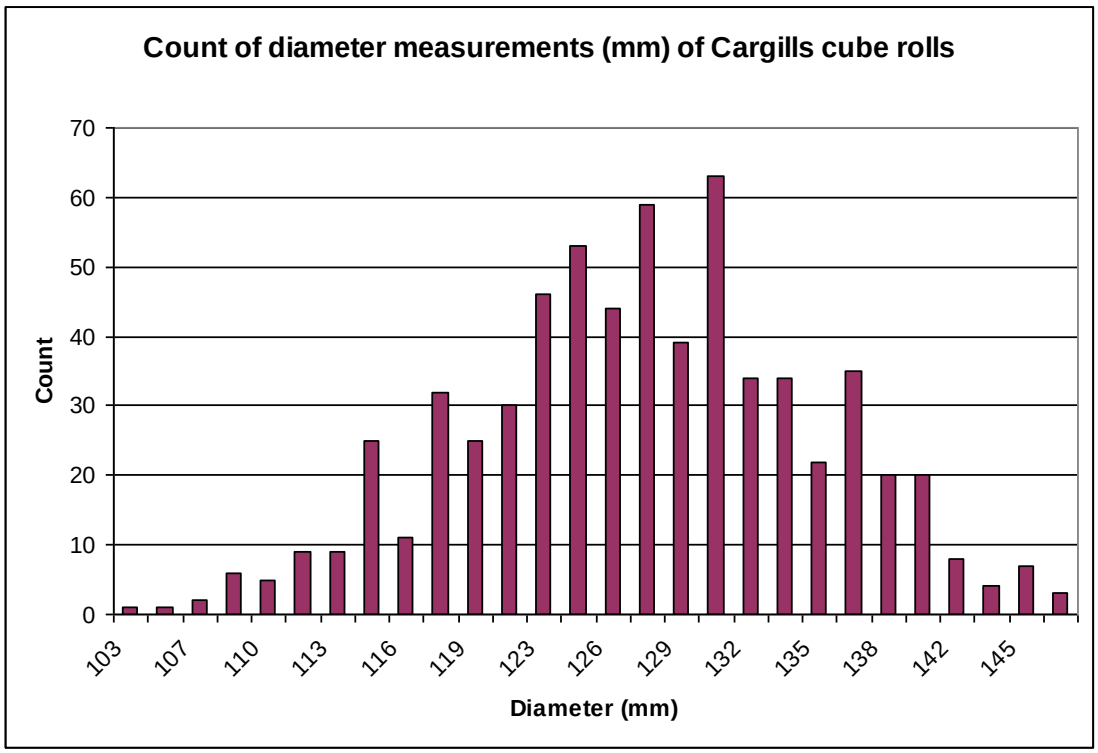

Figure 70: Graph showing the range of cube roll diameters and the count of each measurement (n=647).

The best fit for ranges for the bulk of the measurements is shown in Figure 2 for 3 potential ring sizes. The ranges chosen are <120mm, 120-130mm and >130mm to fit with the bulk of the primals.

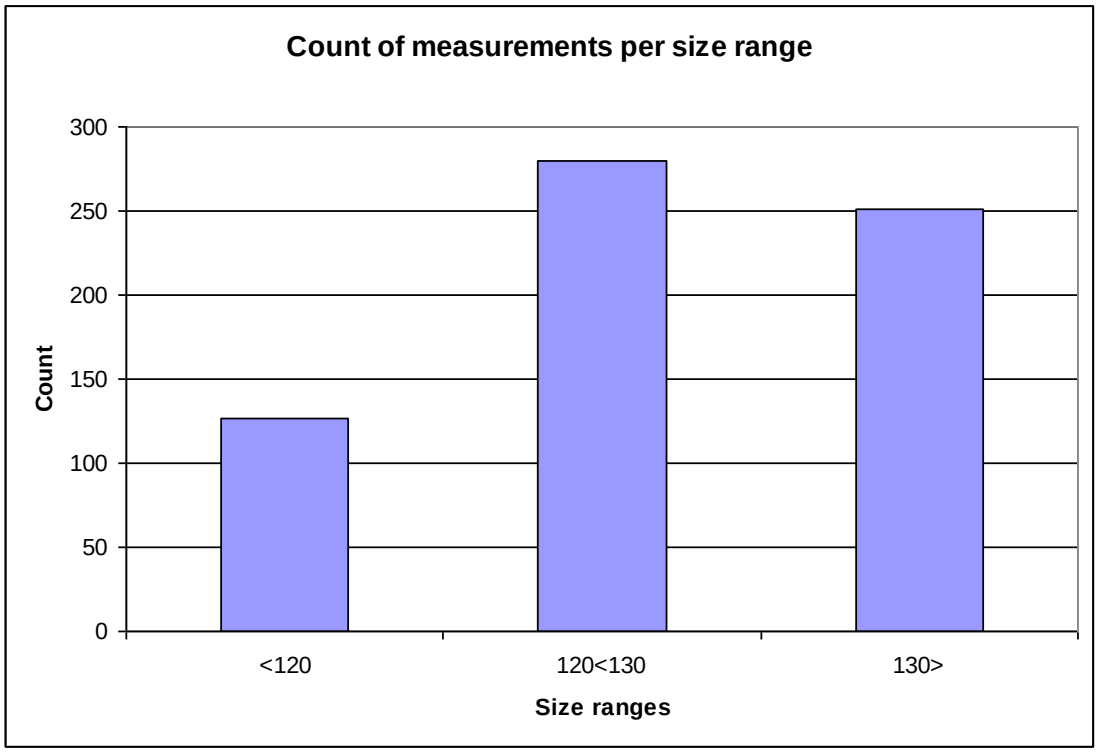

Figure 71: Graph showing a "best fit" for the cube roll measurements (n=647).

Table 65: Ring sizes to fit the "median" primal sizes in the ranges.

Primal range	"Median" diameter	Ring size diameter (approx 90% of median)	Packaging (flat pack width across)
<120mm	115mm	105mm	155mm
120 – 130mm	125mm	115mm	170mm
>130mm	138mm	125mm	185mm

Table 65 shows the ring sizes to fit the "median" primal sizes within each range. These "median" sizes were selected as a "best fit" for the most common sizes within each range (in the middle of where most of the measurements were). The ring sizes were calculated as approx 90% of the median based on previous work done that showed that across a range of primals the ring size used was approximately 90% of the average primal size. The packaging size circumference was calculated by the circumference of the ring minus approx 20mm (based on the relationship between the Phase 3 packaging and the current ring sizes). The flat pack width is half the circumference.

Rubber size

Diameter

The current resting diameter of the rubber is 65mm. The current average diameter of a primal shaped by the rubber is 93mm.

The average diameter of a Cargills cube roll is 128mm.

The resting diameter of the new rubber should be: 128/93 x 65 = 87.5mm
This is 35% larger than the current rubber.

Length

The range of measurements for length in the cube rolls is 36 to 52cm.

The existing rubber is 60cm long, which was measured from top to bottom as shown in Figure 72. The new rubber should be 80cm long. This is based on an assessment of a 46cm cube roll and its performance in the machine during the Cargill development meeting.

Figure 72: Length of the whole rubber was measured.

Aperture size

The current diameters of the aperture (175mm) and of the rubber are shown in Figure 72. The calculation of the new aperture size is based on the calculation of the new rubber size.

The new aperture size should be: 128/93 x 175 = 236mm.

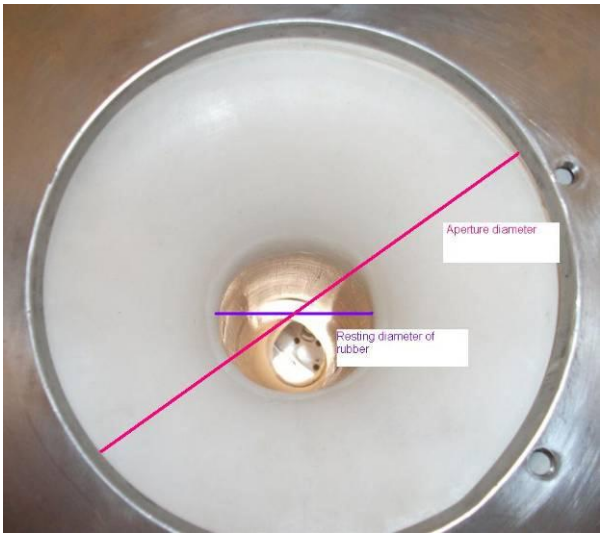

Figure 7: The diameter of the aperture and resting rubber.

8.6 Published Papers

Copies of these will be attached in PDF format