MEAT & LIVESTOCK AUSTRALIA

APPENDIX C:

INNOVATION IN CARCASE YIELD AND EATING QUALITY MEASUREMENT

Author: J.M. Thompson

School of Environmental and Rural Science,
University of New England, Armidale, NSW 2351, Australia

Technical papers for the Australian Beef Language 'WHITE PAPER'

Published by Meat and Livestock Australia, Sydney.

June 2016

Thompson JM (2016) Innovation in carcase yield and eating quality measurement. Technical papers for the Australian Beef Language 'White Paper'. Meat and Livestock Australia, Sydney, 12 Pages

Email: jmthommo@gmail.com

CONTENTS

INTRODUCTION

The beef language traits need to accurately describe attributes of the carcase and its components without bias so that both buyers and sellers have confidence in the traits which allows them to arrive at a value for the product. If the beef language performs this task it will facilitate communication up and down the chain and allow the market to perform more efficiently.

There are really only two broad attributes of the carcase that the beef language has to describe:

- Firstly it needs to describe the amount of product that is produced, whether this be lean meat, trimmed primals, trim or bone weight.
- Secondly it must describe the quality of the various components. Quality of the fresh carcase components is well described by Meat Standards Australia (MSA). This is a unique system which takes commercial inputs and uses them in the MSA model to predict eating quality of individual muscles when prepared using a variety of cooking methods (Polkinghorne et al 2008). Currently MSA focuses on the prediction of eating quality in fresh product although there are plans to develop the model to include prediction of eating quality for value added products.

Section A of this paper will detail new traits to measure carcase yield. Section B will review objective methods to measure eating quality in beef.

PREDICTION OF WEIGHT OR PERCENTAGE YIELD IN THE CARCASE

1.1 PURPOSE

When predicting carcase yield there is the option to predict either the weight, or the percentage of trimmed or denuded product in the carcase. The former is generally predicted with much greater accuracy than the latter figure. An example of the large differences in predicted accuracy can be seen in the equations reported by Perry et al (1993). They showed that when predicting the weight of saleable meat using carcase weight along with a combination of carcase measurements the accuracy (or R^2) of the prediction equation was 95%, compared with using the same data to predict the percentage of saleable meat where the accuracy was down to 58%. The reason for this is the very high correlation between carcase weight and the weight of saleable meat. In the example by Perry et al (1993), just using carcase weight to predict the weight of saleable meat had an accuracy of 89%, whereas using just carcase weight to predict the percentage of saleable meat only accounted for 4% of the variance. In other words carcase weight alone accounted for most of the accuracy in predicting weight of saleable meat, but only a small proportion of the variance in the prediction of percentage saleable meat in the carcase.

This explains why the choice of the variable to be predicted has a large bearing on the accuracy of the prediction equation. However the question that needs to be asked is how the predicted yield trait is to be used, either as a measure of efficiency in the boning room, or as a feedback trait to the producer. To measure efficiency of the boning room the weight of the saleable cuts needs to be assessed relative to the carcase weight entering the boning room – in other words, the percentage saleable meat in the carcase. Similarly for the producer the percentage saleable meat yield is more meaningful than simply the weight of saleable cuts in the carcase.

For payment to both the processor and producer, it is the weight of saleable meat that is important. It should be noted that predicted percentage saleable meat yield can be obtained by simply multiplying predicted percentage yield by carcase weight.

1.2 MEASUREMENT OF PERCENTAGE YIELD IN THE CARCASE

At boning the carcase is broken into primal cuts which vary enormously in eating quality and their subsequent value. The amount of fat which is left on the cuts will vary with the different market specifications. As fat left on the cuts is not separated at retail it effectively assumes the same value as the lean tissue in the primal. However the fat that is trimmed from the primal generally has a lower value and is either mixed with lean trim for grinding, or rendered. Similarly, bone which is retained in the primal effectively assumes the same value as the lean in the primal, but increasingly the consumer is becoming more focused on obtaining value for money and more cuts are prepared as boneless. In the UK concerns regarding BSE have meant that all primals have been free of bone since 1977 (Webster and Young 1997).

The saleable meat yield (SMY%) of the carcase can be defined as the weight of trimmed primals expressed as a proportion of carcase weight (Anon 2002). Whilst this may be the relevant commercial definition for processors to use in valuing the carcase it can, as discussed above, vary widely according to the trim specifications for a particular market and also how this is applied in specific boning rooms.

A more robust and less variable definition of carcase yield would be the weight of lean tissue in the carcase as a proportion of carcase weight (LMY%). Williams et al (1974) made a strong case for using LMY% as a precise and accurate measure of carcase yield which could be used by the market to arrive at a carcase value. This support was made on the basis that the accuracy of prediction of any technology used to predict carcase yield was directly affected by the accuracy with which the joints/tissues could be separated and weighed under commercial abattoir conditions. An accurate measure of LMY% should be independent of market specifications and boning room and as such provide an unbiased measurement of carcase composition.

As some fat and also in some circumstances some bone is left on the trimmed primal cuts, SMY% will generally be greater than LMY%. Whilst SMY% tends to be less consistent than LMY% due to variations in applying a standard trim it would be possible to relate LMY% to a specific market/boning room definition of SMY% for the purpose of the market valuing the carcase. Whether this adjustment is an off-set which is simply added to LMY%, or a non-linear relationship with fatness, will be determined by the accuracy required and the range in carcase weight and fatness of those carcases being processed. Therefore a LMY% of 71% may translate to a SMY% of 74% with forequarter cuts being boned to go to Chile and hindquarter cuts into Europe. The same carcase being boned for the domestic market may have a SMY% of 73%.

There can also be differences in the cutting lines used to define primal boundaries in the carcase. However, in the main, most beef carcase cutting lines tend to follow natural seams and so the differences between carcases are relatively small.

1.3 CURRENT MARKET GRIDS

If the beef language accurately describes yield (as LMY%) and eating quality (as an MSA grade) then it is well placed to underpin the development of value based payment trading systems (VBT).

It was clearly demonstrated by Ferguson and Thompson (1995) that payment grids based on weight, fatness, dentition and marbling perform poorly at predicting individual carcase value realised in the boning room. They examined the ability of commercial market grids to predict carcase value within a number of five different categories (these included cow, Korean grass fed, Domestic grain fed, Japanese grass fed and Japanese grain fed 150 days). In their experiment 30 to 40 sides (total 158 sides for all categories) were selected for each category from the slaughter floor and all cuts, lean trim, fat and bone weighed. Using the company's current wholesale values for each of the trimmed boneless primals, manufacturing trim, fat and bone the $ value was multiplied by their weights and then summed for each side. Realised value was expressed as $/kg cold carcase weight. Similarly current market grids were used to calculate the grid price for individual sides. When the realised value ($/kg) in the boning broom was graphed against grid value ($/kg) there was no relationship between realised value and the grid value (ie what the producer was paid) for each of the five categories. In fact three categories showed a slight negative trend which was disturbing.

Perhaps this was not surprising as individually the traits in the grid (such as weight, fatness, meat colour, marbling and dentition) have only a low relationship with realised value. This low relationship for individual traits was further eroded by categorising the input variables into weight, fatness and marbling classes. Therefore when categorical traits were the basis of any marketing grid it was not surprising there was no relationship between realised value in the boning room and grid value paid to the producer.

1.4 YIELD TECHNOLOGIES

Technologies to predict LMY% can range from simple regression models that predict yield to state-of-the-art computer tomography (CT) scanners. These will require an investment from the processors which could range from using simple carcase measurements which are currently part of the AUS-MEAT chiller assessment language to sophisticated X-ray technologies currently under development by several external providers (e.g. Scotts Technologies). Accuracy of these technologies will vary, most likely in accordance with the investment. The important point is that all technologies predict LMY%, albeit with varying accuracy. There should be an option for processors to state what the accuracy of their particular yield prediction technology is.

a) Yield equations utilising current grading traits

A number of workers have developed yield prediction equations using basic chiller assessment measurements collected at grading. When carcase weight, fatness and eye muscle area are used to predict SMY% the R^2 (or coefficient of determination) tends to be of the order of 30 to 40% (Johnson 1987, Perry et al 1993 Thompson et al 2012). The level of accuracy provided by these simple equations was probably considered too low to underpin a VBT system.

Given these low accuracies Thompson et al (2012) investigated the value of including selected cut weights on the accuracy of the prediction equations. By including carcase portions (butt or loin weights) accuracy increased to 60% and if individual cut weights were included the R^2 rose to over 70%. These improved accuracies were definitely high enough to support a VBT system, however the data set was not sufficiently large to confirm transportability of these functions.

If transportability of this approach was confirmed these equations would provide a simple cheap technique whereby a small plant operator could implement a yield prediction system with virtually no investment in expensive technology. The only capital investment would be several load cells to be installed on the chain or scales to weigh selected cuts. Such a system would be labour intensive but this may not be a problem if throughput was small, or these equations were used in the early development stages of a VBT system.

As discussed previously the measurement of SMY% is prone to errors in maintaining a constant level of level of trim for all cuts and carcases. An interesting set of analyses was recently undertaken by Jose et al (2014) where they used the current MSA grading measurements of HSCW, ribfat and eye muscle area to predict LMY% as calculated from the CT analysis of boned untrimmed cuts. The analysis used data from 5 different experiments where the cuts from full sides had been CT scanned to calculate LMY%. With a more accurate and consistent measurement of the end-point (i.e. LMY%) the accuracy of the equation increased to the order of 70 to 80%. However when the transportability of the equations was tested (i.e. the equations from one data set were applied to an independent data set) the accuracy fell to 40%. This lack of transportability could have arisen for several reasons. Firstly the data sets were each rather small and often weights were not normally distributed because they were part of other experiments. Secondly, the low transportability could have been due to grader effects in the accuracy of collecting the carcase measurements. This line of research needs to be further developed because it suggests that, if accurately collected, simple carcase measurements may provide a useful means to accurately predict LMY%.

b) Ultrasound

Ultrasound is used routinely to measure eye muscle area and backfat in live animals. More recently it has been used for measurement of marbling. Given that it is based on reflection of sound waves from a transducer placed over the loin it is mostly applicable to subcutaneous fat depth and to a lesser extent eye muscle area. Care needs to be taken to ensure good contact between the transducer and the animal, which generally necessitates shaving the hide and the use of oil.

Problems with using ultrasound on the carcase include bubbles of air that may be trapped in fat after removing the hide. For this reason ultrasound measurements taken hide on immediately after knocking may provide the best position to measure fat depth. As the hide has not been removed this has the advantage that fat tearing would not be an issue.

Velocity of sound (VOS) is another option to use ultrasound on the live animal or the carcase although the early equipment used by Wood et al (1991) was rather cumbersome and slow.

Another option examined for both the live animal and the carcase was digital A mode technology. This was a cheap A mode scanner that was capable of measuring the hide/fat and fat/muscles interfaces. By subtracting the two interfaces it gave an accurate estimate of fat depth in mm (Lake 1991). A commercial probe which was accurate and cheap was produced as part of an earlier MLA project, although there were problems with commercialisation and the equipment is no longer available.

c) Video Image Analysis (VIA)

Research into VIA was initiated in the early 1980s by Cross et al (1983). Since then Australia, Canada, Germany, Denmark and the US have undertaken significant research programs. VIA works by capturing images either on the whole carcase (WC) or the chiller assessment system on the quartered carcase (CAS). For the WC the Australian system analysed the carcase by segmenting into portions and measuring colour within these patches. On the other hand the German and Danish systems work by light stripping where an elongated beam is shone at an angle onto the carcase. The curvature of this line effectively allows a measurement of shape or conformation.

Allen and Finnerty (2001) compared the Australian, German and Danish WC systems in two experiments. They showed that all three systems were comparable in accuracy at predicting fat and conformation class based on the EUROP system. They also had similar accuracy at predicting SMY% explaining over 70% of the variation.

At the same time comparisons undertaken in Australia by Smith (2009) showed that the CAS and WCS each explained ca. 55% of the variance in SMY%, however when the data from the WCS and CAS were combined the two systems explained over 70% of the variance. In this data set the VIA system outperformed HCW, fat depth and eye muscle area which only explained ca. 45% of the variance.

A number of researchers have concluded that VIA provides a useful tool by which the industry could predict SMY%. It would be expected that if VIA was calibrated against LMY% the accuracy would increase further. However, for whatever reason, the Australian industry has not embraced VIA technology and currently no beef VIA systems (either WC or CAS) are operational in Australian plants.

In contrast in America and in Europe the VIA technology has been implemented in the beef industry. The US approved the use of VIA to measure firstly eye muscle area, followed by fat thickness and more recently marbling and yield grade. In 2009 two vision grading instruments were approved by the USDA for beef grading and by November 2012 there were seven companies (18 plants) approved for instrument grading and of those, five companies (10 plants) were actively using instrument grading. Canada has also adopted a computer vision grading system called the e+v Technology. This was approved by the Canadian Food Inspection Agency in 1999 for use by the Canadian Beef industry. VIA is also an integral part of the Danish beef classification system and installed in all major plants in the Republic of Ireland.

d) Dual Energy X-ray Absorptiometry (DEXA)

DEXA is a low-radiation technology that beams X-rays with different energy levels through a body. The resultant scans are much more accurate at discriminating between density of tissues than conventional X-ray technology, although the technique has the constraint that the density is recorded as a two dimensional images. Therefore the DEXA technology is less accurate in cuts with a high proportion of bone.

Another constraint with the DEXA technology is that it was developed for humans and therefore the scanning bed is rather small and most suited to small domestic animals such as pigs and sheep. Pearce et al (2009) examined the accuracy at predicting carcase composition in live sheep and their carcases. They showed that the accuracy (R^2) to predict muscle and fat % in the carcase was of the order of 65 and 80%. Understandably bone % had the lowest accuracy.

The early beef studies by Mitchell et al (1997) processed rib sections through DEXA scanners and showed R^2 values in excess of 80% for both lean and fat in the rib joint. More recently Lopez Campoz et al (2105) processed all beef cuts from 158 full sides through a DEXA and found R^2 values in excess of 80% for both fat and lean.

The DEXA technology will most likely be implemented as part of robotic systems to guide automated cutting of the carcase. There are already such systems which have been developed for lamb. Given the small scale of the conventional DEXA plates there are several ways this could be scaled up for beef. The first is to assume a part/whole relationship between the portion scanned and the whole carcase. This would allow the composition of a defined portion scanned by the DEXA to be used to predict the composition of the full side. This may not be ideal and so the second option would be to link a number of DEXA plates together to allow the full side to be scanned.

Given the research input in this area (Canada, New Zealand USA, Australia) it is likely that results will be available for trialling within two to three years.

e) Computer Axial Tomography (CT)

CT uses a system where an emitting X-ray source is rotated around the body with the resultant X-rays collected by a ring of detectors after passing through the body. The speed at which the X-rays pass through the body varies with tissue density. Mathematical algorithms convert the detected X-rays to reconstruct a two-dimensional image using the principles of the magic square. These images clearly separate the two-dimensional slice into fat muscle and bone. From the series of two dimensional images a three-dimensional image of the body can be constructed.

The early CT scanners were developed in the 1960s with the Nobel Prize being awarded to Cormick and Houndsfield in 1979. The first CT occupied a whole room for the scanner and another for the computing system. Since then the speed of scanning has increased followed by the development of spiral scanners. This has meant that a body can be scanned in a matter of seconds, the data stored and used to reconstruct images later. As the number of detectors and computing power has increased the clarity and resolution of the images has improved considerably.

The early CT scanners were complex and unsuitable for use in abattoirs. Since those early days the stability of the electronic equipment and the size and speed of the associated computer resources have improved considerably. In the 1980's scanners were installed in University Departments in Norway, New Zealand and Armidale.

The current CT scanners have the constraint of the donut of detectors and emitters rotating around the body which limits the size of the bodies that can be scanned. Although in the early development stages, work has started on three-dimensional scanners where the emitters and detectors are contained in large rectangular plates. These plates could be well shielded and potentially could be used to scan live animals or more particularly carcases at chain speeds.

Again there is a large research effort being undertaken to use CT as a tool to predict carcase composition on line. MLA currently has over 10 projects in this area (see project A.SCT.0029, MLA 2014), although they are still some way from delivering a practical system that will be sufficiently robust to operate in an abattoir environment.

f) RGBD technology (Wii cameras)

The RGBD camera technology and data acquisition software is an offshoot of the computer gaming industry (Wii cameras). Briefly, it uses a number of small cameras to collect a large number of images and integrate them into a three-dimensional image. To date it has successfully been used to estimate P8 fat depth and muscle scores in live cattle with accuracies in excess of 80% (McPhee 2013). There are no estimates of the accuracy of this technique when applied to carcases but it is expected that it will perform well. The technology is cheap and does not require much space on the slaughter floor.

It is likely that using this technology it would be relatively straightforward to use the RGBD camera and software to develop a vision system for installation on the slaughter line. As mentioned the system is compact, cheap, and appears to be robust. There is potential alignment of these studies with work currently underway in the use of Wii cameras to predict fatness in the live animal. Again this work is being progressed by MLA.

MEASUREMENT OF TRIMMED PRIMAL CUTS

The above refers to technologies to predict the percentage of trimmed primals in the carcase. This need to predict carcase yield may be obviated by technology that is capable of weighing and recording individual ID on trimmed primals as they are packed in the boning room. Given advances in data handling and robotics such a system is currently possible. Unfortunately attempts to set this up as a commercial operation have not been successful in Australia.

CALIBRATION OF YIELD TECHNOLOGIES

Calibration of the different technologies will underpin the industry's confidence in any future VBT systems that are developed. There is a need for the Australian beef industry to take a leadership role in setting up a calibration protocol. Obviously AUS-MEAT would be the most likely organisation to have the role in developing the standard for calibration and auditing the results.

The calibration procedure would require the processor installing the particular technology and recording measurements on their site at operating chain speeds. Using a standard protocol (say 100 sides) carcases would be boned into untrimmed primals which would be vacuum packed and transported to an industry facility for measurement of lean meat yield. Side weigh and individual bone weights would be recorded in the boning room.

The calibration facility y could initially comprise a medical CT scanner that would be used to scan the vacuumed primals. Images would be analysed to calculate lean and fat within each of the cuts and along with side and bone weights used to calculate LMY%. The data would also be capable of describing distribution of lean and fat in the carcase.

In the future, a purpose-built CT scanner could be used for calibration. There could also be an opportunity for a third party provider to set up a commercial calibration service for industry, or alternatively companies could set up their own calibration system which could be transported between plants.

After scanning the untrimmed primals would go back to the boning room for further trimming prior to sale. The processor may be interested in calibrating the LMY% to a particular trim specific for their markets/boning room (i.e. the company's specifications for SMY%). Depending upon the market specifications this could involve more than one level of trim. The final product could then be sold in the domestic market with only a minimal loss in value.

As technologies improve/come on-line they can be implemented in any plant. As previously mentioned it is likely that different plants will use different technologies because of differences in throughput, accuracy and investment required to support their VBT programs. Advances in medical technologies (e.g. DEXA, CT) are likely to provide real opportunity for the beef industry to develop cheap, accurate options to measure carcase yield. It is important to remember that the market for yield technologies in the beef industry is small and it is therefore unlikely that the beef industry can undertake the basic research required to develop new technologies from scratch. Rather it will always be adapting technologies such as DEXA and CT which have come from medical research.

A calibration standard or service would allow the meat industry to calibrate and validate a range of yield prediction technologies. In effect this is only part of the required changes that need to occur as there are also changes in the infrastructure within the company and perhaps more importantly the cultural changes that are required within the company to ensure successful implementation of new initiatives. For too long the promise of a 'new' technology just around the corner that was capable of revolutionising yield prediction has been used as an excuse by both researchers and the meat industry to wait for new technology to arrive. What is needed is for the industry to use the yield technologies that are currently available and start the process of change within their companies.

2. PREDICTION OF EATING QUALITY

2.1 THE MSA GRADING SYSTEM

Australia is unique in that it has a beef grading scheme that is capable of predicting eating quality of a cooked meal outcome for individual cuts in the carcase. The inputs used for the MSA prediction model are easily available in a commercial environment and are collated or measured on the carcase at grading. The accuracy of the MSA model to predict quality was reviewed by Thompson (2002). In an analysis of over 19,000 individual cuts which had been cooked in a variety of ways and consumer tested it was found that the MSA grading model correctly classified between 50 and 70% of the samples into their correct grade. This was an order of accuracy greater than is possible by just using other carcase grading systems.

Given that Australia has implemented the MSA grading system the criteria for a success of a new technology to predict eating quality are perhaps more stringent than those being applied in other markets around the world. In Australia the challenge for new technology to predict eating quality is to complement the current MSA grading scheme and predict eating quality within 3, 4 or 5 star grades. In contrast, in countries without an MSA grading system the challenge of new technology to predict eating quality is perhaps less daunting as there would be a much broader range in eating quality in the population of cattle produced.

Other technologies which have been investigated to predict beef eating quality – the Tendertec probe, Beef Cam, near-infrared reflectance and slice shear force – are discussed below.

2.2 TENDERTEC PROBE

The Tendertec probe was an Australian invention supported by MLA. It comprised a mechanical probe which measured resistance when inserted into the muscle of the chilled carcase. The efficacy of the probe in predicting tenderness was evaluated by several groups. The Beef CRC concluded that the probe was not capable of measuring tenderness and that previous evaluations had over-defined the calibration data by the large number of measurements collected on a single pass. The Beef CRC studies showed that any equations that were generated were not transportable between data sets. Evaluations of the Tendertec probe were also carried out in the US by Belk et al (2001) and George et al (1997) and their results concurred with this conclusion.

2.3 COLORIMETERS AND BEEF CAM

The US have also investigated the use of colorimeters to predict beef tenderness. Initial studies were promising (Wulf et al 1997) but a large evaluation by Wulf and Page (2000) found that colour dimensions added little accuracy to the prediction of eating quality over that explained by pH. The current MSA model uses pH as one of its input variables.

Beef Cam was a further development of a colorimeter which used colour analysis of a VIA images to predict tenderness. Whilst some predictive accuracy was obtained it was concluded the error rate was such that at this stage it was not suitable to progress to commercialisation (Wyle et al 2003).

2.4 SLICE SHEAR FORCE

The moderate relationship between shear force and tenderness led the scientists at Clay Centre to develop a slice shear test that could operate at line speed. The equipment operated at chain speed and a slice shear reading at grading was moderately related to the feedback of sensory panels at 14 days (Shackelford et al 1999 a,b).

However the industry has not embraced this technology, possibly because it is a destructive measurement.

2.5 NEAR INFRARED REFLECTANCE

Near-infrared reflectance technology (NIR) utilises spectroscopic methods to measure the quantity of reflectance in the near-infrared region of the spectrum. The technology is quick easy to use and is non-destructive and is used to predict chemical traits of a wide variety of materials (e.g. protein in wheat).

Workers from a number of laboratories have investigated its use to predict palatability in beef. MLA funded a large co-operative project between the Victorian DPI and Denmark which examined the role of NIR as a tool for use in on-line prediction of meat quality (Baud et al 2011). They showed that the NIR could predict objective colour, intramuscular fat and pH at 24 hours as well as muscle glycogen and/or glycolytic potential and muscle heme pigment levels at 30 minutes post slaughter. However, even though some of these predictors are used as inputs in the MSA model it was found that NIR was a poor predictor of objective tenderness. Similar conclusions were reached by De Marchii et al (2013).

3. RECOMMENDATION

There is a large research effort currently underway to customise medical and other technologies to predict LMY% of the carcase. Ultimately there will be a range of technologies which vary in cost and accuracy operating in the beef industry to measure LMY%. There is a need for the beef industry to develop protocols (and maybe resources) to calibrate the accuracy of these technologies as they become available for trialling in beef plants in Australia. Ultimately the need to predict yield may be obviated by technology capable of weighing every cut from a carcase.

The MSA grading system predicts the eating quality of individual cuts according to how they are cooked. The challenge for new technologies aimed at predicting eating quality is to add value to the existing MSA grading scheme. Whilst a number of other technologies have been trialled they have failed to provide an accurate, non-destructive and transportable measurement of eating quality at grading.

REFERENCES

Allen P, Finnerty N (2001) Mechanical grading of beef. Teagasc, Ballsbridge, Dublin.

Anon (2002) Understanding Meat Yield. Meat Technology Update. Newsletter 02/4 (http://www.meatupdate.csiro.au/data/MEAT_TECHNOLOGY_UPDATE_02-4.pdf accessed 6/12/2014).

Baud S, Kerr M, Weston P, Nantharampatha A, Borggaard C (2011) On line technology to predict beef and sheep meat quality traits using near infra red and other predictive techniques Final Report A.MQT.0016, Meat and Livestock Australia Sydney.

Belk KE, George MH, Tatum JD, Hilton GG, Miller RK, Koohmaraie M, Reagan JO, Smith GC (2001) Evaluation of the Tendertec beef grading instrument to predict the tenderness of steaks from beef carcases. Journal of Animal Science. 79:688.

Cross HR., Gilliland DA, Durland PR, Seideman S (1983). Beef carcase evaluation by use of a video image analysis system. Journal of Animal Science. 57:908–917.

De Marchi M, Penasa M, Cecchinato A, Bittante G (2013) The relevance of different near infrared technologies and sample treatments for predicting meat quality traits in commercial beef cuts. Meat Science. 93:329-335.

Ferguson DM and Thompson JM (1995) VIA Yield Trial Queensland, Final Report Project M.630. Meat Research Committee, Sydney.

George MH, Tatum JD, Dolezal HG, Morgan JB, Wise JW, Calkins CR, Gordon T, Reagan JO, and Smith GC. 1997. Comparison of USDA quality grade with Tendertec for the assessment of beef palatability. Journal of Animal Science. 75:1538.

Johnson (1987) Comparison of twelfth rib and rump fat thickness measurements for predicting commercial beef yield in local market carcasses. Australian Journal of Experimental Agriculture 27:613-617.

Jose C, McGilchrist P, Pethick D, Gardner G (2014) Addressing key issues affecting compliance rates of pasture-fed cattle in Southern Australia. Final Report Project B SBP.0110, Meat and Livestock Australia, Sydney

Lake R (1991). Ultrasonic evaluation: Image analysis and industrial applications. In the Proceedings of Electronic Evaluation of Meat in Support of Value Based Marketing, Purdue University. *West Lafayette*, 25-46.

López-Campos O, Larsen I, Prieto N, Juárez M, Aalhus JL (2015) Using Dual Energy X-Ray Absorptiometry technology for rapid and non-invasive fat and lean predictions in beef carcases Meat Science 99:144

McPhee M (2013) Initiative – trait measurement from 3D images. MLA final report for project B.BSC.0339. Meat and Livestock, Sydney.

Mitchell AD, Solomon MB, Rumsey TS (1997) Composition Analysis of Beef Rib Sections by Dual-energy X-ray Absorptiometry. Meat Science 47:115-124.

Nade T, Fujita K, Fujii M, Yoshida M, Haryu T, Misumi S, Okumura T (200?) Development of X-ray computed tomography for live standing cattle. Animal Science. 76:513-517.

Pearce KL, Ferguson M, Gardner G Smith N, Greef J, Pethick DW (2009) Dual X-ray absorptiometry accurately predicts carcase composition from live sheep and chemical composition of live and dead sheep. Meat Science 81: 285-293.

Perry D, McKiernan WA, Yeates P (1993) Muscle score: its usefulness in describing the potential yield of saleable meat from live steers and their carcases *Australian Journal of Experimental Agriculture*, 33,27-281

Polkinghorne R. Thompson JM, Watson R, Gee A Porter M (2008) Evolution of the Meat Standards Australia (MSA) beef grading system. *Australian Journal of Experimental Agriculture*, 48:1351-1359.

Shackelford SD, Wheeler TL, Koohmaraie M (1999a). Tenderness classification of beef: II. Design and analysis of a system to measure beef *longissimus* shear force under commercial processing conditions. Journal of Animal Science. 77:1474.

Shackelford, SD, Wheeler TL, and Koohmaraie M (1999b). Evaluation of slice shear force as an objective method of assessing beef *longissimus* tenderness. Journal of Animal Science. 77:2693.

Smith CR (2009) The ability of the VIAscan® Beef Carcase System and Chiller Assessment System to predict Saleable Meat Yield for 100 day Grain Fed cattle. A report to Cargill Pty Ltd by The Cedar Creek Company

Thompson JM (2002) Managing meat tenderness Meat Science. Meat Science. 62:295-308.

Thompson JM, Polkinghorne R, Griffiths G (2012) A value based marketing system incorporating quality and yield for Teys supply chains. A report for Teys Pty Ltd, Brisbane.

Webster P and Young R (1997) Beef on bone banned over CJD fears. (http://mad-cow.org/~tom/bone_ban.html accessed on 6/12/2014)

Williams DR., Pomeroy RW, Harries JM, & Ryan PO (1974). Composition of beef carcases: II. The use of regression equations to estimate total tissue components from observations on intact and quartered sides and partial dissection data. The Journal of Agricultural Science, 83, 79–85.

Woerner DR and Belk KE (2008) The history of instrument grading of beef. A focus on the last ten years. National Cattleman's Association

Wood JD, Newman PB, Miles CA and Fisher AV (1991). Video image analysis: Comparisons with other novel techniques for carcase assessment. In Proceedings of Electronic Evaluation of Meat in Support of Value Based Marketing, Purdue University. *West Lafayette*, 147-174.

Wulf, DM, O'Connor SF, Tatum JD, and Smith GC 1997. Using objective measures of muscle color to predict beef *longissimus* tenderness. Journal of Animal Science. 75:684.

Wulf, DM and Page JK (2000). Using measurements of muscle color, pH, and electrical impedance to augment the current USDA beef quality grading standards and improve the accuracy and precision of sorting carcases into palatability groups. Journal of Animal Science. 78:2595.

Wyle AM, Vote DJ, Roeber DL, Cannel RC. Belk KE, Scanga JA, Goldberg M, Tatum JD, Smith GC. (2003). Effectiveness of the SmartMV prototype BeefCam System to sort beef carcases into expected palatability groups. Journal of Animal Science. 81:441.

FOR FURTHER INFORMATION

Contact//

MLA head office
Level 1, 40 Mount Street,
North Sydney NSW 2060
Postal address:
PO Box 1961
North Sydney NSW 2059

General enquiries
T: 02 9463 9333
Free call: 1800 023 100
(Australia only)
F: 02 9463 9393
E: info@mla.com.au

www.**mla**.com.au