MEAT & LIVESTOCK AUSTRALIA

APPENDIX C:

CURRENT CARCASE TRAITS IN THE AUSTRALIAN BEEF LANGUAGE

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CONTENTS

INTRODUCTION

This paper reviews current measurements used in the Australian beef language. Firstly, the definition of the trait is discussed, followed by background on what the trait is measuring and the history of its implementation. A discussion on the accuracy of the current technology follows with comment on any corrective action that may be required in the short to medium term to address any biases. New technology that may be relevant to either replace or improve the measurement in the short, medium or long term is also briefly reviewed. Finally, recommendations are made for the short and longer term.

The traits in the Australian Beef Language are:

- Standard carcase
- Marbling score
- P8 fat depth/12th ribfat
- Carcase maturity (age, ossification score and dentition)
- Meat colour score
- Fat colour score
- Eye muscle area
- Ultimate pH
- Hump height
- Butt shape
- Sex category

THE ON-SITE-CORRELATION AND PRACTICE SYSTEM (OSCAP)

Before discussing the individual carcase traits it is appropriate to describe the audit procedure developed and currently operated by AUS-MEAT. The OSCAP system is the internal audit system developed by AUS-MEAT to standardise the all subjective scores and measurements given by graders. This includes marbling, ossification and meat colour scores, hump height, fat depth and fat colour and eye muscle area. The system draws from a large bank of photographs of the traits that are displayed on a true colour screen. At two monthly intervals accredited graders are required to grade a random selection of images and achieve a threshold in accuracy. The database of photographs is accessed on-site drawing on the central database.

The accuracy of individual graders is assessed after measurements/grades are assigned to individual images selected randomly. The criteria for accuracy are complicated formulae for the correct allocation plus allowances for where there are differences (Anon 2013). It would be an improvement if the measure of accuracy was expressed as a correlation. This would provide a simple figure that could more easily plot progress of how graders are tracking both between graders and across time.

1. STANDARD CARCASE

1a) DEFINITION FOR STANDARD CARCASE

The standard beef carcase is defined by AUS-MEAT (Anon 2010a) as the body of a slaughtered bovine after bleeding, hide removal and removal of all internal digestive, respiratory, excretory, reproductive and circulatory organs. Its definition also stipulates removal of the head (between the skull and the first cervical vertebrae), the forefeet (between the carpal and metacarpal bones), hock (between the tarsal and metatarsal bones), tail (at the junction of the sacral and coccygeal bones), skirts (both thick and thin skirts), kidneys, kidney fat and fat within the pelvic channel, testes, penis and udder, pre-crural fat and fat on the channel rim from the ischiatic tuber to the sacro-coccygeal junction.

In addition to the above, excessive fat is trimmed from the topside (to 10 mm depth) and external fat from the brisket point end (to 10 mm depth). Intra-thoracic fat and the xiphoid cartilage and the linea alba that extends from the xiphoid cartilage to the most caudal point of the thin flank are also removed.

Hygiene trims which result from operational processes such as Halal sticking are also removed along with sufficient trimming of any contaminated areas on the carcases.

Finally the carcase as defined above must be weighed within two hours of slaughter and the actual weight reported with no deduction for shrinkage.

1b) BACKGROUND TO THE MEASUREMENT OF THE STANDARD CARCASE

The standard carcase definition was set up to facilitate "over the hooks" (OTH) trading by providing a standard definition of the carcase that was repeatable both over time and between operators (Anon 2010b). The intention was to provide a means by which producers could compare the different grid prices used by processors in OTH trading. Prior to this, adjustments were required to account for whether certain organs or carcase components were retained or removed from the carcase at different plants.

The introduction of the standard carcase put an end to the practise of discounting hot carcase weight for shrinkage that occurs in the chiller. The evaporative loss from chilling ranges from 0.5 to 3% depending upon chiller loading, fatness, windspeed and humidity of the chilled air. As the variation in weight loss depends upon chiller efficiency, as opposed to producer efficiency, AUS-MEAT decided that processors should pay on the hot standard carcase with no deductions for chilling loss when using OTH trading (Hall 1988).

1c) ACCURACY AND BIAS IN THE MEASUREMENT OF THE STANDARD CARCASE

The intention of the carcase definition was to standardise removal of variable components such as tail, kidneys etc and also to reduce variation in low value components such as excessive fat over the brisket and topside cuts. There would appear to be little dispute over what components are removed or retained on the carcase. However greater oversight is needed to ensure that the same level of trim is being applied in all plants.

There is some anecdotal evidence from producers that since dressing percentage differs in mobs that have been trucked to different plants it must be due to different carcase dressing procedures. Efforts need to be made (perhaps by AUS-MEAT) to investigate these incidents with well-designed trials that allow valid comparison between groups.

The level of fat trim over the topside and brisket is obviously a point that has caused some producers to feel that fat has been excessively trimmed and carcase weight reduced in some plants. From the processor's view, if a variable amount of fat was left on the carcase this would reduce the yield of trimmed primals for some carcases and therefore the average price would need to be adjusted to take account of this. The question of how to standardise the level of trim is difficult to answer.

The degree of hygiene trim from sticking is another variable that causes producer concerns. Other sources of discontent include bruise trimming. On the slaughter floor it is difficult to attribute whether bruise trim has been caused by producer or processors inputs. Similarly, hygiene trim for gut contamination could be argued as being the processor's responsibility but that it needs to be done on the slaughter floor so the carcase can be certified as being suitable for human consumption before being placed in the chiller.

There is often comment in the popular press of anecdotal evidence that dressing percentage varies between lots which have been split and sent to different plants. The immediate conclusion by producers is that such differences are due to differences in carcase trimming, yet there are also differences in trucking distance/time, lairage etc. As producer confidence in the beef language underpins the success of value based marketing there may be a need for an independent team to investigate these occurrences. Whilst an individual investigation might not be conducted in every instance, guidelines should exist to allow claims to be viewed in a structured manner.

1d) TECHNOLOGY TO MEASURE STANDARD CARCASE

As part of a project assessing the accuracy of whole carcase Video Image Analysis (VIA) scanning using a commercially available system called 'VIASCAN', Ferguson and Thompson (1995) collected lateral, medial and dorsal images on 38 sides before and after AUS-MEAT trim. The aim was to evaluate the VIA as a tool to monitor compliance of the level of trimming with that permitted by the standard carcase definition. Trim weight was collected and weighed from the 38 sides. Unfortunately analysis of images resulted in the conclusion that it was not feasible to discriminate between sides which were under- or over-trimmed with respect to the standard carcase definition. This was also reinforced by the fact that such a task was extremely difficult even to naked eye.

If there is continuing dissatisfaction from producers regarding application of the trim standards it may be prudent to revisit this area, particularly considering the recent advances in image analysis. The hygiene trim on the neck is one area that should be easily monitored by images captured at the scales.

1e) RECOMMENDATION FOR STANDARD CARCASE

The current standard carcase definition provides a sound basis for OTH trading and should be retained. Consideration should be given to developing vision systems to audit the level of trimming of the brisket and topside and hygiene trim due to sticking to ensure it complies with the definition in the standards.

2. MARBLING SCORE

2a) DEFINITION OF MARBLING SCORE

Currently, marbling score is assessed subjectively against digitally-constructed standards. The Australian language currently has two systems (AUS-MEAT and Meat Standards Australia, MSA) to describe marbling. The AUS-MEAT marble score is assessed by graders and scored against the AUS-MEAT marbling reference standards. These standards are on a 0 (devoid of marbling) to 9 (abundant marbling) scale and have been digitally enhanced to contain variable amounts of white relative to red pixels. The AUS-MEAT score is based on the total amount of white in the muscle. AUS-Meat currently requires that muscle is below 12oC for grading, with a recommended temperature of 4-8oC (Anon 2004).

The MSA system is based on the United States Department of Agriculture (USDA) marble score system which cover the range from 100 to 1190. MSA marbling is based upon the amount of intramuscular fat as well as fineness and distribution of the marbling within the eye muscle (Anon 2011). MSA marbling has the advantage that it increases in smaller increments (measured in units of 10, although the photographic standards refer to increments of 100). MSA marbling is a continuous score with up to 110 categories and is therefore more suited for use as a predictor in the MSA model than the AUS-MEAT scores which have only 10 discrete categories.

The AUS-MEAT website states that the two systems "can be used in harmony to provide more detail about the product" (Anon 2005). However "MSA Tips and Tools" (Anon 2011) states that there are no formulae to compare MSA and AUS-MEAT marbling scores as the assessment criteria are different. Clearly, equivalence between the two measurements of marbling is an area that needs to be addressed. The results of Muir et al (1998) are interesting in that they found that the grader effect was larger when Japanese Meat Grading Association (JMGA) standards (which use stylised representations of marbling) were used compared with the USDA system (which use photographs of actual rib eye areas).

Much of the world is familiar with USDA marbling scores as they form part of a number of other grading systems around the world (Polkinghorne and Thompson 2010). If the systems were to be merged it would be logical that the new standard for the Australian Beef Language be based on the USDA marbling standards which are currently used by MSA. This would effectively provide some degree of equivalence with a number of other grading systems around the world.

2b) BACKGROUND TO MARBLING SCORE

Marbling in beef refers to the white flecks of visible fat between the bundles of muscle fibres in skeletal muscle. These white flecks of fat comprise clumps of adipocytes which are at various stages of filling with triglycerides. These adipocytes are embedded in a connective tissue matrix in close proximity to blood capillary networks (Harper and Pethick 2004).

Historically, increased marbling or fat content in meat has been associated with increased eating quality, but it was not until the middle of last century that researchers began to collect data to confirm the link (see Smith and Carpenter 1976). Since then numerous studies have examined the association between marbling and eating quality. These were recently reviewed by Mafi et al (2012) who concluded that whilst most studies reported positive relationships between marbling and sensory scores the strength of the relationships were often low and variable. However, marbling scores do provide some assurance for eating quality and hence have been used in this role in the majority of grading schemes around the world (NSLMB 1995, Polkinghorne and Thompson 2010).

Marbling scores (by either the AUS-MEAT or MSA systems) are highly related to intramuscular fat percentage with correlations ranging from 0.7 to 0.9 (Greiner 2002).

However as stated above marbling score is a subjective score of visible fat in the muscle, whilst intramuscular fat is a measure of the total amount of chemical fat within the muscle and so includes both visible fat and invisible triglycerides and phospholipids associated with the cell wall structure. This invisible fat comprises a relatively constant proportion of the muscle as it appears not to vary with short-term changes in nutrition (Masoro 1967). Therefore, it may be possible to adjust chemical fat levels for the invisible fat to better reflect the visible fat levels.

If the tenderness advantage of marbling is due to dilution of a more dense protein matrix by a less dense fat matrix (Park et al 2008), then visual marbling is probably the more appropriate measure. If however the main advantage of marbling is via an increase in juiciness then chemical fat may be the more appropriate measure of marbling.

Alternatively the Queens group in Belfast have suggested that the main advantage of marbling is via increased flavour scores due to the volatiles stored in the lipids being released more slowly (LJ Farmer, personal communication). If this is the case it is not clear whether this would favour a visual or chemical measurement of intramuscular fat.

2c) ACCURACY AND BIAS IN THE MEASUREMENT OF MARBLING SCORE

A major concern that has been raised by industry is the potential bias in subjective marble scores. If there are substantial biases an obvious solution would be to move to objective grading technologies. However the first question that needs to be addressed is to quantify the magnitude of the bias with the current system of subjective marbling scores and, if bias exists, to investigate corrective action to minimise this bias. The second question of objective technologies that could accurately assess marbling without grader bias is a longer-term solution at best.

GRADER BIAS

Analysis of slaughter records indicates several sources of bias in grader marbling scores (Thompson JM and Polkinghorne R *unpublished data*). Using a large industry data set of over a million carcase records the effects on grader on MSA marbling scores were examined after adjustment for production (Hormonal Growth Promotants (HGPs), sex), processing (grader, time from slaughter to grading) and carcase traits (hot standard carcase weight (HSCW), ossification score, ribfat and ultimate pH). To gain an appreciation as to whether the grader effect was repeatable the analyses were repeated in grain and grassfed carcases over a number of plants and showed an average range of 40 marbling units between the highest and lowest marbling scores at each plant, i.e. at each plant the highest grader was consistently giving scores which were on average at least 40 units different from the lowest grader. It is important to note that the grader effects were evident after the marble scores were adjusted for production and processing effects and also were adjusted to the same HSCW, ossification score, ribfat and pH. Muir et al (1998) also reported large grader effects in allocating marbling scores to beef carcases. It was interesting to note that inconsistencies between graders was one of the main reasons the US system has pursued development of VIA systems (Moore et al 2010).

Whilst the analysis of the industry grade data showed significant grader effects, the different graders did not score the same carcases and so one interpretation could be that the grader giving the highest marble score may have actually been presented with more highly marbled carcases and vice versa for the grader with the lowest marble scores presented with poorly marbled carcases. As mentioned, the grader effects were independently analysed in grain and grass fed carcases to gain an appreciation of the repeatability of the grader effect. These analyses showed that within plant the predicted mean marbling scores for the different graders in grain and grass carcases were highly correlated. In other words, the same ranking of graders was evident in both grain and grass fed carcases (with an average correlation between graders of adjusted marble score in grain and grass fed within plant of greater than 0.6, and as high as 0.9 in one plant). This suggested that grader bias was real and that at a number of plants individual graders were consistently giving marble scores that were 40 marble units apart for similar type carcases. It was important to note that these grader effects were apparent even with bi-monthly audits using the OSCAP system.

A possible criticism of the OSCAP system is that these audits are not conducted in a real world environment and hence whilst graders may be complying with accuracy thresholds with OSCAP, this may not relate back to their performance in the chiller. Whilst the motives of the OSCAP system are well placed it would appear that there has never been any investigation to quantify the benefits of the OSCAP system in terms of increased grader accuracy and a reduction in the bias due to individual graders.

The analyses described above clearly showed there were large grader effects on the marble scores currently operating in industry. There are a number of corrective actions that could be taken. An initial suggestion would be to regularly undertake analyses of plant grading data to allow early identification of grader bias. This would only require the statistical inputs to regularly review and analyse plant grading data. It would be possible to set up this analysis up on at least a monthly or bi-monthly basis. It needs to be stressed that the above suggestion is aimed at early identification of grader bias and implementation of corrective action to help graders recalibrate and reduce this bias.

Consideration would also need to be given to the structure of any retraining programs conducted at the plant once problems came to light. As part of any retraining program plant graders would need to be continually retested and the results presented back to them in real time to maximise the effectiveness of any retraining program.

As mentioned previously the AUS-MEAT marbling standards are digitally enhanced as opposed to the USDA standards which are based on photographs. In this context the results of Muir et al (1998) are interesting where they showed larger grader effects when the digitally enhanced JMGA standards were used as opposed to the USDA photographic standards. This would support adoption of the USDA standards.

TIME FROM GRADING TO SLAUGHTER

There is a common perception in industry that if carcases are held over a weekend before grading they will have a higher marble score. It is interesting that there is little published information on this aspect of carcase grading.

The effect of delayed quartering on AUS-MEAT marbling scores was examined using 200 Wagyu carcases where alternate right and left sides were quartered and graded 24 hours post slaughter and the remaining side left for 48 hrs before quartering and grading (JM Thompson *unpublished data*). The results showed an increase in 0.8 of an AUS-MEAT marble score in the 48 hr versus the 24 hr quartered sides. It was interesting that the increase in marbling score was not a temperature effect. Rather it was likely that the increase in marbling was in part due to a structural change in the fat which lead to greater visualisation of marbling fat (R Tume, *personnal communication*).

In addition, the large industry data set referred to previously (JM Thompson and R Polkinghorne *unpublished data*) was also used to estimate the magnitude of the increase in the MSA marbling score by quartering carcases at 18 hrs, 2 and 4 days post slaughter. As for previous analyses the data were adjusted for production, processing and carcase traits. The results showed a curvilinear response for all plants in that there was a 40 point increase in marbling score from grading at 18 hrs compared to grading at 48 hrs but only a 6 point increase if carcases were graded at 96 hours post slaughter. These increases in marble score were substantial and would explain the preference for a Friday kill by many Wagyu producers.

To counter the bias of grading at different times after slaughter a number of strategies could be put in place. The easiest solution would be to quarter and grade all carcases a standard time after slaughter. Therefore, Friday's kill could be quartered on Saturday morning, rather than Monday morning. The exposed eye muscle could be covered with plastic to minimise evaporative loss. If for operational reasons this was not suitable a correction factor could be calculated and applied when carcases were quartered on Monday morning. This would effectively adjust all marble scores to a standard grading time for payment and use in the MSA prediction model. The accuracy of such a correction factor has not been calculated and this would need to be done prior to moving down this path. It is also worthwhile to mention that any correction factor would have error and this could become a source of discontent in the industry.

From the literature, muscle temperature at grading is known to affect the visualisation of marbling. Similarly differences in fatty acid composition can also impact on the visualisation of marbling (Tume 2001). It was interesting that in all analyses of the factors that impacted on marbling scores, muscle temperature over the narrow range experienced in the chillers did not have an effect (JM Thompson *unpublished data*).

2d) TECHNOLOGY TO MEASURE MARBLING SCORE

In the longer term consideration should be given to objective technologies which may reduce some of the biases in measuring marble score. There are a number of technologies that use image analysis to objectively measure marbling. The images are captured from the quartered carcase and then converted to a marble score using various algorithms. Certainly the VIASCAN chiller assessment unit is capable of measuring marbling and is currently approved by AUS-MEAT (Anon 2013). The current Australian VIASCAN unit has the disadvantage of being large and cumbersome and requiring a power connection. In the USA, VIA has been approved to measure marbling for some time (Moore et al 2010).

More recently a high definition camera to capture high quality images and partitioning the resultant images into a number of traits which are related to marbling score has been developed by Kuchida et al (1997a, b). Simple traits such as percentage of white area in the muscle are highly correlated with AUS-MEAT marbling scores (Maeda et al 2014). The technology also calculates a large number of related traits such as fineness and distribution. However it is not clear whether the greater detail on these traits delivers any worthwhile information in terms of customer requirements, or a better insight into eating quality.

With technology developments in cameras and image analysis it is highly likely that a much smaller and more easily transportable unit with a simple output could be developed using tablet technology. However any system that depends upon image capture at grading will suffer from the substantial biases that occur with variation in temperature and differences in the time between slaughter and grading. As previously discussed, this may be addressed by developing appropriate correction factors.

Multispectral scanning collects and processes information from across the electromagnetic spectrum and, as such, has more potential to capture information than a conventional photograph. Certainly initial work in this area (Qiao et al 2007, Elmasry et al 2013) suggests that it can accurately estimate marbling.

An alternative approach is to measure aspects of chemical fat that are not dependent upon visualisation of fat in the quartered carcase. An approach that warrants further investigation is Velocity of Sound (VOS). This technology measures the time it takes an ultrasound signal to travel between two transducers embedded in the eye muscle. An initial investigation Thompson and Bradbury (2005) reported that VOS was capable of measuring chemical fat in the muscle but it was sensitive to muscle temperature. This technique had the advantage that it could be used to measure intramuscular fat or marbling in the hot carcase with subsequent advantages in sorting carcase prior to boning.

Impedance probes also offer another technology to predict chemical fat in beef. A review by Altmann and Pliquett (2006) indicated there were problems at the lower levels of intramuscular fat and that the technology was not yet ready for commercialisation in the meat industry.

Computer Tomography (CT) is another technology capable of delivering an accurate measure of intramuscular fat or marbling. Recent studies have confirmed the accuracy of this technology (Ross et al 2014, McPhee 2014) in beef. Conventional CT passes an object through a donut of emitters and detectors which would relegate the technology to post boning and therefore not able to be used to sort carcases. However, while it would not be useful in conventional boning establishments, CT may well provide a viable technology to sort cuts to exacting specifications post boning. As CT technology becomes more robust and capable of scanning larger objects it may be capable of scanning the hot carcase.

Perhaps in the future there will be the capacity to take a three dimensional CT scan of the side at line speed and deliver an estimate of marbling (adjusted for temperature) of all major primal cuts prior to chilling so carcases could be sorted to better meet market specifications.

2e) RECOMMENDATION FOR MARBLING SCORE

Both the AUS-Meat or MSA scoring systems to describe marbling are referenced against images standards. It is recommended that the two systems be merged in the interests of simplifying the message to the Australian industry and also to improve equivalence with other grading schemes around the world.

The current marbling scores are subject to substantial bias both by graders and the time from slaughter to grading. Systems need to be put in place to quantify and rectify this in real time. In the short term grader bias needs to be monitored by regularly analysing all grade data and where appropriate supplying more training.

Assessment of marbling score using image analysis could remove grader bias but if marbling score is based on visual fat in the muscle the bias due to time from slaughter to grading will still be present. A longer term solution may be to measure intramuscular fat content using other techniques such as impedance or VOS.

3. FAT DEPTH MEASUREMENT

3a) DEFINITION OF FAT DEPTH

P8 fat depth is defined as fat depth at the intersection of a horizontal line from the third sacral vertebra and a vertical line from the sacro-sciatic ligament and dorsal tuberosity of the sacral bone (Anon 2013). P8 fat depth is measured manually using a cut and measure knife, or it can be measured using the Hennessy Grading Probe. P8 fat depth is a mandatory trait for AUS-MEAT. If the P8 site is damaged by dressing or hide puller damage then the other side is measured. If both sides are damaged then fat depth is recorded as an estimate on the kill sheet.

As part of MSA grading fat depth at the quartered rib site is measured as the total fat depth over the last quarter of the eye muscle. Given the quartering site may vary, the site for the measurement of ribfat will vary accordingly. To be eligible for MSA grading carcases require a minimum of 3mm over the ribs. Ribfat is also used as a predictor of eating quality in the MSA model given the positive correlation between marbling and fat depth (Watson et al 2008).

Whilst MSA uses fat depth as an indicator of eating quality its primary use in the Australian beef language is as a predictor of carcase yield. Once the carcase is boned and primals are boxed fat depth is not used as a specification, presumably on the assumption that all primals are trimmed to the same wholesale trim in the boning room.

3b) BACKGROUND TO THE MEASUREMENT OF FAT DEPTH

Fat depth measurement in the beef carcase has been a source of debate over the years. Initially in research studies in the 1970s fat depth was measured at the 10th rib (where most carcases were quartered at this time). Subsequently the quartering site moved back to the 12th rib presumably because the cube roll was extracted from the rib set and sold as a grilling cut. Around this time mechanised hide pullers were introduced resulting in some damage at the proposed fat depth site at the 12th rib. It was also at this stage that AUS-MEAT was establishing the national language for beef carcases. Based largely on the data of Moon (1980) and Johnson and Vidyadaran (1981) the P8 site was selected for inclusion into the language, on the premise that it suffered less hide puller damage than the 12/13th rib site. Subsequent studies by Johnson (1987) and McIntyre and Frapple (1988) showed that when considered in conjunction with hot carcase weight, 12th rib and P8 fat depth were equally accurate at predicting carcase yield. Hopkins (1989) analysed data on ca. 11,000 carcases from Tasmanian slaughter plants and found little difference in fat damage at either the 12th rib or P8 sites. He concluded that there was no evidence that one site was more reliable than the other.

McIntyre (1994) argued for the 12th rib site on the basis that other measurements (such as eye muscle area marbling and meat colour) were recorded at that site. It should be noted that live animal fat or condition scores are based largely on palpation of the loin over the dorsal and lateral spines of the lumbar vertebrae. Hence, fat depth at the 12th rib should better align live animal condition scores. The P8 site in the live animal is much harder to subjectively score as there is no bone to help assess the covering of soft tissue as there is at the 12th rib site.

If fat depth is used as an indicator of carcase yield then a single point estimate at any site on the carcase is likely to be deficient for reasons of operator effects, damage and variation between sites in the carcase. It is likely that in the near future other techniques which measure more than a point estimate of fat depth will be used to accurately measure carcase yield and so the industry will not be reliant on fat depth measurements to predict yield.

MSA has a requirement for greater than 3mm of fat over the loin along with a subjective assessment of fat distribution on the carcase as a means of minimising variation in carcase chilling and hence problems in eating quality (Anon 2011).

3c) ACCURACY AND BIAS IN THE MEASUREMENT FAT DEPTH

Until recently it was difficult to find data on the accuracy and bias associated with measurement of P8 fat depth. Rather than being measured by individual graders, P8 fat depth is measured by one grader at the scales.

Recent analysis of industry data sets showed that after adjustment for production, processing and carcase traits there were significant grader effects on the measurement of ribfat (JM Thompson and R Polkinghorne *unpublished data*). After adjustment for production, processing and carcase traits, grader means generally had a range of 2 to 3mm which although relatively small represented a range of ±20% when expressed as a percentage of the mean ribfat. Using the same approach as for marbling score (see section 2) the ranking of graders for ribfat was assessed in grain and grass fed carcases and their correlation used to assess the repeatability of the grader effects. The correlations for ribfat between graders in grain and grass carcases were positive and significant ($P<0.05$), with a mean correlation of 0.67 (individual plants having correlations ranging from 0.25 to 0.98). This suggests that within some plants (but not all) graders consistently reported high or low ribfats and the grader ranking was the same in grain and grass fed carcases. A number of reasons could be put forward to explain this bias including recording a subjective assessment of fat depth or graders were not measuring the traits correctly.

The other significant effect was that after adjustment for production, processing and carcase traits there was a curvilinear trend for ribfat to decrease with longer times from slaughter to grading. The largest decrease occurred in the first increment from 18 to 48 hours and was generally of the magnitude of 0.2mm. Thereafter the declines were of the order of 0.1mm or less. There are no reports in the literature of a time from slaughter to grading effect on ribfat, but presumably it occurred because the fat was drying out. The effect was evident in all plants surveyed and although statistically significant the magnitude of the effect meant that it was unlikely to be of commercial importance.

The bias due to graders in contrast was large and commercially important given that fat depth generally comprises part of any marketing grid. It is important to note that these biases have occurred in the presence of OSCAP which currently is the only tool used to audit grader performance. Furthermore if yield prediction equations were to utilise fat depth as a trait, grader bias on fat depth would be a greater concern.

Clearly OSCAP is not eliminating grader bias and more needs to be done in monitoring grader performance. As recommended for marbling score, a regular analysis of grade data would allow grader bias to be monitored. If large effects are evident then a retraining program should be undertaken in plant to correct this.

3d) TECHNOLOGY TO MEASURE FAT DEPTH

Australia is the only country that uses fat depth at the P8 site, with most using a fat depth measurement at the site of quartering (Polkinghorne and Thompson 2010). The literature indicates that all point measurements of fat depth are subject to some degree of dressing variation and fat tearing. Perhaps the solution is to investigate new traits that are less influenced by fat tearing and dressing. This is not simply suggesting another site on the carcase but rather measuring a new trait such as the area of fat coving the loin muscle in the quartered side.

Options include measurement on the animal before carcase dressing and any fat tearing has occurred. Ferguson (1996) reported results from a number of studies that showed that ultrasonic measurement of fat depth taken hide-on had a similar accuracy at predicting carcase yield as ribfat measured on the hot carcase. However the commercial adoption of ultrasound technology is currently hampered by the lack of suitable ultrasound devices and also ensuring good contact between the ultrasound head and the hide. Given recent advances in ultrasound this could be worth revisiting.

If an image of the quartered carcase is collected, other traits such as fat area over the eye muscle could be measured and these have been shown to be a more accurate measure of yield and subject to less bias from fat tearing (Anon 2013). The need for a single fat depth would also be negated if a side image of the carcase was used to estimate yield directly, or to assess subcutaneous fat distribution, using technology such as VIASCAN. Alternatively a DEXA image of the whole carcase would provide a direct estimate of yield. As mentioned, the consumer does require some covering of fat over certain cuts. The problem is that a system that just predicts yield could lead to extremely high-yielding, low-fat carcases being produced. This could be avoided if a minimum threshold for subcutaneous fat depth was incorporated in any yield specification.

The grader effects on the measurement of fat depth are large and need to be addressed. Image analysis using technology such as VIASCAN chiller assessment cameras are certainly capable of recording an image which can be used for multiple traits including fat depth, meat colour, fat colour and marbling score. An average of fat depth across the eye muscle would be less prone to the influence of fat tearing. Algorithms could be developed that would exclude points where fat tearing had occurred.

3e) RECOMMENDATION FOR FAT DEPTH

Although fat depths are collected for different purposes, AUS-MEAT measures fat depth at the P8 site and MSA at the rib site. In the interests of equivalence with other schemes around the world it is recommended that a single measurement at the rib site be used. Adoption of fat depth at the rib site would better align condition scores in the live animal and carcase fat depth. If ribfat was adopted then a standard quartering site would be necessary.

There are large grader effects on fat depth measurement which suggests that current auditing methods need improvement. In addition to the current OSCAP auditing tool it is recommended that regular analysis of grader data be undertaken to help identify those graders which consistently give high or low fat depths.

In the short to medium term, measurements of carcase fatness should be developed that are more accurate at predicting carcase yield than a single fat depth and less prone to bias by fat tearing. Image analysis of the quartering site and measurement of total fat area could address accuracy, grader bias and fat tearing problems. In the longer term it is recommended that other traits to assess fatness (and hence yield) be developed. These could involve X-Ray (eg DEXA or CT Scanning) and would assess fatness or yield of the whole side. Any yield specification may have to include a minimum fat depth to avoid ultra-lean carcases being produced.

4 . CARCASE MATURITY

4a) DEFINITION OF CARCASE MATURITY

Carcase maturity can be assessed in three ways:

- ***Age***

  The age of the animal noted in days or months. The impact of animal age on eating quality has recently been reviewed by Tatum (2011) and Purslow (2014). In young animals, collagen fibres tend to be characterised by heat-labile crosslinks that gelatinise during cooking. As animals get older the collagen crosslinks tend to stabilise to an insoluble heat-resistant form so that less collagen is solubilised during cooking then rendering the meat less tender.

- ***Ossification***

  Carcase maturity may be assessed as a subjective score on the degree of ossification of the dorsal spinous processes of the vertebrae, the fusing of the vertebrae and the shape and colour of the rib bones. The USDA scale for ossification is based on photographic standards which range from 100 to 590 in 10 point increments (Romans et al 1994). MSA ossification scores are based on the US standards.

- ***Dentition***

  Dentition is based on the number of permanent incisors that have erupted on the lower jaw of the bovine. An animal may be born with or without teeth but by one month of age they will have eight temporary teeth or baby incisors. These temporary incisors are replaced by pairs of permanent incisors. Animals with 1 or 2 erupted incisors are recorded as two-tooth, whilst three or four erupted incisors are recorded as four-tooth. Tables for the average age and range in age for incisor eruption in beef have been published by AUS-MEAT (Anon 1998).

  Age can be measured by recording birth date, but in the Australian production systems this is not practical and rarely done. Dentition has the advantage that it can easily be assessed in the live animal, whereas this is not possible with ossification.

  Conversely in carcase form, in the absence of age or dentition, any age estimate is reliant on ossification score. The estimation of any age category is reliant on carry-through of information obtained from the live animal (actual age) slaughter floor (dentition) or at grading (ossification).

4b) BACKGROUND TO THE MEASUREMENT OF MATURITY

AGE

There have been a number of studies which have shown that increasing animal age results in decreased collagen solubility with little or no change in total collagen content (Taylor 2004). This decrease in solubility results in increased toughness in older animals although the relationship is not strong. Shorthose and Harris (1990) examined the effect of animal age (ranging from 1 to 60 months) on the tenderness of a number of muscles in the carcase. They showed that age-associated toughening was more pronounced in high collagen muscles (e.g. silverside or m. biceps femoris) than in the low connective tissue muscles (fillet or *m. psoas major*).

OSSIFICATION

Shackelford et al (1995) reported that ossification was moderately related to chronological age (R^2=0.60). Analysis of over 5000 records in the MSA data base showed a lower coefficient of determination when using ossification score to predict age (R^2=0.46, JM Thompson, *unpublished data*). An interesting outcome of the MSA analyses was the significant interaction between *Bos indicus* content and ossification score which indicated that at the same age, high *Bos indicus* content carcases were more ossified than *Bos taurus* carcases, although there was little difference at the lower ossification scores.

A major factor influencing skeletal maturity is oestrogen activity in the animal (Lawrence 2001a). Studies by Field et al (1996) showed that single calved cows had higher ossification scores than their heifer counterparts. They concluded that any biological event associated with elevated oestrogen levels in the female such as oestrus, late gestation, parturition and lactation would increase ossification score. This was supported by a survey of slaughtered animals where females that had calved had more mature skeletal ossification than heifers (Waggoner et al 1990). Similarly heifers have greater skeletal maturity than steers at the same age (Tatum 2011).

Tatum (2011) reviewed the literature on the effect of HGP implants on ossification and concluded that implants that contained zeranol and oestradiol increased ossification scores in beef carcases. Trenbolone acetate, on the other hand, does not affect skeletal maturation (Crouse et al 1987, Apple et al 1991). In reality most HGP implants contain combinations of hormones and therefore in the Australian context most implanted carcases show some increase in ossification scores.

Spray chilling has also been reported to impact on ossification scores. A report by Allen et al (1987) concluded that the spray hydrated the chine buttons and their ossification appeared to be less mature. This certainly is a potential problem in Australia given the number of plants that have recently installed spray chilling misters. An option that has recently been adopted by a number of Australian plants is to move to scoring ossification hot on the slaughter floor rather than after chilling at grading. A preliminary analysis undertaken by MSA concluded that there was little effect of whether carcases were scored for ossification on hot or cold carcases not subjected to spray chilling (R Watson, *unpublished data*).

A commonly held belief is that ossification score reflects the growth path of the animal, with a varied growth path resulting in an increased ossification score. Practically, the ossification scores from fast and slow growing groups are often confounded with age, in that the slower growing groups are older and hence more ossified.

When the literature is examined more closely there are few studies to support the hypothesis that a variable growth pattern results in increased ossification at the same age. McIntyre et al (2009) showed that slow or restricted growth path compared to fast growth tended in result in higher ossification scores and slightly reduced palatability. However it should be noted that in their study the fast growth group were feedlot finished and so were younger and the carcase had decreased ossification scores and increased intramuscular fat content. Perhaps of more interest were the slow and compensatory growth treatments which underwent vastly different growth paths to be slaughtered at the same age with no effect on ossification scores. Greenwood and Café (2007) showed that when growth restriction occurred in utero followed by ad libitum feed intake there was an effect on ossification score (i.e. low growth had higher ossification score). However if the growth restriction occurred pre-weaning there was no effect on ossification score. A study by McKiernan et al (2009) grew steers at fast and slow growth rates to the same slaughter endpoint. They showed that whilst the slow growth group had slightly greater ossification score they were also five months older and had less marbling than the fast growth group. It was worth noting that the slower growing group (which were older and more ossified) had slightly lower eating quality scores (JR Wilkins, *unpublished data*). Most other studies have failed to report effects of growth path on ossification score.

The effect of growth path effects was further complicated by the review of Purslow (2104). He cited several studies where restricted growth had resulted in increased collagen solubility which would be expected to impact positively on palatability. However Purslow (2014) suggested that simply describing the effects of different growth paths in terms of heat-soluble collagen was perhaps too simplistic. He cited the results of Cassar-Malek et al. (2004) who found changes in connective tissue solubility with restricted growth were muscle dependent.

DENTITION

Estimates of the time of eruption of permanent incisors into the oral cavity of the bovine were reviewed by Lawrence et al (2001a). They found that of the 14 published estimates in the literature the mean eruption times were 24, 30, 38 and 46 months for 2, 4, 6 and 8 teeth respectively. The estimates from AUS-MEAT (Anon 1998) were 18, 30, 36 and 42 months for the same four categories. Therefore, although AUS-MEAT estimates aligned well for categories for 4, 6 and 8 teeth, they underestimated the age of eruption of the first pair of incisors by ca. 6 months compared to mean eruption times from other studies. Hearnshaw et al (1996) provided data from the Grafton crossbreeding project which also supported a later eruption time for the first pair of incisors (a mean eruption time of 27 months for 2T). Their results showed that lower nutrition delayed eruption of the first pair of incisors by up to two months and breed effects could be of the order of two months or more.

CONCLUSION

In his review on maturity measurements and their relationships with eating quality, Tatum (2011) concluded that over a wide range of chronological ages, ossification scores and dentition classes, there were only moderate relationships between these three measures of carcase maturity and eating quality.

Field et al (1997) examined collagen characteristics groups of heifers at the same age which differed in ossification class (category A which were between 100 and 190 ossification score and category C which were between 200 and 290 ossification score). They found no association between percentage collagen, the degree of crosslinking, sensory or objective quality with skeletal maturity. They concluded that collagen traits in the muscle were not directly associated with skeletal maturity. Similarly, one could argue that the physiological changes that occur with age or incisor eruption are not directly associated with collagen metabolism and therefore it is not surprising that the associations between measures of carcase maturity and collagen characteristics were moderate at best.

The question then becomes which measurements of maturity are the most appropriate to use in a beef language aimed at describing variation in eating quality. A useful insight into this question was provided using the Beef CRC data where consumer evaluations were undertaken on 2,300 striploin samples at 14 days' ageing (JM Thompson, *unpublished data*). Using the MSA model inputs which included sex, HGP status, hot carcase weight, marbling score, pH and ribfat, the addition of either dentition or ossification accounted for similar proportions of variance in the prediction of eating quality of the striploin (both ossification and dentition had coefficients of determination of ca. 30%). If age was included in the model then dentition and ossification were both not significant (P>0.05), whereas age remained an important predictor of eating quality (P<0.05). These results suggest that age as a predictor of eating quality would be the preferable maturity measure, but unfortunately it is not commercially practical for most Australian production systems.

A disadvantage of using dentition is that it is a categorical trait with no ability to discriminate between carcases within a dentition category. Therefore the above MSA analyses were rerun within dentition class. In this data set 60% of the carcases were in the milk tooth category. Within the milk tooth category ossification score accounted for a significant proportion of variation in eating quality, whereas no discrimination was possible with dentition. As production systems improve growth rates will also improve and a greater proportion of the Australian kill will be slaughtered at younger ages. Therefore ossification score does provide a means of describing eating quality on a continuous scale, whereas the dentition can only separate carcases into broad categories.

From the above it can be concluded that chronological age would be a preferable maturity index to use. Over a wide range of maturity, indices had a similar relationship with eating quality. However an important distinction between dentition and ossification score is that effectively dentition has no predictive value below 24 months of age where ossification does. In the short term ossification would be the preferred measure of maturity to use in the Australian beef language, although research is needed to either develop techniques to estimate age or to develop new measurements of maturity that are better related to the development of cross linkages in collagen.

4c) ACCURACY AND BIAS IN THE MATURITY MEASUREMENT

AGE

Whilst it is compulsory in some countries such as the UK to record age it is often dismissed as being impossible in extensive systems in Australia. However there are many different ways age could be measured. If the time at which the bull is introduced is recorded and assuming a gestation length of 284 days then age could be defined as the oldest for that drop of calves simply from joining date and an estimate of gestation. Therefore from a three-month joining and tagging at marking an age within three months could be measured with little additional cost.

Currently age is simply required as a threshold trait for market access. Examples of this are the 30-month limit imposed by the UK government. An age estimate which could guarantee that carcases were less than a threshold age would allow cattle to be marketed with this trait attached to an NLIS number. If a buyer was interested in accessing markets with an age threshold this could add to the value of the animal at sale. The system to capture the data and lodge it with NLIS would need to be part of an audit packages on the property.

It would be naive to assume that this could be adopted across the Australian industry, but it may be a measure that would allow some producers to add a premium to their animals by having a date of birth/birth month/birth quarter recorded.

DENTITION

An area of uncertainty with dentition scoring could arise with partially erupted incisors. The convention is that, upon the first sign of a new eruption, the animal is advanced to the next category. Broken mouths and missing incisors in older cattle such as cull cows are unlikely to be a problem to an experienced grader.

OSSIFICATION SCORES

There is little data on the biases that occur with ossification scoring. This was investigated using the industry data set used for previous traits (JM Thompson and R Polkinghorne, *unpublished data*). The analyses adjusted ossification score for production, processing and carcase traits within grass and grain fed carcases. Grader effects were significant, although within a plant there was no significant relationship between graders in grass and grain fed carcases. Within feed type the differences between graders were of the order of 5 to 10 ossification units. There are several conclusions that can be drawn. Firstly the differences between graders were small, and secondly the small bias occurring between graders was not consistent for grain and grass fed carcases.

4d) TECHNOLOGY TO MEASURE MATURITY

AGE

As slaughter date is available for all slaughtered animals an estimate of birth date would allow age to be calculated. This could be done manually for all animals or as previously described an estimate age calculated for the oldest animal within a calf drop. Where restricted joining is practised there are a range of options to estimate birth date /birth month /birth quarter.

In extensive production systems technology such as walk over weighing (WOW) could be used to monitor live weight of animals remotely. The WOW system is capable of estimating birth date by identifying when the cows weight dropped by approximately 60 to 70 kg weight (i.e. the weight of the newborn calf – Tim Driver, *personal communication*). Such technology would come at a cost and the producer would need to decide if the extra information warranted the capital and labour investment.

DENTITION

Currently dentition is manually or electronically captured on the slaughter floor. Given advances in vision technology it would be possible to develop a system where an image of the hide-off head was captured and the number of incisors counted automatically.

OSSIFICATION

Ossification is currently a subjective score given by a grader on either the hot or cold carcase. Analysis of industry grading data would suggest that graders currently give a score which is not prone to large biases.

In a review by Zheng et al (2014) work by the authors on a vision system to capture and score skeletal ossification was described. The system involved capturing an image of the sawn vertebrae and then devolving the images into bone and cartilage portions. Using a number of data sets which had been divided into training and validation sets they achieved an accuracy of 70-80% in allocating carcases to the correct ossification category (i.e. in 100 unit increments) as assessed by subjective graders. This technology holds promise for the future.

4e) RECOMMENDATION FOR MATURITY MEASUREMENTS

Skeletal maturity may be measured by a number of traits. In terms of predicting eating quality, animal age is probably the best predictor but not easily achievable across the industry at this stage. For some niche markets simple management procedures such as tagging at marking would allow producers to give a guarantee that an animal is younger than a specified age.

Over an extended range of maturity, ossification score and dentition had similar accuracy at predicting eating quality. However for milk tooth carcases, ossification score does predict eating quality, whereas there is no ability for dentition to discriminate between carcases.

In the short term it is therefore recommended that the Australian beef language adopt ossification as a measure of carcase maturity. Given that ossification score and dentition are only moderately related to retain both measures would only be a source of dispute in the industry.

Whilst technology could be developed to predict ossification score R&D funds would be better directed to ways to predict age or alternative maturity measures.

5. MEAT COLOUR

5a) DEFINITION OF MEAT COLOUR

Meat colour is the colour assessed at the rib eye (m. longissimus dorsi) on the chilled quartered carcase after the muscle surface has been exposed to air for at least 20 minutes and not more than 3 hours. The colour scores are referenced against the AUS-MEAT meat colour reference standards in the area of rib eye that displays the most predominant colour. There are nine chips, labelled 1A, 1B, 1C and then numerically up to 7 (Anon 2004).

5b) BACKGROUND TO THE MEASUREMENT OF MEAT COLOUR

The colour of meat is dependent upon the chemical state of the colour pigment myoglobin, which in muscle can occur in three different oxidative states (Mancini and Hunt 2005). In meat that has not been exposed to air the myoglobin pigment is in the form of deoxymyoglobin, which is dark purple in colour. Once the carcase is quartered the oxygenation of the deoxymyoglobin occurs to form oxymyoglobin which is a bright cherry red pigment. As exposure to oxygen increases the oxymyoglobin penetrates deeper into the meat surface. The depth of oxygen penetration and therefore thickness of the oxymyoglobin layer on the cut surface will depend upon muscle pH, muscle temperature, oxygen partial pressure and the competition for oxygen by other respiratory processes. The conversion of deoxymyoglobin to oxymyoglobin is a direct reaction, however the reverse oxidation reaction occurs via metmyoglobin (a rust coloured pigment). Metmyoglobin is formed at a lower partial pressure and hence is prevalent at the bottom of the oxymyoglobin layer in fresh meat which has been allowed to bloom. This rust coloured layer increases in thickness as the oxygenation capacity of the myoglobin decreases it becomes visible from the surface as a muddy brown meat colour.

Ultimate pH is one of the important factors that impact on the changes in meat colour in beef. High pH meat has an increased water-holding capacity (Lawrie 1988) which effectively reduces the penetration of oxygen and hence the formation of oxymyoglobin in the cut surface of the meat. Hughes et al (2014) showed that higher ultimate pH was associated with darker meat and is often referred to as 'dark firm and dry' or DFD meat. They concluded that higher ultimate pH meat was associated with more tightly packed muscle fibres, reduced light scattering and only a thin layer of oxymyoglobin on the surface of the meat. It also has a different taste, a higher water holding capacity and is more susceptible to microbial proliferation (Purchas and Aungsupakorn 1993). As there is a curvilinear relationship between ultimate pH and eating quality, DFD meat is not necessarily tougher but is generally more variable in eating quality than normal meat (Wulf et al 2002).

High pH also impedes colour formation or blooming in muscle after quartering (Abril et al 2001). Also, the higher the muscle temperature, the slower the blooming rate because at the higher temperatures the cellular enzyme system are competing with the myoglobin for oxygen. The AUS-MEAT standards require that meat colour be assessed in a window from 20 minutes to 3 hours post quartering (Anon 2004). It is of interest that the USDA beef grading scheme only requires a minimum of 10 minutes between quartering and grading (Anon 1997). Young et al (1999) examined bloom time in beef carcases over a range of ultimate pH and concluded that measures of chroma continually increased up to 10 hrs post quartering. Young et al (1999) and Suman et al (2014) have questioned the value of meat colour at grading as a predictor of meat colour in the display cabinet. Certainly the longer the meat is aged the poorer the relationship between colour at grading with colour at display.

Generally there is a strong relationship between ultimate pH and meat colour score. Recent data would indicate that this is not always the case and examples of producers having carcases excluded on meat colour but having acceptable pH have become relatively common.

Murray (1989) investigated the effect of early grading of carcases on meat colour scores and ultimate pH. The study was prompted by an industry survey that showed if grading was done early then nearly 4% of carcases had dark meat colour, whereas only 0.5% had pH over 6.0. Murray's study showed that if grading was done at 15-18h post mortem dark meat colour scores were three times more likely than if grading was done at 23-26h post-mortem, apparently because of incomplete development of muscle colour at the early grading time.

Hughes et al (2014) also investigated the effect of time from slaughter to grading on meat colour scores. They showed that over the time interval between 14 and 31 hours from slaughter to grading there was a difference in meat, with earlier grading resulting in darker meat colour scores. They suggested that this was possibly due to slightly higher pH with earlier grading resulting in swollen myofibres allowing greater light penetration into the meat which is absorbed by the myoglobin. Consequently with early grading times there is less scattered light and the meat is initially darker. As the time from slaughter to grading is increased the muscle fibres shrink with greater oxygen penetration resulting in brighter meat colour scores. Both the studies by Murray (1989) and Hughes et al (2014) support a lightening of meat colour as the time between slaughter and grading increases.

Hughes et al (2014) also reported that the rate of pH fall can also impact on meat colour scores. A rapid decline in pH relative to temperature can result in protein denaturation due to the effect of the hot acid. As reported by Kim (et al (2014) the increased protein denaturation results in lower water holding capacity which generates drip and increases light scattering on the surface of the muscle, hence lighter meat colour.

5c) ACCURACY AND BIAS IN MEAT COLOUR

Some of the factors that can impact on the accuracy and repeatability of meat colour scores have been mentioned, in particular temperature at grading. As discussed previously at higher temperatures the competition for oxygen to form oxymyoglobin is greater and the resultant meat colour scores are darker.

Grader effects on meat colour scores have received little attention in the literature but are likely given the subjective nature of meat colour scoring systems. Utilising a large industry dataset the effect of grader on meat colour scores was examined after adjustment for production, processing and carcase traits (JM Thompson and R Polkinghorne, *unpublished data*). In these analyses the categorical meat colour scores were treated as a continuous variable with 1A, 1B and 1C treated as 1.0, 1.33 and 1.67 respectively. At all plants examined, grader effects on meat colour scores were highly significant ($P<0.05$). Within plants the mean differences between graders were of the order of 0.8 of a colour score. To test the repeatability of the grader effects the correlation between graders within plants was examined in grass and grain fed carcases. In some plants grader means were highly correlated, whilst in others there was no relationship. This showed that in all plants there were large differences between graders and that in some plants similar ranking of graders was found in grain and grass finished carcases. In other words, in some plants individual graders were on average scoring almost 1 colour unit higher in both grain and grass fed carcases. It was important to note that this bias occurred with graders being audited bi-monthly using the OSCAP system.

The dataset also allowed the effect of time between slaughter and grading on meat colour scores to be examined within grain and grass carcases. In all cases the time between slaughter and grading had an effect on meat colour scores. If grading was delayed from 18 to 48 hours the meat colour scores decreased by 0.1 to 0.3 of a meat colour score. This result aligns with the results of Murray (1989) who also showed a significant decrease in dark meat colour of carcases that were graded later. Presumably this improvement was associated with more rapid blooming as the enzyme activity which was competing for oxygen declined and the conversion of deoxymyoglobin to oxymyoglobin increased. In some plants the meat colour became darker if carcases were left another 48 hours before grading. As discussed by Young et al (1999) this could indicate that all enzyme systems were slowing down after four days post-mortem.

The industry data set (JM Thompson and R Polkinghorne *unpublished data*) also allowed the lack of correlation or disconnect between meat colour score and ultimate pH to be investigated. As mentioned previously ultimate pH and meat colour scores are highly correlated, but in some instances there are a significant proportion of carcases graded with high meat colour and low pH. Effectively this excludes these carcases from MSA grading.

At five different plants the level of disconnect between meat colour and pH in grain finished carcases varied from 0 to 3.0% of cattle graded. However in grass finished carcases it was much higher, ranging from over 1.0% to 7.0% of cattle graded at those plants suggesting that the problem was associated with particular processing plants and also to particular producers supplying cattle to those plants. Whilst at a national level the disconnect between pH and meat colour scores was relatively small it had a large financial impact on particular producers supplying to those plants. It was of note that McGilchrist (2014) examined the disconnect in over 1 million carcases processed in southern Australia and found that overall the disconnect between pH and meat colour at grading at these plants to be negligible.

Time to grading had a large effect on the disconnect supporting the results of Murray (1989) that in early-graded carcases there is incomplete development of muscle colour at ca. 18 h after slaughter. Following on from Murray (1989) where a proportion of carcases were found to have low pH but dark meat colour Holdstock (2014) examined eating quality in carcases from three groups, namely those that were normal (i.e. Canadian grade AA low pH and low meat colour), atypical (i.e. AT low pH and high meat colour) and finally DFD carcases (i.e. high pH and high meat colour). They reported a significant increase in sensory toughness scores in the AT group (i.e. with low pH and high meat colour). However, this was contrary to the results of a recent analysis by Kelly and Thompson (2014) which used data from the Long Distance Transport experiment. This study showed no difference in eating quality between striploin samples from normal carcase (AA, i.e. low pH and low meat colour) and atypical (AT, i.e. low pH and high meat colour carcases) and DFD carcases (i.e. high pH and high meat colour).

If expression of meat colour at grading is delayed this can have a large financial impact on individual producers as most Australian grids include a threshold for meat colour scores, above which carcases are excluded. What is concerning is that when carcases with a dark meat colour score but low pH are re-graded many of the re-graded meat colours are acceptable (JM Thompson and R Pokinghorne *unpublished data*). Also relevant to the question about meat colour scores are the conclusions of Young et al (1999) and Suman et al (2014) that the relationship between meat colour scores at grading and later at retail display is poor at best. With the review of the Australian Beef Language it is timely to ask whether meat colour at grading is a useful trait for inclusion in the beef language. Since the introduction of MSA the beef language includes ultimate pH. It is possible that ultimate pH at grading does a much better job of identifying primals which are dark at retail than meat colour score at grading.

It is clear that there are many questions about the usefulness of meat colour scores. The MSA Pathways group recently removed meat colour from its specifications as it concluded that meat colour scores did not contribute to prediction of eating quality in the presence of other inputs (including pH) for the MSA model. There are many unanswered questions as to why blooming of meat colour is delayed in some carcases and the relevance of meat colour scores at grading to meat colour at retail display.

5d) TECHNOLOGY TO MEASURE MEAT COLOUR

The magnitude of the grader bias in scoring meat colour indicated that in future if meat colour scores are included as a trait in the Australian beef language then efforts should be made to move towards an objective measurement of meat colour. When the current AUS-MEAT chips are assessed using a Minolta colour meter the relationships between the CIE L*a*b* dimensions and the 10 colour chips are not linear for the a* and b* dimensions (Thompson JM and Polkinghorne R, *unpublished data*). This is particularly noticeable for the 1A chip which has similar a* and b* readings to the 6 meat colour chip. As digital data capture and analysis within the supply chain increases the need to treat meat colour as a continuous variable will become more important.

Colorimeters are used across a range of industries as a means of objectively describing colour. The most widely used is the CIE, L*a*b* system which describes colour as a three-dimensional space. As discussed by Tapp et al (2011) there are problems in standardisation and use of the colorimeters which need to be addressed. However even if these are addressed a number of recent studies have shown that the vision systems have the capability to provide a better description of meat colour than the colorimeters (Tinderup et al 2015).

More recently there have been a number of studies that have evaluated multispectral imaging systems to describe meat colour and have concluded that they are superior to simple red, green and blue (RGB) analysis of captured images and have the potential to provide a better description of what the eye captures in terms of meat colour. The Sheep CRC is currently evaluating a multispectral vision system for intramuscular fat percentage in lamb. This would provide an opportunity to broaden their study to include meat colour of bloomed meat in beef.

5e) RECOMMENDATION FOR MEAT COLOUR

In the short term, research inputs are required to quantify the benefits of meat colour at grading as a tool to predict display colour over and above the measurement of ultimate pH.

Also, the magnitude of the grader bias on the allocation of meat colour scores is concerning and needs addressing. The disconnect between meat colour and pH is also a concern and needs to be addressed, because whilst not a huge problem on a national level it does appear to be a particular problem for some plants and some producers.

The preference would be to discard meat colour as a trait in the Australian Beef Language and rely on ultimate pH to identify dark cutting meat at retail. Failing that if the measurement of meat colour is to be retained as a trait in the Australian Beef Language research inputs are required to development technology to measure meat colour in an accurate and repeatable manner. This would most likely involve use of a vision system, but more likely would utilise technology such as colorimeters (such as the Hunter or the Minolta) or multispectral scanning.

6. FAT COLOUR

6a) DEFINITION OF FAT COLOUR

Fat colour is a subjective assessment of the colour of the intermuscular fat lateral to the rib eye muscle and adjacent to the m. iliocostalis. It is assessed on the chilled quartered carcase and scored against the AUS-MEAT fat colour reference standards on a 10-point scale from white (0) to yellow (9) (Anon 2005).

6b) BACKGROUND TO THE MEASUREMENT OF FAT COLOUR

White fat is more acceptable to consumers in both domestic and export markets and hence fat colour is often included as a specification in marketing grids as a threshold where the fat must have a colour score less than a specified colour chip (usually less than a fat colour 3, Anon 2013). Yellowness in fat is due to the presence of carotenoid pigments within the adipocytes. The main pigment causing yellowness is beta-carotene which is a major precursor of Vitamin A (Tume 1995).

An early Australian abattoir survey conducted by Walker et al (1990) found significant effects of feed type, breed, breed age and sex along with several interactions on fat colour. Feedlot carcases had whiter fat than grass fed carcases as did British breed carcases compared with dairy breeds. Steers had whiter fat than females and those with less than eight erupted incisors had whiter fat than those with more than eight incisors erupted. From a sample of 662 carcases (of which 63% were pasture fed and 37% grain fed), Walker et al (1990) reported that using fat score 3 as a threshold 15% of the carcases would incur a penalty on fat colour. Using a more recent data set with over a million carcases the proportion of carcases with fat colour scores greater than 3 was 8% whilst in grain fed carcases it was less than 0.1% (JM Thompson and R Polkinghorne *unpublished data*). This decrease in yellow fat in the more recent data was possibly due to improved growth rates for cattle resulting in slaughter at a younger age.

There is a perception by the consumer that fat colour impacts on negatively on eating quality. This most likely stems from yellow fat accumulating more in older dairy type cows which in turn produce tougher meat. Small changes in fatty acid composition and antioxidant content are detectable but whilst associated with yellow fat are more a consequence of pasture feeding, as opposed to grain feeding (Dunne et al 2009).

6c) ACCURACY AND BIAS IN THE FAT COLOUR

There are few published data on the accuracy or biases in fat colour scores. The industry data set described previously was also used to quantify the significance and magnitude of the grader effects on fat colour scores after adjustment for production, processing and carcase traits (JM Thompson and R Polkinghorne *unpublished data*). Analysis showed a significant grader effect at all plants ($P<0.05$). The magnitude of the range of grader means was of the order of 0.2 to 1.0 fat colour scores. Given the bulk of the carcases had very low fat scores this was a relatively large grader effect and cause for concern.

These grader effects are occurring with OSCAP being used as the auditing tool. As for other traits a corrective action would be to regularly analyse grading data and provide feedback to graders and further training where necessary.

6d) TECHNOLOGY TO MEASURE FAT COLOUR

The colour dimension b* of the CIE, L*a*b* system represents the change from blue to yellow and has been used successfully by several researchers as an objective tool to measure fat colour in beef carcases (Walker et al 1990, Dunne et al 2004). Certainly in the medium term the industry should try to develop objective techniques to measure fat colour, but it is stressed that the technology should be bundled so that it is capable of measuring a number of traits (e.g. marbling score, meat colour, fat depth or fat area over loin and eye muscle area) to warrant the development and capital costs of the equipment.

6e) RECOMMENDATION FOR FAT COLOUR

Whilst fat colour has little relationship to yield or eating quality traits it is considered important by consumers and generally the market specifications are for whiter fat colours.

Even though it is audited by OSCAP, grader bias is often evident and large relative to mean fat colour scores. It is recommended that regular analysis of grader data be undertaken to help identify those graders which consistently give high or low fat colours.

In the longer term resources should be invested to develop image analysis methods providing the technology is bundled to include a number of traits.

7. EYE MUSCLE AREA (EMA)

7a) DEFINITION OF EYE MUSCLE AREA IN BEEF CARCASES

AUS-MEAT defines EMA as the area of the surface of the *M. longissimus dorsi* at the ribbing site and is calculated in square centimetres. Currently with AUS-MEAT, EMA may be measured at the 10th, 11th, 12th or 13th rib sites (Anon 2010).

EMA is measured using the AUS-MEAT acetate grid which has one cm squares marked. This grid is laid over the quartered eye muscle and the number of square centimetres which are either inside or touching the boundary of the eye muscle are counted. The number of squares inside the muscle are weighted by 1 and the number that are only partially within the boundary are weighted by 0.5. The numbers of full and partial squares are added to estimate eye muscle area.

7b) BACKGROUND TO THE MEASUREMENT OF EYE MUSCLE AREA

Currently EMA is provided as a stand-alone measurement. Obviously it is positively related to carcase weight but as EMA is a two-dimensional measurement and carcases are three-dimensional the expectation is that EMA will increase less slowly than carcase weight (i.e. EMA is early maturing relative to carcase weight). Therefore simply expressing eye muscle area as a ratio of carcase weight will disadvantage heavier carcases.

Whereas EMA has little value as a standalone measurement it is a useful indicator of muscle or lean in the carcase when it is considered along with other carcase measurements as an input into regression equations to predict carcase yield. A number of authors have published equations to predict percentage carcase yield which use a combination of hot carcase weight, fat depth and eye muscle area (e.g. Johnson et al 1995, Hopkins and Roberts 1995, Johnson and Baker 1995). As expected due to different numbers of carcases used, their weight ranges, the location of the measurements and the carcase trim specifications the accuracy varies enormously. Generally eye muscle area accounted for a significant amount of the variation, which testifies to its important in any equation to predict percentage carcase yield.

7c) ACCURACY AND BIAS IN THE MEASUREMENT OF EMA

Hopkins and Roberts (1995) compared methods of measuring EMA at the 10th and 5th rib sites. They found that the acetate grid method only accounted for ca. 65% of the variance in planimeter measurements at the same site. In addition they showed no relationship between eye muscle area at the 5th and 10th rib sites.

Currently EMA is simply reported as a carcase trait and is not part of an algorithm to predict carcase yield. If EMA were incorporated into a yield prediction model standardisation of the measurement would be much more important. This would include ensuring a square cut across the loin muscle at the quartering point, ensuring a standard rib number was used and exclusion of adjoining muscles such as the *Mm. mutifidius dorsi*, *spinalis dorsi* and *iliocostalis*.

Obviously, dropping the spencer roll on the forequarter negates any useful measurement of EMA at grading unless a digital system can be devised to measure EMA on the hind quarter portion.

7d) TECHNOLOGY TO MEASURE EMA

The acetate grid was perhaps the only option available to measure EMA when AUS-MEAT was implemented. Currently EMA is only reported as a standalone measurement and is seldom part of any grid specifications.

If as anticipated the push to develop value based marketing increases the importance of EMA as an accurate standardised predictor of carcase yield will increase. Given this, it is recommended that digital technology such as VIASCAN be used to capture an image of the quartered carcase to calculate an accurate EMA. Algorithms already exist that can automatically trace the boundary of the eye muscle to calculate area. If VIASCAN is not suitable then more portable alternatives should be developed.

7e) RECOMMENDATIONS FOR EMA

Currently EMA is reported as a stand-alone measurement. If it is to be used as part of an algorithm to predict carcase yield the site of measurement needs to be standardised.

The measurement of EMA using digital technology, with internal standards to account for varying focal length, should be investigated.

8. ULTIMATE PH

8a) DEFINITION OF ULTIMATE PH MEASUREMENT IN MEAT

Ultimate pH measures the acidity and alkalinity in post-rigor muscle. pH is measured on a 1 to 14 scale, although in meat the range is rather restricted from 7.0 in the live animal to a minimum of 5.4 in the post rigor carcase. pH is measured as the negative antilog of the hydrogen ion concentration in the meat. The live animal has a pH around 7 (ie a concentration of hydrogen ions of 10-7).

After death anaerobic metabolism in the muscle converts muscle glycogen to lactic acid and hydrogen ions. If there is sufficient glycogen at slaughter hydrogen ion concentration will increase and the muscle pH will decline to a plateau of 5.4 (i.e. a concentration of hydrogen ions of 10-5.4) before the acidic conditions in the muscle inhibit further enzyme activity.

8b) BACKGROUND TO THE MEASUREMENT OF ULTIMATE pH

Ultimate pH was first used in the Australian meat industry as a measurement tool to exclude high pH carcases from chilled vacuum pack export consignments. Vacuum packs with high ultimate pH meat had a higher risk of ‘greening’ during shipment which led to down-grading or rejection of consignments at the destination port.

More recently pH has been used by MSA as an objective measurement of whether the animal had sufficient glycogen reserves to achieve an ultimate pH consistent with acceptable eating quality, meat colour and shelf life. Ultimate pH has a curvilinear relationship with eating quality (Bouton et al 1973, Purchas 1990, Jeremiah et al 1991), with a trend for the most tender meat to be either low (i.e. pH of 5.5) or high (i.e. pH of 6.5) pH, with intermediate pH meat being the toughest (i.e. pH 6.0). The curvilinear relationship is thought to be due to greater activity of calpains and cathepsin at higher and lower pH levels (Lomiwes et al 2013). Unfortunately at high pH the higher tenderness is also associated with a different taste and greater susceptibly to spoilage. Watanabe et al. (1996) reported that as meat is aged the curvilinear relationship between ultimate pH and tenderness weakened, although this was not a universal finding (see Purchas et al 1999). High pH meat also has a darker meat colour and higher water holding capacity (Monin 2004). Reasons for the differences in meat colour between normal and high pH meat are discussed in section 5 (meat colour).

The higher water-holding capacity means that meat from high pH cuts can often appear to be drier, although this does not always translate to lower juiciness scores in the cooked meat. It should be noted that although ultimate pH is related to eating quality the predictive accuracy of this measurement in isolation of other input traits is not particularly high (Watson et al 2008).

8c) ACCURACY AND BIAS IN THE MEASUREMENT OF ULTIMATE pH

A question often asked about pH measurements is their repeatability. A small study on the repeatability of the current TPS glass electrode pH meter was undertaken for AUS-MEAT (JM Thompson, A Blakely and P Reynolds, *unpublished data*). Analysis of over 750 repeated pH measurements using different cuts/primals, operators and allowing for recalibration of the meters concluded that an error range of ±0.05 of a pH unit would be expected to contain ca. 90% of the readings. If these sources of variation were ignored then an error range of ±0.05 pH units would be expected to contain ca. 80% of the readings. In effect this showed that readings from the pH probe were very repeatable with a standard deviation of ±0.04 pH units. In other words 66% of the readings would lie within ±0.04 units of the true value.

There was also an opportunity to use industry data to examine the effect of grader and time from grading on pH measurements (Thompson JM and Polkinghorne R *unpublished data*). Analyses of over one million grading data from five separate plants showed four had significant ($P<0.05$) grader effects for the measurement of ultimate pH, after adjustment for production and processing and effects. However the magnitude of these grader differences were generally less than 0.10 pH units and given the standard deviation for pH measurements would not be considered large.

Similarly there were also significant time from slaughter to grading effects, whereby pH decreased a further 0.01 units from the reading obtained at 18 hours compared to grading at 48 hours after slaughter. Again given the variance associated with the pH measurement this would not be considered important.

What was of concern for pH measurements were the results of McGilchrist (2014). He examined the distribution of pH readings from a total of 1.25 million carcases from nine processing plants. The pH readings appeared to be normally distributed in all plants, except around the MSA threshold of 5.7 where there appeared to be a significant decrease in the numbers of carcases grading just over 5.7. This drop in the number of carcases with pH readings between 5.70 and 5.72 was unexpected. Reasons for this are not clear but do suggest that readings were being manipulated by graders to pass carcases that were just above the threshold. Whatever the reason for the change in the pH distribution it suggests that pH readings were not being reported in an unbiased manner.

8d) TECHNOLOGY TO MEASURE ULTIMATE pH

Ultimate pH in meat is commonly measured using a multimeter to detect the current between a glass and reference electrode. In pre-rigor carcases the small amount of current is thought to accelerate glycolysis and therefore if the pH meter is left in the muscles or the probe is reinserted into the same hole in the muscle the reading from the pH meter will be below the real value. Whilst this is not a problem in post-rigor carcases where chemical energy in the muscle has been depleted and the glycolytic enzymes are no longer active, this has implications for developing pH probes to automatically log pH decline in pre-rigor carcases.

Other technologies to accurately and rapidly measure pH in post-rigor muscle are limited. Colour indicator strips have been examined in earlier MLA studies but found to lack the required accuracy. Colour indicator strips are also cumbersome for use in the chiller.

There are alternative electrode methods available for pH measurement. These use different electrodes made from platinum, quinhydrone or antimony. Most have problems with protein coagulation in the meat.

More recently a semiconductor pH sensor has been developed. This sensor, known as an ion sensitive field effect transistor (ISFET), is not only resistant to damage but also easily miniaturised. Miniaturisation allows the use of smaller amounts of sample for measurement, and makes it possible to perform measurements in very small spaces and on solid state surfaces. This sensor promises useful applications in measurement in the fields of biology and medicine. However, to date prototypes of such devices have been disappointing in real-world applications for the meat industry.

The measurement of ultimate pH is currently undertaken as part of MSA chiller grading. Whilst in the hands of a trained operator the technology provides a reasonably accurate measurement of pH there are problems with repeatability, cleaning the probe (protein build-up), calibration, equilibration and temperature correction. As the pH measurement is a function of the sample temperature MSA has incorporated a 'Bendall correction' to adjust ultimate pH readings to 7oC (Bendall and Wismer-Pedersen, 1962).

One of the problems with the measurement of ultimate pH is that it cannot be determined until the meat has effectively depleted glycogen reserves, or that the activity of the glycolytic enzymes in the muscle has ceased due to low pH in the muscle. Young et al (2004) proposed collecting a muscle sample from the pre-rigor carcase, reacting it with amyloglucosidase and using a diabetic meter to measure the liberated glucose which could be converted into an estimated ultimate pH. They also found the prediction of ultimate pH was improved if lactate was also included in the calculation. Young et al suggested that the method was suitable for on-line application in beef slaughter chains with a sample turnaround was of the order of 7 minutes. Knowing ultimate pH at the end of the slaughter chain would allow sorting of carcases into boning runs prior to chiller entry and would be invaluable for hot boning plants.

The evaluation by Young et al (2004) did not quantify the error rate of their predicted ultimate pH in a commercial environment. This was investigated as part Beef CRC II (G Gardner and JM Thompson; *unpublished data*). In this study muscle samples from 602 domestic grain-fed carcases were taken at the hide puller along with a pH measurement. Overall accuracy of prediction was high at 80%, however the misclassification rate was a concern. Eighteen percent of carcases classified by the glucose reading as being low pH (ie <5.7) were in fact high pH (ie >5.7). Of less importance but still a concern were those carcases which were predicted as high pH, where 42% of the time they were low pH. These results were obtained in a sample with a relatively low level of dark cutting (11% had pHu > 5.7) and the usefulness of the technique may improve with higher levels of dark cutting. However the misclassification rate of the rapid glycogen technique was too high for implementation in the Australian industry.

Other technologies to measure ultimate pH in muscle include visible-near infrared spectroscopy (NIR). In the post-mortem carcase NIR appears capable of providing an accurate measurement of ultimate pH (Craigie et al 2014). Given that NIR can predict glycogen in muscle it follows that it can predict ultimate pH from pre-rigor measurements (Reis and Rosenvold 2014). As discussed previously a pre-rigor measurement of pH would be valuable particularly in hot boning plants, although the value of NIR to measure pH in the post-rigor carcase could simply be viewed as replacing a simple cheap robust measure (i.e. pH meter) with a more expensive complicated predictor (i.e. NIR).

8e) RECOMMENDATION FOR ULTIMATE pH

The industry should continue to use the glass electrode to measure pH in both pre- and post-rigor carcases. In the hands of a trained operator the measurement is accurate to ±0.04 pH units, which is sufficient for industry needs. Other technologies such as NIR could predict ultimate pH, although there would appear to be limited gain in any investment to replace the pH meter unless a number of technologies were bundled to measure a range of carcase traits.

9. HUMP HEIGHT

9a) DEFINITION OF HUMP HEIGHT

Hump height is measured using a ruler parallel to the surface of the sawn chine and perpendicular to the 1st thoracic vertebrae. Height hump is measured from the paddy wack (*Ligamentum nuchae*) to the highest point of the hump. Hump height is measured with a ruler in 5 mm increments.

9b) BACKGROUND TO THE MEASUREMENT OF HUMP HEIGHT

The MSA model uses *Bos indicus* content as one of the key predictors of eating quality. Numerous studies have shown that varying degrees of *Bos indicus* content impact negatively on eating quality (Crouse et al 1989; Hearnshaw et al., 1998; Wheeler et al 1999. Morgan et al 1991, Sherbeck, et al 1995, Rymill, 1997) and that the magnitude of the effect interacts with muscle (Shackelford, et al 1995, Thompson et al 1999).

Initially *Bos indicus* content was declared on the National Vendor Declaration (NVD) and this was visually verified by the MSA grader using photographic standards. In mixed lots the *Bos indicus* content was taken as the highest in the lot, primarily as a safeguard to protect the consumer against receiving a piece of meat which ate below expectation.

Hump height was introduced as a MSA measurement as a cross-check to assist phenotype assessment against declared tropical breed content (TBC) and to assist in accurate estimation of tropically-adapted *Bos taurus* or Africander cattle. In addition there was a request from the feedlot sector for a carcase measurement that did not necessitate drafting animals into like phenotypic groups at the abattoirs

Sherbeck et al (1996) showed that the *Bos indicus* content was positively associated with hump height. In lieu of other commercial predictors MSA quantified the relationship between *Bos indicus* content and hump height adjusted for carcase weight and included it as an option in the MSA model. Initially this option was only for feedlotters but over time it was used by all sectors of the beef industry as an alternative method of estimating *Bos indicus* content from carcase measurements. A recent review of grading records indicated that using hump height and carcase weight was now the preferred method of estimating *Bos indicus* content for MSA cattle, particularly in northern Australia where lots have varying content Brahman content (MSA, *unpublished data*).

9c) ACCURACY AND BIAS IN THE MEASUREMENT OF HUMP HEIGHT

As hump height is a relatively recent addition to the Australian Beef Language there is little information on the accuracy or bias that can occur in measuring the trait. MSA has examined hump height taken on hot and cold carcases and concluded that there was no difference between the two measurements (J Lau personal communication).

Using a large industry dataset of 82,500 records, an analysis was undertaken of hump height measurements that had been recorded on carcases of known TBC (JM Thompson and M Kelly, *unpublished data*). The analyses examined variation between graders in measurement of hump height from the different works after adjustment for TCB and carcase traits (carcase weight, marbling, ossification, rib fat and pH). The results showed that whilst significant ($P<0.05$), grader effects only accounted for a small proportion of variance in hump height within works. In effect most graders had mean hump height measurements which were within a range of 10 to 15mm. However, what was concerning was the difference between works.

Again these differences in carcase traits due to location are occurring in the presence of the OSCAP system, which suggests that if carcase measurements are to be applied in a standard manner across the country more attention to grader assessment is needed.

9d) TECHNOLOGY TO MEASURE HUMP HEIGHT

A recent MLA project (Kelly and Thompson 2014) used DNA single nucleotide polymorphisms (SNP) to accurately describe *Bos indicus* content in a number of MSA data sets. After imputation, the 10K SNP chip was capable of accurately predicting *Bos indicus* content (R2=98%). However the cost of the SNP chip at $40/profile is unlikely to be routinely used in the foreseeable future and therefore measurement of traits such as hump height and carcase weight are the only option currently available to industry.

The results from Kelly and Thompson (2014) showed that when evaluated with the other MSA traits, *Bos indicus* content predicted from hump and carcase weight was of similar accuracy as *Bos indicus* content predicted from DNA technology, even though the current algorithm using hump height and carcase weight tended to underestimate *Bos indicus* content at the lower levels. Therefore when used to predict eating quality both methods accounted for a similar proportion of variance in eating quality because in effect the curvilinear relationship between *Bos indicus* content by hump and *Bos indicus* content by SNP chip did not change the ranking of carcases in these analyses. This change in the algorithm to calculate TBC from hump height and carcase weight will be reviewed by the MSA Pathways Committee.

Using a large industry data set where *Bos indicus* content was known the MSA algorithm was optimised so that the bias in using hump and carcase weight to estimate *Bos indicus* content was minimised across the range of *Bos indicus* content.

From a practical viewpoint there may be issues with accurately measuring hump height at grading in the chiller if the neck has been hot boned and the paddy wack removed prior to chilling. As neck boning occurs after the scales, hump height could be recorded hot on the floor or as part of the routine AUS-MEAT measurements at the scales.

Although no data are available it is possible that images used to monitor compliance with the standard carcase definition could be used to automate a measurement of hump height.

9e) RECOMMENDATION FOR HUMP HEIGHT

It is recommended that the industry continue to use hump height and carcase weight to predict Bos indicus content in carcases. Sources of bias for hump height measurement are not well understood and should be further investigated. In addition removal of the paddy wack should be investigated and if necessary measurement of hump height at the carcase scales before any neck boning occurs should be investigated.

10. BUTT SHAPE

10a) DEFINITION OF BUTT SHAPE

Butt shape is a subjective shape score based on the visual silhouette of the beef hindquarter. The scores are on a five point scale from A to E, with A being the most convex and E the most concave (McKiernan, 2001).

Although not supported by data, purportedly the more convex the butt shape the higher proportion of butt cuts and also higher carcase yield. There is also the belief in some sectors of the industry that a convex butt shape is also associated with higher eating quality.

10b) BACKGROUND TO THE MEASUREMENT OF BUTT SHAPE

Butt shape, or a conformation score, has been a feature of many beef carcase description schemes around the world (Jones et al 1977, Bass et al 1981, Kempster et al 1982). Initially AUS-MEAT included butt shape as a mandatory measurement in the beef language (Anon 1987). Since then a number of studies have questioned the usefulness of butt shape as a predictor of carcase yield traits. Taylor et al (1990) concluded that butt shape had no relationship to percentage saleable meat yield, muscle or fat in the carcase. In addition they showed that even in the presence of HSCW and fat depth, butt shape added nothing to the prediction of yield measurements.

In a report to the Australian Meat and Livestock study into butt shape Thornton (1991) gave the strong recommendation that "there is no indication of a useful role for butt profile in the estimation of saleable meat yield". This was supported in a study by Johnson et al (1996) in which the usefulness of butt shape was examined in several different breeds. They concluded that butt shape was not related to proportions of intermuscular fat, muscle or bone, but was associated with the proportion of subcutaneous fat. The implications of these results were that as butt shape score increased from E to A there was a trend for increased subcutaneous fat which was the opposite effect of the intention of the butt shape score.

Subsequently butt shape or butt profile was dropped as a mandatory trait for AUS-MEAT but it was still retained in the AUS-MEAT Language as an optional trait. It is often included as a specification in market grids and at various times has been the subject of criticism from producers who feel that they have been unfairly penalised by a subjective trait that is not related to yield or carcase value.

Butt shape is not to be confused with muscling score which has been shown in a number of studies to have moderate association with lean meat yield. Muscle score in both the live animal and in the carcase is a score which is based on the thickness of the muscle with the scorer making an adjustment for carcase fat. McKiernan (1995) makes the case that unlike butt shape, muscle score is a three-dimensional score of the muscularity of the carcase rather than the two-dimensional silhouette for butt shape which makes no adjustment for fatness. The earlier work of Perry et al (1993) reported a correlation of 0.6 between carcase muscle score and percentage saleable meat yield. These results aligned well with a number of European studies which showed that EUROP score (a subjective conformation score measured on a 15-point scale) was moderately related to carcase yield, although less so with the distribution of high-priced cuts (Drennan et al 2007, Craigie et al 2012).

There are few data on the eating quality of cattle which differ in butt shape /conformation /muscling score. An early study by Taylor (1982) used Yeates' fleshing index to describe carcase shape and showed that it did not impact on eating quality as assessed by sensory and objective methods. Care needs to be taken with these results as carcase numbers were low. A more recent study utilised steers from the high and low muscling lines developed by the NSW Department of Agriculture to examine if there were differences in eating quality between the extremes in muscling between the lines (Café et al 2012). Steers with one copy of the myostatin gene were excluded from the analysis. The difference between the high and low lines in muscling was larger than the between-breed extremes which exist in the Australian industry. Using the MSA consumer tasting protocol the results showed no difference between the high and low muscling lines in tenderness, juiciness, like flavour overall liking and the composite MQ4 score.

It is interesting to note the history of conformation score in the USDA beef grading scheme. In 1962 it was proposed that conformation be dropped from the grading scheme because it had been shown to be unrelated to differences in palatability and the relationship to yield was better measured by yield grades (Anon 1997).

10c) ACCURACY AND BIAS IN THE MEASUREMENT OF BUTT SHAPE

Kempster et al (1982) made the point that subjective conformation scores are always subject to error, the magnitude of which will depend upon the competence of the assessors. However in reporting these studies this error is rarely quantified. No results were found to quantify the repeatability of butt shape scoring in beef carcases.

It is interesting to examine the frequency distribution for butt shape scores in industry data sets. Using over 1 million records it was found that over 99% of the butt shape scores were C. Within plants some graders exclusively scored all carcases as butt shape C, with no other scores given. In addition to the lack of relationship between butt shape and carcase yield or eating quality the results from the industry data set effectively means that butt shape has no ability to discriminate between carcases.

10d) TECHNOLOGY TO MEASURE BUTT SHAPE

Initially, simple linear dimensions taken on the carcase or an image of the carcase provided relatively poor prediction of conformation in carcases (Kempster et al 1982), although if measurements were expressed as ratios rather than simple linear measurements their prediction accuracy improved (Bass et al 1981). With the development of Video Image Analysis (VIA) techniques in Australia, the US and Europe the accuracy of using a large number of linear measurements provided a reasonable measure of carcase conformation (see Craigie et al 2012). However the logic of developing sophisticated technology to measure something like conformation (or butt shape) which at best only has a moderate to poor relationship with carcase yield must be questioned.

10e) RECOMMENDATION FOR BUTT SHAPE

A large body of research has concluded that a more convex butt shape is not related to improved carcase yield and it is therefore recommended that this trait be removed from the Australian Beef Language.

Subjective conformation or muscling scores have some predictive power for carcase yield but given the potential in the medium term for whole body scanners to directly predict yield it is unlikely that conformation or muscling would be useful additions to the Australian Beef Language.

11. SEX CATEGORY

11a) DEFINITION OF SEX CATEGORIES

The current AUS-MEAT language refers to sex in the basic and alternate categories for beef and bull with reference to dentition (Anon nd).

BASIC CATEGORY

- Veal (V) – carcases with no permanent incisors under 70 kg carcase weight. Carcases can be from heifers, steers or bulls, the latter showing no secondary sex characteristics (SSC).
- Beef (A) – carcases with less than eight permanent incisors greater than 70 kg carcase weight. For Beef A carcases can be from heifers, steers or bulls, the latter showing no SSC.
- Bull Beef (B) – carcases with less than eight permanent incisors greater than 70 kg carcase weight and can be entire male or castrate male showing SSC.

ALTERNATIVE CATEGORIES TO BEEF

In these categories sex is defined within dentition categories.

- 0 permanent incisors carcases can be either yearling beef (Y) or yearling steer (YS)
- 0-2 permanent incisors carcases can be either young beef (YG) or young steer (YGS)
- 0-4 permanent incisors carcases can be either young prime beef (YP) or young prime steer (YPS)
- 0-6 permanent incisors carcases can be either prime beef (PR) or prime steer (PRS)
- 0-8 permanent incisors carcases can be either ox (S) or steer (SS)

ALTERNATIVE CATEGORIES TO BULL

- Yearling (YE) is from an entire male (not assessed for SSC) having no permanent incisors with a carcase weight greater than 150kg
- Yearling entire (YGE) is from an entire male (not assessed for SSC) having 0-2 permanent incisors with a carcase weight greater than 150kg
- Young bull (BYG) is from an entire male showing SSC having 0-2 permanent incisors with a carcase weight greater than 150kg

Secondary sex characteristics are masculine traits in the carcase. They are assessed on pizzle muscle size, pizzle muscle characteristics, development of the 'jump' muscle (*m. biceps femoris*) and overall masculinity (Pietersen 1992).

11b) BACKGROUND TO THE MEASUREMENT OF SEX CATEGORIES

Historically, castration was practised as a means of taming oxen for draught purposes. Castration also provided a management tool to control unwanted breeding, decrease aggression and enable easier handling of males. In an era where fat in slaughtered carcases was prized, castration was an easy tool to increase fatness and improve eating quality along with the management benefits. Castration is widely practised in in Britain, the Americas (both North America and South America) and Australia. In contrast, much of Europe uses entire males for beef production which are generally slaughtered from 12 to 30 months of age.

The literature appears to be universal on older entire males being tougher than females or castrates. Field et al (1971) reviewed the results from seven studies comparing bulls and steers and concluded that bull beef had less tender meat when assessed by both objective and sensory panels. Hedrick et al (1969) showed that at 16 months there was no difference in palatability, but in contrast Forrest et al (1979) showed that at 15 months sensory scores were lower in bulls than steers.

Seideman et al (1982) concluded that whilst the meat from young bulls was not always tougher than steers it did appear to be more variable. They made the point that unless processing was controlled (i.e. carcases were stimulated) leaner bull carcases were often more prone to processing problems, including cold shortening. They reviewed a number of studies which showed it was possible to slaughter bulls up to 24 months without detrimental effects on eating quality. Dransfield et al (2003) showed no increase in toughness and a small increase in flavour in the older carcases from entire males slaughtered at 13, 19 and 24 months of age. More recently Thompson et al (2011) reported on a Polish study which showed no differences in a number of muscles from dairy and beef bull carcases slaughtered at 16 and 28 months of age. It should be noted that in this study only 30 carcases were sampled although consumer testing was carried out on 11 different muscles per carcase. It was likely that some carcases had cold shortened. In this study heifers at 27 months produced the highest consumer sensory scores due largely to their higher marbling scores. As expected old cows with a mean age of 110 months had the lowest eating quality.

The lack of difference between steers and heifers was supported by a recent study by Moss et al (2013) who showed no difference in eating quality between steers and heifers, although consistent with other studies bulls had the lowest eating quality. A recent review by Venkata Reddy et al (2015) also concluded that the often-cited advantage in eating quality from heifers relative to steers was due largely to the higher marbling levels in these carcases.

From the literature it is clear that carcases from older bulls were tougher but not always less flavoursome than steers at the same age. The question remains as to what age bulls become less palatable than steers and heifers. Certainly the literature questions whether there should be any separation of bulls, heifers and steers in the younger age category (milk teeth animals). Once adjusted for marbling there would appear to be little difference in eating quality between steers and heifers. This questions the current language categories where carcases from steers and heifers can be bulked under Y, YG, YP and PR, but then there is a separate category for steers as YS, YGS, YPS, PRS. The need to separate steers from heifers in the latter case cannot be justified on an eating quality basis.

There have been numerous reports which have shown that entire males have less fat and more muscle in the carcase (see Seideman et al 1982). These changes would be described either currently by changes in fat depth and eye muscle area, or perhaps in the future using technology that scans the carcase to directly measure composition and distribution of fat and muscle.

In conclusion, the categories used in the current beef language are more complex than necessary. There is a good case to differentiate older bull beef from that of heifers and steers. There is no literature to justify the separation of steer and steer plus heifer categories within dentition classes as currently occurs in the alternate beef categories. It is also not clear based on the ability of the consumer to detect differences in palatability at what age bull beef needs to be separated from heifer and steer beef.

The new MSA model has an input term for a bull category. The penalty in terms of eating quality depends upon ossification with different functions for variation in Bos indicus content. This bull input term has been currently developed on a trial basis and needs more data to confirm the empirical functions across a range of muscle and cooking types, in particular the ages at which the bull effect can be detected by the consumer.

Differences in carcase composition between steers, heifers, bulls and cows will be described by other beef language traits.

11c) ACCURACY AND BIAS IN THE MEASUREMENT OF SEX CATEGORIES

The criteria for classing a carcase as a bull is based on an assessment of SSC of the carcase. A recent MLA project slaughtered a total of 526 animals from four different sex treatments being early and late castration treatments, along with short scrotum and entire treatments (Fitzpatrick 2011). Although individual ages were not known the cattle were between 25 and 28 months of age and the short scrotum bulls and the entire bulls should have expressed their SSC. Of the early and late castrates less than 1% of the steers were classed as bulls by plant graders. However what was disturbing was that ca. 70% of the short scrotum and entire carcases were also classed at steers by plant graders. Given that this was a relatively small sample of only 500 animals these results are not conclusive, but do suggest that the current system of categorising carcases into bulls or steers based on SSC was not working and the system either needs modification or the company graders need retraining.

These results suggest there is a strong case to determine if sex category should be determined on the primary sex characteristics (i.e. the presence of testes on the stunned animal or if testes were left on the carcase) rather than secondary sex characteristics.

11d) TECHNOLOGY TO MEASURE SEX CATEGORIES

It is possible that SSC could be determined using images captured on the slaughter floor. However primary sex characteristics (i.e. testicles) on the live animal would be much less prone to error. Rather than the vagaries of classifying sex category on SSC it may be better to have the carcase allocated to a sex category based on inspection of primary sex characteristics after inspection at the knocking box or if testes were left on the carcase until the carcase could be stamped at the offal table.

11e) RECOMMENDATION FOR SEX CATEGORIES

It is recommended that the industry investigate changing the current method of describing sex on SSC to one where primary sex characteristics are used. Also, the need for the partial segregation of steer and heifer carcases into eating quality categories is questioned.

Further research is required to better understand when consumers can detect differences in bull beef compared with steers and heifers. It is likely that the MSA model will have an option to include sex in the MSA prediction model.

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