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Beef Carcass Grading in Europe and U.S.A. – The Prospects for Using VIA Systems

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SUMMARY

Europe and the USA have quite different grading schemes for beef carcasses. However, one factor they have in common is that they are both reliant on human judgement to categorise carcasses into quality classes. This makes them open to criticism that they are not truly objective. Whether or not this is justified is irrelevant, as it is not possible to demonstrate their objectivity. It is not true to say that the schemes are subjective, as they are based on photographic standards and graders are highly trained and skilled at their job. The result is that the confidence of farmers in quality based payments schemes linked to grading is never as high as it could be. This is likely to diminish their effectiveness to the detriment of the whole industry.

It should be easier to demonstrate the objectivity of instrumental grading methods since the results will be more consistent over time and from location to location, provided that such methods have high repeatability and reproducibility. Video Image Analysis (VIA) systems have been developed for beef carcass grading over the last 15 or more years. These classify carcasses into quality grades in the same manner as human graders, but based on actual measurements taken from carcass images. Because the software extracts and processes lots of data from the carcass images they can potentially do more than allocate carcasses to conformation and fat classes, as in the EUROPE scheme. They can also predict saleable yield which is not part of the present grading in Europe. Used in the right way, VIA systems could improve the consistency of grading schemes and increase the efficiency of the beef industry by providing additional information such as accurate yield data.

This paper briefly reviews the development of VIA systems and attempts to assess their potential for implementation in Europe and the USA.

Keywords

on-line measurements, slaughter, carcass yield, carcass quality, VIA, carcass classification

Beef carcass grading in Europe (the European Union)

European Union regulations state that beef carcasses must be classified according to their conformation and fat cover by trained classifiers (EC 1208/1981), the so-called EUROP system. For conformation the classes E U R O P are used with E denoting carcasses with the best conformation. There is an option to use an extra S class for carcasses with extremely good muscle development such as double-muscled individuals. Fat cover is assessed on a five-point scale using the numbers 1-5. Many countries subdivide each of the categories for conformation and fat into 3 subclasses to give a 15 x 15 grid. In other countries, such as Ireland, the most common fat class or classes are sub-divided into L (Low) and H (High). The classes each have descriptions and photographic standards. Classifiers are highly trained and must be regularly monitored and retrained if necessary. Standards throughout the EU are maintained by an expert panel who visit each country on a regular basis to check that the grading is in line with the EU standards. The classification scheme is used by the EU for price reporting market intervention purposes and by the industry for quality-based payments to producers and carcass trading.

Beef carcass grading in the USA

In the USA beef carcasses are graded according to quality and yield grades. The yield grades estimate the amount of boneless, closely trimmed retail cuts from the high-value parts of the carcass – the round, loin, rib and chuck. The grades are numbered 1 –5, YG1 having the highest expected yield and YG5 the lowest. The grades are calculated form a formula that includes the fat depth over the ribeye, the percentage kidney, pelvic and heart fat (KPH), carcass weight and ribeye area. The ribeye fat depth is measured at the 12th rib, three quarters of the length of the ribeye from the chine bone, but skilled graders make an adjustment of this measurement to reflect unusual amounts of fat in other parts of the carcass. In other words they assess how representative this fat depth is of total carcass fat. The amount of KPH fat is evaluated subjectively and expressed as a percentage of carcass weight, which is the hot carcass weight recorded by the scales. The area of the ribeye muscle is measured using a dot-grid.

The yield grades have descriptions in terms of the external and internal fat deposits and a stepwise procedure is adopted to determining the yield grade. Firstly, the preliminary yield grade (PYG) is determined from the ribeye fat measurement. This is then adjusted for the carcass weight, using 600lbs (270kg approx.) as the baseline, then the percentage KPH and finally the ribeye area.

Beef quality grades are designed to sort carcasses according to their expected palatability, that is their tenderness, juiciness and flavour. The quality grading is based primarily on marbling, that is the amount of intramuscular fat, but also on maturity. Graders evaluate the amount of marbling fat in the ribeye muscle after the carcass has been ribbed between the 12th and 13th ribs. Quality grades are called Prime (most marbling), Choice, Select and Standard (least marbling). Each quality grade is divided into three marbling score subclasses e.g. Prime is divided into Abundant, Moderately Abundant and Slightly Abundant. Each degree of marbling is divided into 100 subunits, but in practice marbling scores are generally referred to in tenths within each marbling grade, e.g. Slightly Abundant^{90}, Moderately Abundant^{50} etc.

Maturity is the second criterion of beef quality grading. Maturity refers to the physiological age of an animal rather than the chronological age and is used mainly because the latter is generally not available. The indicators of maturity are the bone characteristics, the degree of ossification of the cartilage of the sacral and lumbar vertebrae and the spinous processes of the thoracic vertebrae (increases with age) and the colour (darkens with age) and texture (becomes more coarse with age) of the ribeye muscle. Carcass maturity grades are labelled A-E, A being 9-30 months and E being over 96 months. Lean maturity grades are also labelled A-E and when the two do not agree a balancing is carried out with slightly more weighting on the bone score.

The final quality grade is determined by combining the marbling and maturity grades according to a plan. A stepwise procedure is used to determine the final quality grades of Prime, Choice, Select, Standard, Commercial, Utility and Cutter.

Development of VIA systems

The potential for using VIA for beef classification was probably first recognised in the mid 1980's. Initiatives to develop the technology were launched in Denmark and France. The first system developed by the Danish Meat Research Institute (DMRI), the BCC-1, was mechanically complex. It consisted of a cabinet to completely enclose the carcass and exclude ambient light, a monochromatic camera, lamps, a holding frame to keep the carcass stationery and a fat and muscle depth probe. The latter was deemed necessary in order to achieve a sufficiently accurate estimate of the fat class. The approach to data analysis was quite straightforward. A few measurements were extracted from the image and these were combined with the fat and muscle depths and carcass weight to predict the grading and the saleable yield. In 1993 the BCC-1 was replaced by BCC-2. This differs from the earlier prototype in several respects. Firstly, the cabinet was discarded. Ambient lighting variations are accounted for by taking two images, one with the lamps on and one with just ambient light. These are then subtracted to remove the ambient light effect. Secondly, the insertion probe was discarded. A more detailed analysis of the image data renders the fat and muscle depth measurements unnecessary. Striped light is projected onto the carcass to give information about the contours. Finally, neural network analysis is used in place of traditional regression analysis.

In France, the Normaclass system was developed. This uses six monochromatic cameras and two carcass holding frames on a rotating turntable. The two half carcasses are moved into different positions and images are taken from several angles. Data are extracted from the images and used to predict the grade and the saleable yield.

The VBS2000 was developed in Germany by a private company, E + V. Like the BCC-2 it uses striped light to gain pseudo-3D information. In contrast to the Danish system it does not take an image with the lights off to correct for ambient light and it does not use neural network analysis to predict the grades.

All the above systems stop the carcass to obtain high quality images of a stationary object. This necessarily slows down the operation and limits the maximum throughput to about 120 carcasses per hour. Two systems that take images while the carcass is moving can operate at speeds up to five times as fast. These are the VIAscan and CVS systems. The former was developed by Meat and Livestock Australia and the latter was developed in Canada by the Lacombe Research Centre. Both these systems were designed as part of multi-component systems. VIAscan, for instance, have

VIA equipment for hot carcasses, quartered chilled carcasses and for cuts. These can be used individually or as part of an integrated system.

Performance of VIA systems

Adoption of VIA grading systems by the beef industry will depend upon their effectiveness in accurately discriminating carcasses according to criteria that are related to their commercial value. Accuracy and repeatability will be important criteria in making the decision to install systems and this will be the main focus of this paper. Cost, practicality and reliability will also be important considerations. Regulatory issues will also be a factor in the timing of the adoption of the technology by the industry and this will also be discussed, particularly in relation to the EU.

Prediction of EUROP conformation and fatness

The EUROP system has been described above. Before commencing a review of the performance of VIA systems at predicting EUROP scores for conformation and fatness it is important to note that the VIA systems have to be trained and calibrated using 'reference' scores determined by one or more human classifiers. Thus, any inaccuracy and inconsistency in the 'reference' scores is included in the error of the VIA systems. Their performance is then subsequently judged against a similar 'reference' so that the inherent inaccuracy of the 'reference' is likely to be compounded. The developers of the systems will obviously take measures to maximise the objectivity of the carcass scores used to train and calibrate their systems, such as using a panel of experienced classifiers and using only those carcasses where there is total agreement about the classification scores. It is also essential, though, to pay attention to the quality of the reference scores in trials to determine the performance of the systems.

Madsen et al. (1996) reported a large trial where the BCC-2 was compared with a classifier and an inspector. The results showed that the BCC-2 was more accurate than the plant classifier for both conformation (SEP = 0.57 for BCC-2 v 0.75 for classifier) and fat class (SEP = 0.97 for BCC-2 v 1.15 for classifier). Moreover, the BCC-2 was more repeatable that the inspector when carcasses were reclassified within 1 hour (RMS = 0.12 v 0.51 for conformation and RMS = 0.17 v 0.80 for fat, for BCC-2 and inspector respectively).

Two trials of the VBS2000 system were reported by Sonnichsen et al. (1998). In the first trial a single classifier was compared with the VIA system on 301 young bulls of three breeds. The performance differed little between breeds and was better for conformation (R^2 = 0.90, SEP = 0.93) than for fat class (R^2 = 0.75, SEP = 1.20). In the second trial two experienced classifiers were used as the reference and the results were improved (R^2 = 0.91, SEP = 0.81 for conformation and R^2 = 0.80, SEP = 0.91 for fat).

The Normaclass system was tested by the national research organisation INRA (unpublished data). For conformation 100% of young bulls and 99% of cows were classified within 2 subclasses of the reference (15-point scale). Corresponding figures for fat class were 98% and 89%.

In 1999, the first comparative trial of VIA systems was undertaken in Ireland (Allen and Finnerty, 2000). Three systems, BCC-2, VBS2000 and VIAscan were installed side by side in the Dawn Meats factory in Midleton, County Cork. The first two systems had both been developed for predicting EUROP grades, but the VIAscan system had little previous experience of EUROP grading. A panel of three experienced classifiers scored the carcasses using the 15 x 15 grid and agreed a consensus score when they gave different scores. This consensus score was used as the reference. It was believed that this would give a more accurate reference than using the scores of individual classifiers. A total data set of over 7,000 carcasses was divided into a calibration set (n = 4,278) and a validation set (n = 2,969). As none of the systems had previously been trained on Irish carcasses the calibration set was used by the operators of the VIA systems to derive suitable algorithms. These were then tested on the validation set. For conformation the percentage classified to within one subclass (1/3 of a class) of the reference was 96.5, 92.8 and 91.0% for VBS200, BCC-2 and VIAscan respectively. The corresponding errors (RMS) were 0.75, 0.70 and 0.80. In common with previous tests of the systems individually, the performance for fat class predictions was poorer than for conformation, with the percentage predicted to within one subclass of the reference being 74.6, 80.4 and 72.0% for VBS200, BCC-2 and VIAscan respectively, and errors of 1.38, 1.14 and 1.38 respectively.

A second validation trial was undertaken at the same factory in Ireland in 2000. All the data from the first trial (calibration and validation sets) were made available to the companies to optimise their algorithms prior to this second trial. These were then tested on over 2,000 carcasses. The performance of all three systems was again very acceptable for conformation with the percentage classified to within one subclass of the reference being 95.4, 97.0 and 94.2 for VBS200, BCC-2 and VIAscan respectively. For fat class the percentage classified to within one subclass of the reference was again lower than for conformation and was unchanged for two systems with VIAscan showing an improvement to 76.1%.

Prediction of saleable yield

Conformation and fatness as assessed in the EUROP scheme are both related to the commercial value of a carcass, but this relationship is mostly, though not totally, due to their effect on the saleable yield. When the scheme was devised there were no satisfactory instrumental methods of measuring yield on line so the best tool available was a visual assessment of conformation and fat

cover. No attempt was made to convert the different classes into yield percentages, as there was no standard definition of yield. If VIA systems are able to predict saleable yield more accurately than the EUROP grading then they would have an additional value to the industry.

Borgaard et al. (1996) showed that the BCC-2 was more accurate than a classifier in predicting the percentage saleable yield (SEP = 1.34 v 1.63), the percentage hindquarter (SEP = 1.01 v 1.26) and the ribeye area (SEP = 5.8 v 6.7). VIAscan was shown to be more accurate at predicting saleable yield than the existing grading system that used weight and a fat depth for three out of our types of carcasses (Ferguson et al., 1995). Standard errors for the VIAscan were between 0.98 and 1.52%. Sonnichsen et al. (1998) reported a slightly higher SEP of 1.8% for predicting the saleable yield of 301 young bulls of three breeds. However, it is not meaningful to compare the results of different trials due to differences in the variability of the samples and in the specification of saleable yield. The first Irish trial is the only comparative trial to have been conducted (Allen and Finnerty, 2000). A sample of nearly 400 steer half carcasses were boned out and trimmed to a commercial specification. Roughly two thirds of these were used to calibrate the three systems and the rest (n = 139) were used for validation. There were only small differences between the three systems in their ability to predict saleable yield, with RSD's between 1.12 and 1.20%. Surprisingly though, the classification scores plus carcass weight were equally accurate (RSD = 1.21). This may have been due to the fact that a panel of three classifiers was used and the consensus scores were probably more reliable than those of individual classifiers as used in other trials. The fact that the specification did not involve heavy trimming of fat may also have been a factor. Primal yield was therefore calculated by excluding the trim and the flank. However, the VIA systems were less accurate than the classification scores and weight at predicting primal yield (RSD = 1.44 v 1.50 – 1.56).

Potential of VIA systems in Europe

EU regulations require that the EUROP classification scoring be carried out by trained personnel. In some countries these are employees of the factory, monitored and controlled by an independent body, while in other countries they are employed by an independent body or a state organisation. The key to achieving widespread adoption of the technology by the beef industry in Europe is a recent decision to change the regulation to allow machines to do the classification. This was agreed in principle by the EU authorities some time ago but there has been a long debate on what criteria and what the pass levels should be adopted for the approval for use of mechanical grading equipment. It was clear from the results of the Irish trials and others that the first proposal was not realistic as none of the systems would come close to passing all the criteria, particularly for fat. The principle that fat classification was more problematic even for classifiers and therefore the required standard should be lower was eventually accepted by the authorities. The VIA systems appear to have a good chance of passing the criteria now adopted. A scoring system be applied to the percentages of carcasses classified with no error or within 1, 2, 3 or more subclasses of the reference class. The penalties are higher for conformation than for fat class to reflect the difference in the reliability of the reference for these. The minimum pass level is 600 points for both conformation and fat class. Additionally limits have been proposed for the bias and the slope of the regression line. Applying these criteria to the data from the second Irish trial all three systems would have passed the 600 point threshold for both conformation and fat class, though one system would have failed on the bias criterion for fat.

Now that the regulation has been amended approval trials are likely to follow shortly, at least in some countries. The level of interest in mechanical grading differs across the EU member countries, depending on many factors. Those with the highest level of interest are the countries that have been most proactive in bringing about the acceptance of the principle of mechanical grading and the adoption of realistic criteria for their approval. These include Denmark, France, Germany, Sweden and Ireland and these are the countries most likely to organise the first approval trials. The first three of these have embraced the technology to varying degrees in advance of a change in the regulation. The BCC-2 was installed in the larger beef abattoirs some years ago and has been operated with a qualified classifier doing the official grading by accepting or rejecting the grades given by the BCC-2. One installation of VBS 2000 has operated in a similar way in Germany for several years. The Normaclass system was tested in at least two locations over extended periods and the French industry plans to install systems in at least 20 locations, though these may not all be Normaclass systems as the VBS 2000 has also received French approval.

In summary, it is now highly likely that approval trials will follow the adoption of the new regulation in some European countries. It is also likely that they will meet the approval criteria, though this cannot be guaranteed in advance. Installations in those countries are likely to follow successful approval trials as the industry seeks to improve the perceived objectivity of carcass grading and to benefit from the additional information about yield.

Potential of VIA systems in the USA

As described earlier the USDA grading system is quite complex, involving yield, quality and maturity grades. This might be seen as a barrier to VIA technology, but it could also present an opportunity since VIA can be a tool to assist rather than to replace the grader.

There seems little doubt that VIA systems are able to predict saleable yield with a degree of accuracy that would be useful to the industry. Jones et al. (1995) reported that data from the VIAscan whole carcass and chiller assessment

systems combined were better predictors of saleable yield than the standard Canadian grading system. The CVS system was also shown to be more accurate than the standard grading system when multiple measurements from either the whole carcass or the chiller assessment systems were used as predictors (Tong, 1997). But the greatest improvement was achieved when the two systems were combined (RSD = 1.61 (CVS) v 2.16 (grader plus ribeye area)).

The importance of factors such as the choice of a standard to compare instrumental systems against and the trimming specification used is illustrated by the results of Cannell et al. (1999). The dual component VIAscan was superior to the online grader at all three trimming specifications, but was less accurate than an expert grader working without time constraints. However, when the VIAscan ribeye area was combined with the expert grader's estimates of the other yield grade factors the percentage of the variation in yield at all trim levels was greater than for the expert grader alone. This illustrates the potential of VIA systems in augmenting the grader and allowing more time for the other factors to be assessed by the grader. Interestingly, the percentage variation explained increased as the trim level increased from commodity to closely trimmed for all models, but there was a further increase as the trim increased to very closely trimmed only for the VIAscan system alone. At this level of trim the advantage of augmenting the grader compared to using the VIAscan alone was marginal (75 v 71%). Similar results were found using the dual component CVS system (Cannell et al., 2002). The CVS system was far superior at predicting closely trimmed wholesale yield than the online grader (% variation explained = 64 v 39) but almost as accurate as the expert grader working offline when used alone or to augment the expert grader. The most recent results are from trials in two commercial beef processing facilities of the Meat Animal Research Centre (MARC) system (Shackleford et al., 2003). Prediction equations that included image analysis variables and hot carcass weight accounted for 90% of the variation in calculated yield grade compared to 73% for the online graders. MRAC data plus carcass weight also accounted for 88, 90, 88 and 76% of the variation in eye muscle area, preliminary yield grade, adjusted preliminary yield grade and marbling score respectively. The authors concluded that the system could be used to determine yield grade on-line but is not accurate enough to be used alone for predicting marbling score.

The potential of VIA systems for online grading in the US was officially recognised in 2001 when the USDA announced its approval for such instruments for determining yield grade. They authorised their use for measuring ribeye area to augment the online graders. This followed the conclusions of the National Beef Instrument Assessment Plan (NBIAP) that VIAscan was very accurate at predicting ribeye area but not as accurate as a USDA grader in predicting carcass yield when yield grade factors were correctly estimated (NCBA, 1998).

Predicting palatability with VIA

VIA also has potential for palatability grading. Measurements of the appearance of the lean and fat, perhaps surprisingly, have proved more useful at predicting eating quality than those based on mechanical resistance to penetration. Wulf et al. (1997) found that colour measurements and tenderness were more highly correlated than marbling score and tenderness. Wulf and Wise (1999) showed that colour measurements were correlated with lean maturity scores. The relationship between lean colour and palatability probably arises from underlying relationships between colour and factors such as marbling, pH, physiological maturity of the lean, degree of degradation of the sarcomeres etc. This has lead to the development of instruments to predict palatability from data derived from images of the ribeye after quartering. These include the BeefCam, developed by Colorado Sate University in and Hunterlab Associates Laboratory, Inc.. Colour measurements alone, however, are unlikely to be useful in grading carcasses on expected eating quality. Wulf and Page (2000) found that colour measurements explained only between 15 and 23% of the variation in palatability of a sample of 100 carcasses taken from 4 packing plants. They did suggest, however, that a grading system based on maturity, marbling, hump height and colour measurements could improve the accuracy of the current USDA beef quality grading standards and that colour measurements could be used in a branded-beef programme to increase the consistency of palatability.

An objective method of predicting eating quality that is not VIA-based, the Koohmaraie Tenderness Classification System, was compared with two VIA-based systems by Wheeler et al. (2003). The Koohmaraie System involves taking a slice of the eye-muscle, cooking it and measuring the shear force. This direct measure of tenderness was more accurate in identifying tender carcasses than either the BeefCam or the colorimeter. However, the direct measurement system is invasive and not truly on line as there is a delay before the results are available. There is therefore continued interest in developing on-line systems using VIA. Vote et al. (2003) concluded that on-line measurements by a CVS VIA system equipped with a BeefCam were useful for predicting the tenderness of beef longissimus muscle steaks.

CONCLUSION

VIA systems undoubtedly have potential for the objective grading of beef carcasses. This has been recognised by the responsible authorities in Europe and the USA. In the latter country the USDA has authorised their use to augment the yield grade assessment by trained classifiers and there is industry interest in adopting VIA technology to improve the accuracy of palatability grading. In Europe, VIA systems have recently been given the go-ahead to replace

trained classifiers for determining the EUROP grades, subject to passing certain performance criteria.

Adoption of this technology by the industry should improve the confidence of producers in carcass grading and make quality-based payment schemes more acceptable to them. Additional information, such as saleable yield where it is not part of the existing grading system, i.e. in Europe, and more accurate assessment of grading factors should help to improve efficiency in the industry.

REFERENCES

P. Allen and N. Finnerty (2000). Objective beef carcass classification – A report of a trial of three VIA classification systems. Teagasc, Dublin, Ireland.

C. Borggaard, N. T. Madsen and H. H. Thodberg (1996). In-line image analysis in the slaughter industry, illustrated by beef carcass classification, **Meat Science, 43**: S151-S163.

R. C. Cannell, J. D. Tatum, K. E. Belk, J. W. Wise, R. P. Clayton and G. C. Smith. (1999). Dual-component video image analysis system (VIAscan™) as a predictor of beef red meat yield percentage and for augmenting application of USDA yield grades. **J. Anim. Sci., 77:** 2942-2950.

R. C. Cannell, K. E. Belk, T. D. Tatum, J. W. Wise, P. L. Chapman, J. A. Scanga and G. C. Smith. (2002). Online evaluation of a commercial video image analysis system (Computer Vision System) to predict beef carcass red meat yield and for augmenting the assignment of USDA yield grades. **J. Anim Sci., 80:** 1195-1201.

D. M. Ferguson, J. M. Thompson, D. Barrett-Lennard and B. Sorensen. (1995). Prediction of beef carcass yield using whole carcass VIAscan, **Proceedings 41st ICoMST,** San Antonio, USA, Paper B16: 183-184.

S. D. M. Jones, R. J. Richmond and W. M. Robertson. (1995). Beef carcass grading or classification using video image analysis. **Proceedings 48th Annual Reciprocal Meat Conference**, San Antonio, Texas, USA: 81-84.

N. T. Madsen, H. H. Thodberg, T. Flig and E. Ovesen. (1996). BCC-2 for objective beef carcass classification and prediction of carcass composition. **Proceedings 42nd Annual Reciprocal Meat Conference,** Lillehammer, Norway, Paper G-6: 244-245.

NCBA (National Cattlemen's Beef Association). (1998). NBIAP key element in product enhancement program. **NCBA Quarterly Research Update, 3(3)**: 1-2.

S. D. Shackleford, T. L. Wheeler and M. Koohmaraie. (2003). On-line prediction of yield grade, longissimus muscle area, preliminary yield grade, adjusted preliminary yield grade and marbling score using the MARC beef carcass image analysis system. **J. Anim. Sci., 81**: 150-155.

M. Sonnichsen, C. Augustini, A. Dobrowolski, and W. Brandscheid. (1998). Objective classification of beef carcasses and prediction of carcass composition by video image analysis, **Proceedings 44th ICoMST, Barcelona, Spain,** Paper C59: 938- 939.

A.K.W. Tong, R.J. Richmond, S.D.M. Jones, D.J. Robinson, B.P. Chabot, S.M. Zawadski, W.M. Robertson, X. Li and T. Liu. (1997). Development of the Lacombe computer vision system (Lacombe CVS) for beef carcass grading, Agriculture and Agri-food Canada, Lacombe Research Centre, AB., Canada, 1997.

D. J. Vote, K. E. Belk, J. D. Tatum, J. A. Scanga and G. C. Smith. (2003). Online prediction of beef tenderness using a computer vision system equipped with a BeefCam module. **J. Anim. Sci., 81**: 457-465.

T. L. Wheeler, D Vote, J. M. Leheska, S. D. Shackleford, K. E. Belk, D. M. Wulf, B. L. Gwartney and M. Koohmaraie. (2003). The efficacy of three objective systems for identifying beef cuts that can be guaranteed tender. **J. Anim. Sci., 80**: 3315-3327.

D. W. Wulf, S. F. O'Connor, J. D. Tatum and G. C. Smith. (1997). Using objective measures of muscle colour to predict beef longissimus tenderness. **J. Anim. Sci., 75**: 684-692.

D. M. Wulf and J. K. Page. (2000). Using measurements of muscle colour, pH and electrical impedance to augment the current USDA beef quality grading standards and improve the accuracy and precision of sorting carcasses into palatability groups. **J. Anim. Sci., 78**: 2595-2607.

D. M. Wulf and J. W. Wise. (1999). Measuring muscle colour on beef carcasses using the L*a*b* colour space. **J. Anim. Sci., 77**: 2418-2427.