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European conformation and fat scores have no relationship with eating quality

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Short title: European carcass grade does not relate to eating quality

Abstract

European conformation and fat grades are a major factor determining carcass value throughout Europe. The relationships between these scores and sensory scores were investigated. A total of 3786 French, Polish and Irish consumers evaluated steaks, grilled to a medium doneness, according to protocols of the "Meat Standards Australia" system, from eighteen muscles representing 455 local, commercial cattle from commercial abattoirs. A mixed linear effects model was used for the analysis. There was a negative relationship between juiciness and European conformation score. For the other sensory scores, a maximum of three muscles out of a possible 18 demonstrated negative effects of conformation score on sensory scores. There was a positive effect of European fat score on three individual muscles. However, this was accounted for by marbling score. Thus, while the European carcass classification system may indicate yield, it has no consistent relationship with sensory scores at a carcass level that is suitable for use in a commercial system. The industry should consider using an additional system related to eating quality to aid in the determination of the monetary value of carcasses, rewarding eating quality in addition to yield.

Keywords: Meat Quality, Sensory Testing, European conformation score, European fat score

Implications

There is limited evidence in this study that European conformation score or European fat score have any relationship with eating quality. If value is defined by a combination of quality and volume, then the European industry must look beyond the European conformation and fat scores in order to deliver an eating quality based price signal to all levels of the supply chain, and therefore meet consumer demands for a consistent and quality product.

Introduction

Variability in eating quality is seen as a major factor in the decline in beef consumption (Morgan, 1992, Polkinghorne *et al.*, 2008). With all industry revenue either directly or indirectly linked to both consumer satisfaction and purchase volume, payment systems within the supply chain should ideally reflect the consumer value delivered by that sector (Polkinghorne and Thompson, 2010), with value being defined as a combination of weight and quality. In the European Union however, beef carcasses are valued on the basis of production class (bull, steer, heifer, cow), carcass weight and the European carcass classification score. This score is a combination of a visual assessment of carcass muscling and fatness by either a certified human grader or video image analysis system. The European carcass classification system was introduced to provide a standardised description of the carcass that would underpin an industry pricing system, particularly where the purchaser was unable to view the carcass prior to sale (Fisher, 2007) and the value of each class or category would be determined by the requirements of each individual market. Many of the factors which influence carcass muscling and fatness characteristics, and therefore the European carcass grade, also influence eating quality, such as breed, sex and production system (Field, 1971, De Roest, 2015, Soji et al., 2015). However, few studies have evaluated the relationships between the European carcass classification system and sensory evaluation of meat quality. Consumer assessment of eating quality, in particular juiciness and flavour, has a strong positive relationship with marbling score and chemical intramuscular fat percentage (IMF) (Thompson, 2001 and 2004). European fat cover score also demonstrates some correlation with marbling score and chemical IMF (R^2= 0.29 to 0.49) (Indurain *et al.*, 2009) along with other measures of adiposity. For example, Conroy *et al.* (2010) found with a one unit increase in European fat cover score (using the full 15 point scale) as the proportion of total fat in the carcass increased by 12.00 g/kg (determined with dissection). Similarly, in Irish steers fat depth over the *m. longissimus thoracis et lumborum*, as recorded with ultrasound pre-slaughter, also has a moderately strong positive correlation (0.63) with European fat cover score (Conroy *et al.*, 2009). Given the association between fatness and eating quality, this indicates that it is possible that increasing European fat cover score will be associated with improved eating quality.

In contrast the other part of the European carcass classification score, European conformation score, has a negative relationship with carcass fat proportion, marbling score and chemical IMF. In Holstein-Friesians, every one point increase in European conformation score (using the full 15 point scale) was associated with a 4.40 g/kg reduction in carcass fat proportion (Conroy *et al.*, 2010). Likewise, European conformation score demonstrated a negative simple correlation with marbling score in two year old Holstein-Friesian and Holstein-Friesian cross Angus steers with values of r= -0.19 and -0.22 (Conroy *et al.*, 2009), and also with chemical intramuscular fat levels in Pirenaica yearling bulls with values of -0.44 (Conroy *et al.*, 2009, Indurain *et al.*, 2009). In contrast, Guzek *et al.* (2014) found that cross-bred Limousin-Holstein-Friesian bulls failed to exhibit a difference in IMF and collagen levels between European conformation scores P and O. Therefore on the balance of the evidence and given the importance of fatness and IMF for eating quality, it seems plausible that European conformation score will have a negative relationship with eating quality.

However, despite the negative relationship between IMF and European conformation score, Guzek *et al.* (2013) found no difference in tenderness (estimated by Warner-Bratzler Shear Force) between Limousin bulls with a very limited range of European conformation scores, U-, U= or U+. This may be due to the influence of the myostatin mutation. It has been demonstrated that this mutation concurrently increases European conformation scores and improves tenderness while decreasing IMF. Allais *et al.* (2010) found that heterozygous carriers of the myostatin mutation within the breeds Charolais, Limousin and Blond d'Aquitaine scored 1.40±0.12, 1.38±0.24, 0.83±0.43 points respectively higher European conformation scores (using a 18 point scale) than animals without the mutation. When the eating quality of these carcasses was evaluated the heterozygous animals scored significantly higher by 2.13±0.69 points in tenderness and significantly lower by 0.96±0.21 points in flavour (trained taste panel, score 0-100) than individuals without the myostatin mutation. Juiciness scores were unchanged. Therefore, as a result of the conflicting influences of muscling and fatness on eating quality, there appears to be no consistent association between European conformation score and eating quality. Consequently we hypothesise that, while European fat score will have a positive relationship with eating quality, European conformation score will have no overall relationship with eating quality for commercial carcasses.

Material and methods

Animals and muscle samples

A total of 455 cattle were chosen randomly at abattoirs on the day of sampling to reflect the different commercial production practices within France, Poland, Ireland and Northern Ireland. As a result the carcasses had an uneven distribution of age, sex and carcass composition (Tables 1 and 2). The Polish carcasses were processed at a number of facilities distributed across the country. The Irish carcasses were processed at two commercial abattoirs and one pilot scale abattoir. The French carcasses were processed at a single facility in the West of France. The carcasses from Northern Ireland were processed at 5 different facilities distributed across the region. The cattle travelled for up to 5 hours to the abattoirs and were slaughtered commercially according to standard practice in each country. European conformation and fat scores were graded automatically by certified video image analysis systems already installed at the abattoirs. These scores both have a 5 point scale (E-U-R-O-P for conformation and 5-1 for fat score) and each score can be further broken down into high; medium and low creating a total of 15 possible scores. There is an additional ‘S’ class in the conformation score to describe carcasses from double muscled animals, which are beyond the scope of this study.

Other measurements were graded by personnel trained in MSA (Meat Standards Australia) and USDA meat grading (USDA, 1997) according to standard MSA protocols for characteristics such as USA ossification (an estimate of maturity), USA marbling and ultimate pH. Ultimate pH was recorded at 24h post slaughter. All cattle were growth-promotant free as these are prohibited in the European Union.

There was a wide range in the carcass traits measured and the raw means and standard deviations are presented in Table 1. Due to the constraints of such an observational study, not all measurements were recorded for all carcasses. The wide ranges for ossification score and animal age reflect the very broad range of maturities represented in this dataset. There is also a wide range in carcass weight and marbling score reflecting the different production systems both within and between the different countries. However, no information was collected on the individual farm management or production systems. A total of 30 carcasses had an ultimate pH greater than 5.7. The majority of affected carcasses were from Poland (data not shown). All of the carcasses without records for ultimate pH were sourced from Northern Ireland or Ireland and there was no evidence during sampling that these carcasses were affected by high pH.

There were 45 French cattle, all females and all aged for 10 days except for the tenderloin (*m. psoas major*) which was aged for 5 days. In Ireland, there were 47 heifers and 32 steers which were sampled and had a single ageing period of 14 days. The Northern Irish cattle were split into two groups according to the degree of doneness (medium or well-done) for the statistical analysis and interpretation. All other samples in the study were prepared to a medium doneness for relevant cooking methods. Of the Northern Irish carcasses with samples prepared medium, there were 48 females and 48 bulls, aged for both 14 and 21 days and 66 steers aged for 7, 14 and/or 21 days. There were 21 females from Northern Ireland with samples cooked well done, and there were 91 steers. Bulls from Poland were aged for either 10 or 21 days, and the females were aged for 10 days (Table 2). There was an uneven spread of carcasses within the European conformation and fat cover scores. The majority of carcasses had a European fat cover score of 3 and a European conformation score of either U, R or O (Table 2). This reflects the random nature of carcass selection and the distribution of carcasses found within Europe.

Seventeen different muscles were represented in the 2530 different samples (Table 3); however the number and type of muscles collected varied between carcasses. The muscles sampled were the: blade (*m. triceps brachii caput laterale*), chuck tender (*m. supraspinatus*), cube roll a (*m. longissimus thoracis*), cube roll b (*m. spinalis dorsil*), eye of round (*m. semitendinosus*), knuckle a (*m. rectus femoris*), knuckle b (*m. vastus lateralis*), outside (*m. biceps femoris*), oyster blade (*m. infraspinatus*), rump cap (*m. biceps femoris*), rump tail (*m. tensor fasciae latae*), eye of rump centre (*m. gluteus medius*), eye of rump side (*m. gluteus medius*), striploin (*m. longissimus thoracis et lumborum*), tenderloin (*m. psoas major*), topside a (*m. adductor femoris*) and topside b (*m. semimembranosus*). These muscles represent a wide range of eating qualities and locations in the carcass. Six of the muscles, the silverside, eye of rump centre, eye of rump side, shortloin, tenderloin and the topside b were selected from carcasses across the full range of European conformation and fat scores.

Meat preparation and consumer panels

Consumer assessment of eating quality was done according to protocols for MSA (Meat Standards Australia) testing described by Watson *et al.*, (2008b). Each sample (muscle) was sectioned into 5 steaks of 25 mm in thickness. These steaks were halved after cooking making 10 portions available for tasting from each muscle. Each consumer received seven portions: the first portion (a link sample) was a steak derived from either a generic striploin or rump muscle and designed to be of average quality – the sensory scores for this steak were not part of the final statistical analysis. The remaining 6 steaks were derived from one of the muscles samples collected. Grilled steaks were cooked on a SILEX S-Tronic 163 GR Dual Contact grill with cast iron plates (Silex, Hamburg, Germany) set to 220°C to achieve an internal temperature of 60°C for a ‘medium’ cooking doneness, and 70°C for a well-done cooking doneness (Watson *et al.*, 2008b).

In total, 960 French consumers (each scoring one link sample and 3 steaks from this study and 3 steaks sourced from Polish carcasses, the scores for which were not included in this analysis), 469 Irish consumers, 1552 Northern Irish consumers and 835 Polish consumers took part in the sensory testing. Consumers were sourced through both commercial consumer testing organisations and local clubs and charities. They were selected to reflect the general population of each country with the only requirement being that they considered meat an important part of their diet. Consumers only tested steaks from their own countries and scored them for tenderness, juiciness, flavour liking and overall liking, by making a mark on a 100mm line scale, with the low end of the scale representing a negative response and the high end of the scale representing a positive response. For a more detailed description of the testing procedures see Anonymous (2008). The consumers were expected to have only a small amount of variation between countries on the basis of previous work using the same consumer protocols (Thompson et al., 2008, Polkinghorne et al., 2011, Legrand et al., 2012).

Meat quality score (MQ4)

Each muscle from each carcass was assessed by 10 individual untrained consumers. There is a high correlation between all four sensory scores with a minimum partial correlation coefficient between any of the scores of 0.66 calculated on a subset of the data (Bonny *et al.*, 2015).The highest and lowest two scores for each muscle were removed, helping to eliminate extreme values and reducing the variability associated with using untrained consumers. The average was calculated for the remaining six scores. The combination of clipping and then averaging the remaining six scores acts to reduce the influence of any demographic effects in the database, allowing us to approximate a ‘general consumer’ response with the final value reached. Additionally, these clipped mean values for tenderness, juiciness, flavour liking and overall liking were used to create a single MQ4 score. The weightings of the four sensory parameters (tenderness, juiciness, flavour liking and overall liking) to create the MQ4 score were 0.3*tenderness, 0.1*juiciness, 0.3*flavour liking and 0.3*overall liking. The weightings were calculated using a discriminant analysis, as performed by Watson *et al.* (2008a).

Statistical analysis

The sensory scores tenderness, juiciness, flavour liking, overall liking and the composite score MQ4 were analysed using a linear mixed effects model (SAS v9.1). Initially, a base model was established, using muscle and a concatenated term, experimental group, comprising of carcass source country, sex and post mortem ageing period. Animal identification number, within source country, and kill group (animals slaughtered on the same day at the same abattoir) as random terms. A term for carcass grader (either the human or video image analysis system measuring the European carcass grade, ossification score or marbling score) was not included in the model. Any variation in scores attributable to grader differences will have been captured by the random term kill group already present in the model as all the carcasses in the same kill group were measured by the same grader. The inclusion of animal identification number assumes that the correlation between eating quality scores in different muscles within the same animal are equal. This will result in the analysis being over sensitive in the case where the correlations of sensory scores between different muscles within the same animal are not equal, as could reasonably be expected. In order to account for this the significance level has been changed to $p<0.01$ for the term muscle type and all interactions with muscle type. The degrees of freedom were determined using the Kenward and Rodger technique. Consumers only scored meat samples from the same country, therefore any variation in consumers between countries will be encompassed by carcass source country in the analysis. The consumers were also not expected to have much variation between countries on the basis of previous work (Thompson *et al.*, 2008, Polkinghorne *et al.*, 2011, Legrand *et al.*, 2012).

Separately the European conformation score and European fat cover score were then incorporated into the base models as fixed effects, including all interactions, to assess their association with the sensory scores. In all cases, non-significant terms (p>0.05) were removed in a step-wise fashion. Where European conformation score or fat score was significant within individual muscles, an individual F-test was performed for the range of European conformation or fat score for each muscle. Where this F-test was significant (p<0.05) the predicted means were compared using the least significant differences, generated using the Pdiff function in SAS (SAS v9.1). Following this the covariates USA ossification score, USA marbling score, ultimate pH, animal age and carcass weight were tested in the models to evaluate their effects on the relationship between the sensory scores and the European conformation and fat scores.

Results

European conformation score and sensory scores

Outcomes for the core model are presented in Table 4. Muscle type and experimental group and the interaction between these two terms were significant for all sensory scores and MQ4. European conformation score had a significant interaction with muscle type for all attributes except juiciness, where it was significant as a main effect.

Only two muscles, the eye of rump centre and the shortloin, showed differences in MQ4 between the European conformation scores (Table 5). For the eye of rump centre, the MQ4 increased by approximately 7 points from score U (49.2±2.47) through to the lowest score P (56.2±2.71). For the shortloin the MQ4 increased by 6.5 points as the conformation score decreased from score U (53.2±1.80) to score P (59.8±2.45).

Similar to MQ4, overall liking also demonstrated a negative relationship with European conformation score for the eye of rump centre and the shortloin (Table 6). For the eye of rump centre, scores increased by 7 points as the European conformation score decreased from U (50.5±2.21) to P (57.5±2.47). There was a similar pattern for the shortloin where overall liking scores increased by 7.5 points as the European conformation score decreased from U (53.2±1.35) to P (60.7±2.14).

Only the eye of rump centre increased in tenderness as European conformation decreased, with an increase of 8.6 as conformation score decreased from U (45.7±4.67) to P (54.3±4.89). This trend was also seen with score R (41.1±4.13) having a lower tenderness than scores O (50.1±4.21) and P (54.3±4.89). The predicted mean tenderness score for conformation score E (55.5±10.69) was not different to the scores for any other conformation class. No other muscles showed differences in tenderness between the European conformation scores.

Three muscles demonstrated a difference in flavour liking between European conformation scores, the eye of rump centre, the shortloin and the topside b (Table 7). For all three muscles the trend was for flavour scores to increase as European conformation scores decreased from U through to P. Flavour liking for the eye of rump centre increased by 9 points as conformation score decreased from R to P. The shortloin and the topside flavour liking scores increased by 5 points between conformation scores U and P.

The effect of European conformation score on juiciness scores were consistent for all muscles tested. Juiciness score for European conformation scores U (49.7±2.19) and

R (50.9±2.02) were different to O (53.4±2.10) and P (56.0±2.50) with a decrease in juiciness scores of 4 points across the range. Carcasses with score E (49.8±3.81) did not differ from any other conformation class.

When ossification score, animal age, marbling score, carcass weight or ultimate pH were added to the models there was no change. In contrast, when USA marbling score was included in the model predicting juiciness, European conformation score was no longer significant.

European fat score and sensory scores

European fat score interacted with muscle type for tenderness. It was not significant when predicting flavour liking or any other attribute (Table 4). There was a general trend for tenderness score to increase as the European fat score increased for the three muscles, the silverside, eye of rump side and the tenderloin (Table 8). The addition of USA marbling score, another measure of carcass adiposity, eliminated the relationship between tenderness and European fat score. No other covariates had an effect.

Discussion

European conformation score and sensory scores

The hypothesis that there would be no relationship between the European conformation score and untrained consumer sensory scores was almost completely supported by our results. For the vast majority of muscles there were no relationships between European conformation score and eating quality attributes. These results expand on the findings of both Guzek *et al.* (2013) and Guzek *et al.* (2014) who also found no relationship between a limited range of European conformation scores and intramuscular fat, collagen and tenderness.

Where there was a relationship between eating quality and European conformation score it was negative. However when marbling score was included in the statistical model predicting juiciness, European conformation score was no longer significant. This suggests that the negative relationship between juiciness and European conformation is a result of the positive relationship between marbling score and juiciness (Thompson 2004) and the negative relationship between marbling score and European conformation score (Conroy *et al.*, 2009). This relationship between marbling score, conformation score and quality was not present for the other sensory scores. This is unexpected given the high correlation between the sensory scores (Bonny *et al* 2015) and the relationship between marbling and tenderness, flavour and overall liking of beef (Thompson, 2004, O'Quinn et al., 2012). Given the small number of significant results we cannot discount the possibility that these few differences found in the sensory scores other than juiciness, are simply due to the oversensitivity of the covariance structure. Furthermore the likelihood of detecting random relationships, particularly within individual muscle groups, would be increased by the relatively small and unbalanced nature of this data set. This includes uneven representations of sex, animal source countries, production systems and breed, which are also known to influence both muscling score and eating quality (Field, 1971, De Roest, 2015, Soji et al., 2015).

However, if it is proven that these relationships are not random and were repeatable, the relatively small magnitude of these effects, within a small number of muscles, would make it difficult for an eating quality grading system based on the European conformation score to be accurate and simple enough to be embraced by industry

(Strydom 2011). This is particularly true given that the international beef trade is now dominated by chilled primal cuts rather than whole carcasses (Polkinghorne and Thompson, 2010).

European fat score and sensory scores

The hypothesis that European fat score would have a positive relationship with sensory scores was very minimally supported by our results. Only three of the 17 muscles showed a positive relationship between European fat score and tenderness. Where the relationship between tenderness and European fat score was present, it was completely explained by marbling score. This indicates that, for those three muscles, European fat score was explaining a proportion of the variance in eating quality through its relationship with carcass fatness and marbling score (Conroy et al., 2009, Indurain et al., 2009, Conroy et al., 2010). All other muscles and sensory scores demonstrated no relationships. This is unexpected given the high correlation between the sensory scores (Bonny *et al* 2015), the relationship between European fat score and carcass fatness and marbling (Conroy et al., 2009, Indurain et al., 2009, Conroy et al., 2010), and the relationship between marbling and tenderness, flavour and overall liking of beef (Thompson, 2004, O'Quinn et al., 2012).This discrepancy between the results and the hypothesis may be due to the poor spread of data across the range of European fat scores, particularly at the fat score extremes effectively truncating the range of this study. Additionally the subsets of the data include uneven representations of sex, animal source countries, production systems and breed, all of which are also known to influence both fatness and eating quality (Field, 1971, De Roest, 2015, Soji et al., 2015). However these factors represent the standard production systems within the countries sampled, with therefore a large proportion of effect of production system and the distributions of sex and breed on both eating quality and European fat score being absorbed by including animal source country in the analysis. A meat grading system needs to be simple, easy to apply and accurate in order to facilitate market uptake (Strydom 2011). Therefore if a relationship between European fat score and eating quality exists outside of the distribution and range of sex, breed, and fat scores found in this study, it would be of limited usefulness in a commercial eating quality grading system.

Conclusion

The lack of any strong clear relationship between sensory scores and the European conformation and fat scores in this study indicates that the European beef industry cannot rely on these carcass grades alone to incorporate eating quality in the determination of carcass value. Alternative measures must be investigated to enable the inclusion of eating quality into the European meat grading system and the subsequent delivery of consistent, quality beef to the consumer.

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References

Allais S, Leveziel H, Payet-Duprat N, Hocquette J-F, Lepetit J, Rousset S, Denoyelle C, Bernard-Capel C, Journaux L, Bonnot A and Renand G 2010. The two mutations, Q204X and nt821, of the myostatin gene affect carcass and meat quality in young heterozygous bulls of French beef breeds. Journal of Animal Science 88, 446-454.

Anonymous 1982. Commission of the European communities (Beef Carcass Classification) regulations. . In Commission of the European communities, Brussels, Belgium.

Accessory publication 2008. MSA sensory testing protocols. From: Watson R, Polkinghorne R and Thompson JM 2008. Development of the Meat Standards Australia (MSA) prediction model for beef palatability. Australian Journal of Experimental Agriculture 48, 1368-1379.

Bonny SP, Gardner GE, Pethick DW, Legrand I, Polkinghorne RJ and Hocquette JF 2015. Biochemical measurements of beef are a good predictor of untrained consumer sensory scores across muscles. Animal 9, 179-190.

Conroy SB, Drennan MJ, Kenny DA and McGee M 2009. The relationship of live animal muscular and skeletal scores, ultrasound measurements and carcass classification scores with carcass composition and value in steers. Animal 3, 1613-1624.

Conroy SB, Drennan MJ, McGee M, Keane MG, Kenny DA and Berry DP 2010. Predicting beef carcass meat, fat and bone proportions from carcass conformation and fat scores or hindquarter dissection. Animal 4, 234-241.

De Roest K 2015. Beef production, supply and quality from farm to fork in Europe. In Proceedings of the 66th annual meeting of the European Federation of Animal Science 31st of August to the 4th of September, Warsaw, Poland, p. 230.

Fisher A 2007. Beef carcass classification in the EU: an historical perspective. In European Association for Animal Production, pp. 19-30. European Federation of Animal Science, Dublin, Ireland.

Guzek D, GŁĄBska D, Lange E and GŁĄBski K 2014. Study of beef blade muscles' differentiation depending on conformation and fat class. Turkish Journal of Veterinary & Animal Sciences 38, 195-199.

Guzek D, Glabska D, Pogorzelski G, Kozan K, Pietras J, Konarska M, Sakowska A, Glabski K, Pogorzelska E, Barszczewski J and Wierzbicka A 2013. Variation of meat quality parameters due to conformation and fat class in Limousin bulls slaughtered at 25 to 27 months of age. Australasian Journal of Animal Sciences 26, 716-722.

Indurain G, Carr T R, Goni M V, Insausti K and Beriain M J 2009. The relationship of carcass measurements to carcass composition and intramuscular fat in Spanish beef. Meat Science 82, 155-161.

Legrand I, Hocquette J-F, Polkinghorne RJ and Pethick DW 2013. Prediction of beef eating quality in France using the Meat Standards Australia system. Animal 7, 524-529.

Morgan JB 1992. Tenderness problems and potential solutions. In Improving the consistency and competitiveness of beef: the final report of the National Beef Quality Audit, pp. pp. 180–187, National Cattlemens' Association, Englewood, CO.

O'Quinn TG, Brooks JC, Polkinghorne RJ, Garmyn AJ, Johnson BJ, Starkey JD, Rathmann RJ and Miller MF 2012. Consumer assessment of beef strip loin steaks of varying fat levels. Journal of Animal Science 90, 626-634.

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

Polkinghorne R, Philpott J, Gee A, Doljanin A and Innes J 2008b. Development of a commercial system to apply the Meat Standards Australia grading model to optimise the return on eating quality in a beef supply chain. Australian Journal of Experimental Agriculture 48, 1451-1458.

Polkinghorne RJ and Thompson JM 2010. Meat standards and grading: a world view. Meat Science 86, 227-235.

Polkinghorne RJ, Nishimura T, Neath KE and Watson R 2011. Japanese consumer categorisation of beef into quality grades, based on Meat Standards Australia methodology. Animal Science Journal 82, 325-333.

Soji Z, Mabusela SP and Muchenje V 2015. Associations between animal traits, carcass traits and carcass classification in a selected abattoir in the Eastern Cape Province, South Africa. South African Journal of Animal Sciences 45, 278-288.

Strydom PE 2011. Quality related principles of the South African beef classification system in relation to grading and classification systems of the world. South African Journal of Animal Science 41, 177-U1500.

Thompson JM 2001. The relationship between marbling and sensory traits. In Beef CRC Marbling Symposium 2001, Coffs Harbour, NSW, Australia, pp. 30-35.

Thompson JM 2004. The effects of marbling on flavour and juiciness scores of cooked beef, after adjusting to a constant tenderness. Australian Journal of Experimental Agriculture 44, 645-652.

Thompson JM, Polkinghorne R, Hwang IH, Gee AM, Cho SH, Park BY and Lee JM 2008. Beef quality grades as determined by Korean and Australian consumers. Australian Journal of Experimental Agriculture 48, 1380-1386.

Verbeke W, Van Wezemael L, de Barcellos MD, Kügler JO, Hocquette J-F, Ueland Ø and Grunert KG 2010. European beef consumers' interest in a beef eating-quality guarantee: Insights from a qualitative study in four EU countries. Appetite 54, 289-296.

Watson R, Polkinghorne R and Thompson JM 2008a. Development of the Meat Standards Australia (MSA) prediction model for beef palatability. Australian Journal of Experimental Agriculture 48, 1368-1379.

Watson R, Gee A, Polkinghorne R and Porter M 2008b. Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. Australian Journal of Experimental Agriculture 48, 1360-1367.

Table 1 Number of carcasses and the raw maximum, minimum, mean and standard deviation for the measured covariates

Covariate	n[1]	Mean	Std Dev	Minimum	Maximum
Ossification score[2]	310	212	123	110	590
Animal age[3] (days)	455	938	744	226	6133
Marbling score[2]	455	338	115	100	820
Carcass weight (kg)	454	344	57.9	168	531
Ultimate pH[4]	307	5.63	0.25	5.33	6.92

n = Number of carcasses; Std Dev = Standard deviation;

[1] The number of carcasses varies for each measure because not all measurements were recorded for all carcasses.

[2] Measures were recorded as standard MSA (Meat Standards Australia) measurements by trained graders.

[3] Chronological age in days.

[4] The pH of the *m. longissimus thoracis et lumborum* recorded 24h post slaughter.

Table 2 The number of carcasses for each European conformation and fat score by experimental group[1]

	European conformation score[2]					European fat cover score					
	E	U	R	O	P	1	2	3	4	5	Total
France females (10d[3])	0	3	21	14	7	0	2	42	1	0	45
Ireland females (14d[3])	0	6	19	22	0	1	5	27	14	0	47
Ireland steers (14d[3])	0	5	15	11	1	4	5	11	12	0	32
Nth Ireland bulls (14d[3])	5	21	14	8	0	0	12	35	1	0	48
Nth Ireland bulls (21d[3])	5	21	14	8	0	0	12	35	1	0	48
Nth Ireland females (14d[3])	1	9	30	8	0	0	4	26	18	0	48
Nth Ireland females (21d[3])	1	9	30	8	0	0	4	26	18	0	48
Nth Ireland steers (7d[3])	0	1	12	7	0	0	5	13	2	0	20
Nth Ireland steers (14d[3])	0	9	31	8	0	0	10	28	10	0	48
Nth Ireland steers (21d[3])	0	9	31	8	0	0	10	28	10	0	48
Nth Ireland females WD[4](7d[3])	0	3	17	3	0	0	3	11	9	0	23
Nth Ireland steers WD[4](7d[3])	1	14	49	26	19	0	15	73	20	1	109
Nth Ireland steers WD[4](14d[3])	1	2	8	1	0	0	0	8	3	1	12
Poland bulls (10d[3])	2	3	5	26	1	8	16	13	0	0	37
Poland bulls (21d[3])	0	0	2	5	0	0	3	2	2	0	7
Poland females (5d[3])	0	0	6	4	0	0	0	7	2	1	10
Total[5]	16	115	304	167	28	13	106	385	123	3	630

[1] Experimental group is a concatenated term comprising of carcass source country, sex and post mortem ageing period.

[2] A visual assessment of carcass muscling. Carcasses graded as ‘E’ have the most muscularity, and this decreases through to ‘P’ which have the least muscularity

[3] Days post mortem ageing before taste testing.

[4] Samples cooked well done.

[3] The total number of carcasses here is greater than the total number in the study because some carcasses are represented in more than one ageing period.

Table 3 The number of samples for each European conformation and fat score by muscle

	European conformation score[1]					European fat cover score					
Muscle	E	U	R	O	P	1	2	3	4	5	Total
Blade[2]	0	0	0	14	0	0	2	9	3	0	14
Chuck Tender[3]	0	0	2	10	0	7	5	0	0	0	12
Cube Roll a[4]	0	0	2	10	0	7	5	0	0	0	12
Cube Roll b[5]	0	0	2	10	0	7	5	0	0	0	12
Eye round[6]	0	7	25	11	0	1	4	21	17	0	43
Knuckle a[7]	4	8	60	68	8	14	28	100	6	0	148
Knuckle b[8]	2	2	3	5	0	3	8	1	0	0	12
Silverside[9]	4	10	53	89	11	14	26	114	12	1	167
Blade[10]	0	1	10	11	3	0	0	22	2	1	25
Rump cap[11]	1	10	22	13	18	0	11	42	11	0	64
Rump tail[12]	0	0	2	10	0	7	5	0	0	0	12
Eye of rump centre[13]	6	37	152	120	31	17	48	223	56	2	346
Eye of rump side[14]	4	9	39	18	1	5	15	35	13	3	71
Shortloin[15]	20	149	440	238	51	20	133	545	195	5	898
Tenderloin[16]	4	16	76	95	12	15	37	123	27	1	203
Topside a[17]	0	2	16	7	4	0	4	21	4	0	29
Topside b[18]	8	46	204	164	32	21	68	276	84	5	454
Total[19]	53	297	1108	893	171	138	404	1532	430	18	2522

[1] A visual assessment of carcass muscling. Carcasses graded as ‘E’ have the most muscularity, and this decreases through to ‘P’ which have the least muscularity

[2] *m. triceps brachii caput laterale* [3] *m. supraspinatus* [4] *m. longissimus thoracis et lumborum* [5] *m. spinalis dorsil* [6] *m. semitendinosus* [7] *m. rectus femoris* [8] *m. vastus lateralis* [9] *m. biceps femoris* [10] *m. infraspinatus* [11] *m. biceps femoris* [12] *m. tensor fasciae latae* [13] *m. gluteus medius* [14] *m. gluteus medius* [15] *m. longissimus thoracis et lumborum* [16] *m. psoas major* [17] *m. adductor femoris* [18] *m. semimembranosus*.

[19] The total number of muscles can be greater than the total number of carcasses per European conformation or fat score in Table 3 because muscles from both sides of the carcasses were tested in a subset of the data.

Table 4 The F values for the base model, European conformation score model, the European fat cover score model predicting MQ4[7] and sensory score values

	MQ4[1]			Tenderness			Juiciness			Flavour liking			Overall liking		
Effects	NDF[2]	DDF[3]	F value	NDF[2]	DDF[3]	F value	NDF[2]	DDF[3]	F value	NDF[2]	DDF[3]	F value	NDF[2]	DDF[3]	F value
Base model															
Muscle type[5]	15	47.3	4.45***	15	22	3.69**	15	37.4	4.14***	15	68.4	4.51***	15	106	5.09***
Experimental group[6]	16	1764	78.09***	16	1776	90.76***	16	1770	43.44***	16	1723	48.75***	16	1778	67.24***
Experimental group[6] * Muscle type[5]	35	1766	4.09***	35	1773	4.33***	35	1769	3.35***	35	1773	3.13***	35	1776	3.76***
European conformation score model[4]															
Muscle type[5]	15	51.4	4.10***	15	22.5	3.64**	15	39.9	3.80***	15	72.4	3.84***	15	108	4.26***
Experimental group[6]	16	1781	31.88***	16	1777	37.08***	16	1766	43.25***	16	1788	18.72***	16	1792	27.31***
Experimental group[6] * Muscle type[5]	35	1736	3.69***	35	1748	3.95***	35	1766	3.33***	35	1758	2.91***	35	1754	3.51***
Fixed effect[7]	4	910	0.84	4	985	0.49	4	387	4.52**	4	899	0.92	4	959	0.8
Muscle type[5] *Fixed effect[7]	37	1855	1.94***	37	1846	1.97***	-	-	-	37	1897	1.55*	37	1870	2.06***
European fat cover score model															
Muscle type[5]	15	47.3	4.45***	15	23	3.69**	15	37.4	4.14***	15	68.4	4.51***	15	106	5.09***
Experimental group[6]	16	1764	78.09***	16	1773	33.81***	16	1770	43.44***	16	1723	48.75***	16	1778	67.24***
Experimental group[6] * Muscle type[5]	35	1766	4.09***	35	1738	3.76***	35	1769	3.35***	35	1773	3.13***	35	1776	3.76***
Fixed effect[7]	-	-	-	4	531	1.41	-	-	-	-	-	-	-	-	-
Muscle type[5] *Fixed effect[7]		-	-	40	1824	1.5*	-	-	-	-	-	-	-	-	-

[1] A composite eating quality score out of 100 comprised of weighted (0.3, 0.1, 0.3, 0.3) untrained consumer scores for tenderness, juiciness, flavour liking and overall liking.

[2] Numerator degrees of freedom.

[3] Denominator degrees of freedom.

[4] A visual assessment of carcass muscling. Carcasses graded as ‘E’ have the most muscularity, ant this decreases through to ‘P’ which have the least muscularity

[5] Muscle Type: blade (*m. triceps brachii caput laterale*), chuck tender (*m. supraspinatus*), cube roll a (*m. longissimus thoracis et lumborum),* cube roll b (*m. spinalis dorsil),* eye round (*m. semitendinosus*), knuckle a (*m. rectus femoris*), knuckle b (*m. vastus lateralis*), outside (*m. biceps femoris*), oyster blade (*m. infraspinatus*), rump cap (*m. biceps*

femoris), rump (*m. tensor fasciae latae*), eye of rump centre (*m. gluteus medius*), eye of rump side (*m. gluteus medius*), striploin (*m. longissimus thoracis et lumborum*), tenderloin (*m. psoas major*), and topside (*m. semimembranosus*).

[6] The experimental group refers to a concatenated term that comprises of carcass source country, carcass sex and post mortem ageing period of the muscle sample. There are a total of 16 different experimental groups.

[7] The ‘fixed effect’ is either European conformation score of European fat cover score in the respective models.

*=$p<0.05$; **=$p<0.01$;***=$p<0.001$;

Table 5 Predicted means (± SE[1]) for the effects of European conformation score (5 grades) on ^MQ4 for each muscle

MQ4	E	U	R	O	P
Blade[2]				53.8±3.29	
Chuck Tender[3]			38.1±7.11	39.7±3.56	
Cube Roll a[4]			50.9±7.11	58.7±3.56	
Cube Roll b[5]			65.7±7.11	65.2±3.56	
Eye round[6]		43.2±4.30	46.7±2.64	48.8±3.57	
Knuckle a[7]		58.7±5.35	49.5±2.15	50.5±2.07	59.9±5.40
Knuckle b[8]		41.3±9.96	34.4±5.88	34.2±4.70	
Silverside[9]		38.4±4.49	35.4±2.23	32.4±1.96	27.0±4.27
Blade[10]		59.1±10.23	55.0±3.55	61.6±3.43	60.7±6.15
Rump cap[11]		57.1±3.58	59.7±2.62	61.1±3.21	58.3±3.05
Rump tail[12]			56.0±7.11	46.8±3.56	
Eye of rump centre[13]	53.2^{abc}±8.12	49.2^{ab}±2.47	45.1^{a}±1.72	53.2^{bc}±1.85	56.2^{c}±2.71
Eye of rump side[14]	39.1±8.11	57.1±4.88	54.8±2.32	49.8±3.54	
Shortloin[15]	55.2^{abc}±3.66	53.2^{a}±1.80	55.3^{ac}±1.53	56.7^{bc}±1.67	59.8^{b}±2.45
Tenderloin[16]		73.7±3.48	76.5±2.00	73.8±1.96	82.0±4.27
Topside a[17]		42.7±7.32	38.8±2.95	37.4±4.15	37.2±5.38
Topside b[18]	41.5±6.53	37.9±2.32	37.5±1.65	41.1±1.78	41.9±2.71

^MQ4 is a weighted combination (0.3, 0.1, 0.3, 0.3) of four sensory scores, tenderness, juiciness, flavour liking and overall liking as scored by untrained consumers;

[1] Standard error.

[2] *m. triceps brachii caput laterale* [3] *m. supraspinatus* [4] *m. longissimus thoracis et lumborum* [5] *m. spinalis dorsil* [6] *m. semitendinosus* [7] *m. rectus femoris* [8] *m. vastus lateralis* [9] *m. biceps femoris* [10] *m. infraspinatus* [11] *m. biceps femoris* [12] *m. tensor fasciae latae* [13] *m. gluteus medius* [14] *m. gluteus medius* [15] *m. longissimus thoracis et lumborum* [16] *m. psoas major* [17] *m. adductor femoris* [18] *m. semimembranosus*.

^{a,b,c} Values within a row with different superscripts differ significantly at *P*<0.05.

Blank spaces indicate cells without data.

Table 6 Predicted means (± SE[1]) for the effects of European conformation score (5 grades) on overall liking for each muscle

Overall liking	E	U	R	O	P
Blade[2]				53.5±3.17	
Chuck Tender[3]			38.9±7.29	40.5±3.43	
Cube Roll a[4]			50.8±7.29	57.7±3.43	
Cube Roll b[5]			66.0±7.29	63.9±3.43	
Eye round[6]		43.5±4.26	47.1±2.43	47.6±3.47	
Knuckle a[7]		59.0±5.41	50.1±1.84	50.5±1.72	61.4±5.44
Knuckle b[8]		44.6±10.29	38.0±5.97	37.0±4.70	
Silverside[9]		38.2^{a}±4.48	36.1^{a}±1.95	31.8^{ab}±1.59	24.7^{b}±4.23
Blade[10]		60.0±10.56	53.6±3.47	61.0±3.34	60.8±6.25
Rump cap[11]		57.1±3.49	60.1±2.42	61.2±3.09	57.8±2.86
Rump tail[12]			57.2±7.29	49.5±3.43	
Eye of rump centre[13]	53.4^{abc}±8.24	50.5^{ab}±2.21	46.1^{a}±1.26	53.7^{bc}±1.43	57.5^{c}±2.47
Eye of rump side[14]	40.6±8.23	57.5±4.91	55.6±2.06	50.1±3.46	
Shortloin[15]	54.0^{abc}±3.45	53.2^{a}±1.35	55.6^{ac}±0.98	57.0^{bc}±1.17	60.7^{b}±2.1
Tenderloin[16]		73.5±3.38	76.5±1.66	74.0±1.58	81.8±4.23
Topside a[17]		45.6±7.50	40.0±2.81	40.8±4.12	39.7±5.43
Topside b[18]	42.4±6.52	39.4±2.03	38.8±1.16	42.1±1.33	42.5±2.47

[1] Standard error.

[2] *m. triceps brachii caput laterale* [3] *m. supraspinatus* [4] *m. longissimus thoracis et lumborum* [5] *m. spinalis dorsil* [6] *m. semitendinosus* [7] *m. rectus femoris* [8] *m. vastus lateralis* [9] *m. biceps femoris* [10] *m. infraspinatus* [11] *m. biceps femoris* [12] *m. tensor fasciae latae* [13] *m. gluteus medius* [14] *m. gluteus medius* [15] *m. longissimus thoracis et lumborum* [16] *m. psoas major* [17] *m. adductor femoris* [18] *m. semimembranosus*.

^{a,b,c} Values within a row with different superscripts differ significantly at $P<0.05$.

Blank spaces indicate cells without data.

Table 7 Predicted means (± SE[1]) for the effects of European conformation score (5 grades) on flavour liking for each muscle

Flavour liking	E	U	R	O	P
Blade[2]				56.8±3.04	
Chuck Tender[3]			42.1±6.96	46±3.370	
Cube Roll a[4]			51.3±6.96	60.1±3.37	
Cube Roll b[5]			61.5±6.96	62.9±3.37	
Eye round[6]		46.6±4.03	49.5±2.35	52.5±3.30	
Knuckle a[7]		58.3±5.12	51.8±1.8	52.4±1.68	58.5±5.13
Knuckle b[8]		49.2±9.78	42.9±5.73	42.8±4.54	
Silverside[9]		42.8±4.24	42.3±1.9	39.4±1.57	33.1±3.98
Blade[10]		60.2±9.96	53.1±3.32	58.3±3.19	62.0±5.89
Rump cap[11]		56.6±3.32	59.1±2.34	62.5±2.95	60.4±2.7
Rump tail[12]			58.6±6.96	49.2±3.37	
Eye of rump centre[13]	51.9^{ab}±7.67	52.4^{ab}±2.11	48.5^{a}±1.29	55.4^{b}±1.42	57.5^{b}±2.33
Eye of rump side[14]	43.1±7.66	56.7±4.66	56.9±2.01	52.4±3.32	
Shortloin[15]	55.5^{ab}±3.15	54.9^{a}±1.34	56.7^{ab}±1.04	58.4^{b}±1.19	60.2^{b}±2.01
Tenderloin[16]		71.1±3.21	74.8±1.64	72.9±1.56	79.0±3.98
Topside a[17]		49.4±7.08	42.6±2.70	42.4±3.91	41.9±5.12
Topside b[18]	49.1^{abc}±6.00	41.8^{a}±1.95	43.1^{ac}±1.20	46.0^{b}±1.33	47.3^{bc}±2.33

[1] Standard error.

[2] *m. triceps brachii caput laterale* [3] *m. supraspinatus* [4] *m. longissimus thoracis et lumborum* [5] *m. spinalis dorsil* [6] *m. semitendinosus* [7] *m. rectus femoris* [8] *m. vastus lateralis* [9] *m. biceps femoris* [10] *m. infraspinatus* [11] *m. biceps femoris* [12] *m. tensor fasciae latae* [13] *m. gluteus medius* [14] *m. gluteus medius* [15] *m. longissimus thoracis et lumborum* [16] *m. psoas major* [17] *m. adductor femoris* [18] *m. semimembranosus*.

[a,b,c] Values within a row with different superscripts differ significantly at $P<0.05$.

Blank spaces indicate cells without data.

Table 8 Predicted means (± SE[1]) for the effects of European fat score (5 grades) on tenderness for each muscle

	1	2	3	4	5
Blade[2]		47.9±9.87	46.4±6.00	55.7±8.26	
Chuck Tender[3]	24.2±7.03	28.3±6.89			
Cube Roll a[4]	53.7±7.03	52.4±6.89			
Cube Roll b[5]	64.6±7.03	69.8±6.89			
Eye round[6]	44.6±13.8	58.5±7.75	41.8±4.90	42.3±5.14	
Knuckle a[7]	47.1±6.25	46.0±4.96	45.7±4.22	56.3±7.02	
Knuckle b[8]	18.2±8.78	18.6±6.87	31.5±12.8		
Silverside[9]	18.4^{a}±6.25	24.9^{a}±5.05	20.3^{a}±4.18	35.6^{b}±5.82	28.7^{ab}±13.9
Blade[10]			57.0±4.79	75.6±9.80	69.4±13.9
Rump cap[11]		57.5±5.65	56.1±4.4	58.1±5.51	
Rump tail[12]	32.3±7.03	46.6±6.89			
Eye of rump centre[13]	36.1±6.25	43.6±4.52	46.0±4.04	47.3±4.37	34.4±11.2
Eye of rump side[14]	38.3^{ac}±10.1	42.8^{a}±5.83	53.9^{bc}±4.63	55.1^{bc}±5.85	66.3^{b}±9.61
Shortloin[15]	60.4±6.03	54.3±4.18	53.5±3.96	53.4±4.09	72.7±8.72
Tenderloin[16]	68.9^{a}±6.25	72.1^{a}±4.96	79.4^{b}±4.15	83.6^{b}±4.77	85.9^{ab}±13.9
Topside a[17]		32.3±7.46	31.1±4.82	38.2±7.47	
Topside b[18]	30.4±5.96	33.1±4.42	31.6±4.01	33.6±4.26	35.1±8.72

[1] Standard error.

[2] *m. triceps brachii caput laterale* [3] *m. supraspinatus* [4] *m. longissimus thoracis et lumborum* [5] *m. spinalis dorsil* [6] *m. semitendinosus* [7] *m. rectus femoris* [8] *m. vastus lateralis* [9] *m. biceps femoris* [10] *m. infraspinatus* [11] *m. biceps femoris* [12] *m. tensor fasciae latae* [13] *m. gluteus medius* [14] *m. gluteus medius* [15] *m. longissimus thoracis et lumborum* [16] *m. psoas major* [17] *m. adductor femoris* [18] *m. semimembranosus*.

[a,b,c] Values within a row with different superscripts differ significantly at $P<0.05$.

Blank spaces indicate cells without data.