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Review: The variability of the eating quality of beef can be reduced by predicting consumer satisfaction

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The Meat Standards Australia (MSA) grading scheme has the ability to predict beef eating quality for each 'cut × cooking method combination' from animal and carcass traits such as sex, age, breed, marbling, hot carcass weight and fatness, ageing time, etc. Following MSA testing protocols, a total of 22 different muscles, cooked by four different cooking methods and to three different degrees of doneness, were tasted by over 19 000 consumers from Northern Ireland, Poland, Ireland, France and Australia. Consumers scored the sensory characteristics (tenderness, flavor liking, juiciness and overall liking) and then allocated samples to one of four quality grades: unsatisfactory, good-every-day, better-than-every-day and premium. We observed that 26% of the beef was unsatisfactory. As previously reported, 68% of samples were allocated to the correct quality grades using the MSA grading scheme. Furthermore, only 7% of the beef unsatisfactory to consumers was misclassified as acceptable. Overall, we concluded that an MSA-like grading scheme could be used to predict beef eating quality and hence underpin commercial brands or labels in a number of European countries, and possibly the whole of Europe. In addition, such an eating quality guarantee system may allow the implementation of an MSA genetic index to improve eating quality through genetics as well as through management. Finally, such an eating quality guarantee system is likely to generate economic benefits to be shared along the beef supply chain from farmers to retailors, as consumers are willing to pay more for a better quality product.

Keywords: meat, palatability, modelling, genetics, economic impact

Implications

Delivering quality beef to the consumer relies upon both quantifying beef palatability and then accurately predicting that from information available at slaughter. The Meat Standards Australia (MSA) system has proved to be effective in predicting beef eating quality not only in Australia but also across a diverse range of countries and production systems in Europe. The implementation of the MSA index at the carcass level may offer new opportunities by calculating a potential 'eating value' for each carcass. Thus, the MSA index will give the possibility to improve eating quality through genetic selection and to reward processors and producers according to the carcass 'eating value', and thereby encouraging the *production of better quality* beef.

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Prospects for an eating quality-based grading system in Europe

The beef industry is facing a changing market place, with evolving consumer demands and competition from emerging and alternative sources of protein (Bonny *et al.*, 2015a). To remain competitive, the European beef industry must become more consumer-focussed, moving away from a basic, commodity type product, traded solely on price. For this to occur there must be ideological and structural changes throughout the supply chain, changing the type and amount of information flow between different sectors of the industry (Field *et al.*, 2007). Currently, there is a disconnection between the consumer and the producer within the European Union, with no available mechanism for delivering feedback from the consumer to the producer. This was highlighted by Normand *et al.* (2014) who found no clear relationship between the selling price of beef and its tenderness in France.

The lack of clear information about eating quality has been addressed in the domestic Australian beef industry with the MSA system (Polkinghorne *et al*., 2008), which uses carcass and animal factors, along with stress minimisation protocols to grade beef carcasses on expected eating quality. Briefly, the system has two components: pre-slaughter guidelines and grading information, which are used to generate eating quality grades for different cut by cooking method combinations. Registered producers follow on farm requirements governing nutrition and welfare in the last 2 weeks before slaughter and supply information on animal breed to the processor. Processors follow similar pre-slaughter protocols and combine the information supplied by the producer with information collected at slaughter and at grading (after 24 h post slaughter) to generate the eating quality grades. If a similar system was implemented in the European Union, it would facilitate demand linked to eating quality and price signals enabling beef producers to receive clear messages from consumers.

One marked difference between Australia and Europe is the measurements and records available at slaughter. The European carcass grading system scores every beef carcass in Europe for fat-cover and conformation, and due to the relationship between this score and carcass fatness and yield (Indurain *et al*., 2009; Allais *et al*., 2010), the potential of this score to add value to an eating quality prediction system was investigated. In addition, while carcass maturity is estimated by ossification score in Australia, European processors have access to chronological age of each animal slaughtered. It is of interest to both industries to determine which of these measures has the strongest relationship with eating quality.

By allowing the average consumer to create the definition of beef eating quality, as is done within the MSA system, the industry can be confident that quality grades actually reflect a consumer's eating experience (Watson *et al*., 2008a). An MSA-like quality-based grading system in Europe would reduce the variability in beef quality for consumers and provide a price signal to encourage the production of quality beef. However, for such a system to be implemented, it must be adapted to the European consumers and beef production systems. This review assesses the suitability of an MSA-like system for European consumers, and the ease with which it could be integrated into Europe, based on the existing measures, and the additional new measures that may be required. The review will also highlight the economic value of implementing a system of this type. Research into this area has been ongoing since 2005 and this paper presents the conclusions from this and other work with regards to grading beef for eating quality in the European Union. Preliminary results were presented at the 67th annual meeting of the European Association for Animal Production (Bonny *et al*., 2016a).

Quality in the European Union

Currently in the European Union, there is no standardised provision for beef grading on the basis of eating quality. The European carcass grading system (EUROP), which is mandatory, was never designed to give an indication of eating quality, but provides a grade for carcass conformation and fatness (Anonymous, 1982). This allows destination markets to make their own decisions on what constitutes 'quality', though in practice, this system has encouraged the production of high yielding, low fat carcasses, as producers respond to this price signal. The system also allows sectors to apply their own standards and requirements on top of the carcass grading system. Official quality labels (such as Label Rouge in France) and branded products such as Waitrose in the United Kingdom and Charal in France have a 'pathways' type approach to quality, proscribing certain production techniques in addition to minimum fatness and conformation scores (Codron *et al*., 2005; Charal, 2013). Other labels, such as the European Protected Geographical Indication and European Protected Designation of Origin, indicate that the product comes from a certain region and/or was produced using a specific technique (Anonymous, 2017). Importantly, these European labels confer no information as to the expected eating quality of the product and only occupy around 5% of the market in France (Hocquette *et al*., 2013) while significant variation in the quality of beef still exists in Europe, partly underpinning the continuous decline in beef consumption (FAO, 2015).

Clearly, an opportunity exists for adopting an MSA-like eating quality system in the European market. However, the existing MSA system may not be seamlessly applicable as it was designed for the Australian beef industry, and as such focusses on carcass measurements, cattle breeds and sexes that are common in Australia (Watson *et al*., 2008b). Furthermore, European beef itself is derived from a diverse range of production systems and climates (Peel *et al*., 2007), consumers and cultures that differ markedly to those in Australia. Therefore, it is essential to investigate how these differences will influence the design of an eating quality-based grading system in Europe.

Can we guarantee eating quality for the European consumer?

Previous research has confirmed that European consumers would be responsive to an eating quality guarantee system similar to the MSA system (Verbeke *et al*., 2010). However, the system would need to be simple and accurate as it will be competing with numerous pre-existing quality labels in the market (Hocquette *et al*., 2011). This is despite the fact that these labels are more directed to extrinsic quality traits and none really guarantees eating quality specifically. In addition, it must be questioned whether a single descriptor of eating quality would be applicable to all consumers, with the wide variety of branded products on the market targeting different consumer groups, and the diverse range of cultures that coexist within and between the different member states of the European Union,.

A consumer's eating experience is one of the biggest determinants of repeat purchase intent, and as such, vital in maintaining, or growing market share for the beef industry (Morgan *et al*., 1991). Therefore, the most important goal for a grading system based on eating quality is to accurately identify beef of unsatisfactory quality. This unsatisfactory beef can then be directed away from the fresh beef market, thereby providing the consumer with a more consistent experience and more confidence in buying beef. The risk of a consumer having a negative eating experience with beef was investigated by Bonny *et al.* (2017b) who analysed consumer scores of over 19 000 samples from 22 different muscles of European beef in France, Poland, Ireland and Northern Ireland. It was found that the chances of a consumer having a negative eating experience was on average 26%, though this varied by cut and cooking method. The same experiment found that, with a single score, unsatisfactory beef could be identified with 80% accuracy. If this beef could be identified before sale, then the chances of a consumer having a negative eating experience would decrease from around 25% to 7% (Figure 1). This alone would be hugely beneficial to the European beef industry.

When determining quality grades for European consumers, tenderness was slightly more important than flavour liking, and much more important than juiciness, though this did vary between countries (Bonny *et al.*, 2017b). The relative importance of the sensory attributes of beef in determining quality grades has shifted slightly in Australia over the last decade. This is evidenced by the evolution of the weightings for tenderness, juiciness, flavour liking and overall liking, used in the MSA system, in which the relative weighting for tenderness (previously 0.4) has decreased to 0.3, the same as that applied to flavour and overall liking (previously 0.2 and 0.3) (Watson *et al.*, 2008a; Thompson *et al.*, 2010). It is possible that the MSA system itself is responsible for this reduced weighting, with the controls imposed reducing the variation in tenderness evidenced within Australian beef at the point of consumption. On this basis, the relative importance of the other descriptors (i.e. flavour and juiciness) would be enhanced. Understanding the relative contribution of different traits to the evaluation of eating quality by consumers would allow the development of successful, high-value, niche products in the beef industry. This highlights the importance of continued consumer testing to ensure the grades remain linked to consumer expectations (Watson *et al.*, 2008a; Thompson *et al.*, 2010).

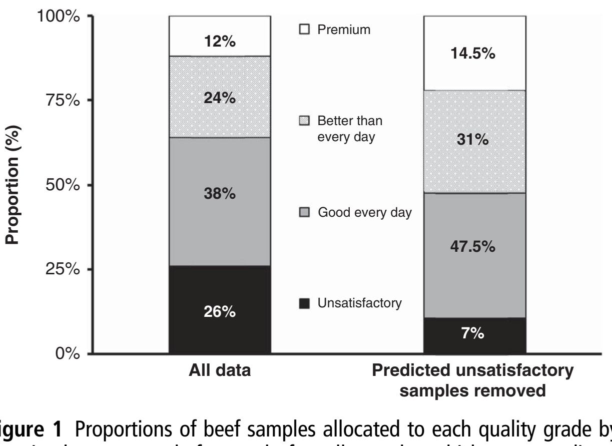

Figure 1 Proportions of beef samples allocated to each quality grade by untrained consumers before and after all samples which were predicted as unsatisfactory were removed. Adapted from Bonny *et al.* (2016a).

Consumer scores were also consistent between different European demographic groups (Bonny *et al.*, 2017a and 2017b), similar to previous work in other countries (Hwang *et al.*, 2008; Watson *et al.*, 2008a; Thompson *et al.*, 2010). As was seen in Australia, Bonny *et al.* (2017a) found that the biggest influence on sensory scores across Europe was how important consumers considered red meat in their diet. Consumers considering meat more important scored beef more favourably than consumers who considered red meat as less important in their diet. However, the differences found were small, between 1 and 3 points out of 100. These small differences are unlikely to affect the accuracy of a grading system based on eating quality. This demonstrates that a single grading system could accurately categorise beef into quality grades for the entire market, serving consumers across all demographic categories. However, further work in additional countries, such as new collaborative partners in Italy and Spain, will help to characterise these relationships in different cultural groups.

Ease of adoption of an eating quality-based grading system in Europe

Previous experience with the implementation of the MSA system in Australia has shown that an eating quality-focussed grading system needs to be demand-driven, starting with retailers, before significant commercial advantages can be made throughout the supply chain (Polkinghorne *et al.*, 2008). This is because, ultimately, consumer demand for quality beef is expressed through sales at retail. It is also the initial source of price signals. Price differentials at retail will drive increased demand for this product from processors who will ultimately pass this value back to producers as they compete more strongly for the cattle that deliver this premium quality meat. This process was seen during the development of the Australian MSA system, which now commands an average AUD$ 0.32/kg premium for MSA-graded carcasses, which delivered a total of AUD$ 185 million extra to Australian farmers in 2014/2015 (MLA, 2016). However, the notion that the MSA system can be directly implemented in the European Union would be naïve, particularly given that this system has been specifically designed for Australian cattle and local production systems. The Australian production system and cattle breeds are, in many ways, quite different to those present in the European industry. Nevertheless, several studies have shown that MSA, with or without some adaptation, can be applied to European beef and improve eating quality (Farmer *et al.*, 2009; Hocquette *et al.*, 2011; Legrand *et al.*, 2013). This highlights the fact that there are many relevant areas of overlap between the two industries and opportunities for new grading measurements.

Relevance of existing measures of eating quality in Europe

Around the time of slaughter, there is a wide array of information available to producers and processors within the European Union, and some of this information has the potential to add precision and accuracy to an eating quality-based grading system. One example of routinely collected information is the European carcase grading scores (conformation and fatness) which are recorded on every carcass slaughtered in the European Union (Anonymous, 2009). Furthermore, all carcasses have a 'European passport' which includes information about breed, sex and chronological age with a precision of 1 day (Anonymous, 2009). Investigating this information was prioritised as there is evidence that breed and sex affect the eating quality of beef (Dransfield *et al.*, 2003). In addition, there were some concerns that the EUROP conformation score might have a negative relationship with eating quality due to the positive relationship between this score and lean meat yield (Oliver *et al.*, 2010).

Whilst correlated with yield, Bonny *et al.* (2016c) demonstrated that the European conformation score had no relationship with eating quality, confirming other results (Guzek *et al.*, 2013). On this basis, the last 30 years of selection to optimise conformation and fat scores are unlikely to have impacted eating quality, although this may have affected eating quality by reducing marbling. Importantly, this means that the continued use of these scores for carcass classification and price reporting will not contradict efforts to improve the eating quality of beef. However, this also indicates that the European carcase grading system will not help to predict eating quality.

The vast majority of the data underpinning the MSA system comes from steers or heifers of British breeds (*Bos taurus*) such as Aberdeen-Angus and Hereford, or *Bos indicus*, or crosses between these breeds (Watson *et al.*, 2008b). In contrast, in Europe, all cattle are *B. taurus*. Within France and Poland, cows and/or young bulls of both beef and dairy breeds are the biggest contributors to beef production, with heifers only contributing around 14%, and steers even less. Alternatively, steers are very important in Ireland and Northern Ireland, consisting of ~38% of the annual kill, with heifers at 27%, and almost no bulls (De Roest, 2015). Therefore, it is essential to investigate the ability of the MSA model to predict consumer scores from bulls and dairy animals.

Dairy breeds make up a significant proportion of beef production in the European Union (De Roest, 2015). Differences between dairy and beef breeds (Lizaso *et al.*, 2011) and across beef breeds (Cuvelier *et al.*, 2006) have been well documented, though most differences, such as carcass weight and intramuscular fat (IMF) content could be accounted for with standard carcass measurements (marbling and hot carcass weight) at slaughter. However, the results from Bonny *et al.* (2016b) demonstrated that, even after correcting for these standard carcase measurements, a number of cuts from dairy breeds still had better eating quality scores than those from beef breeds, confirming a previous study indicating a higher flavour for the Holstein breed compared with the Salers breed (Jurie *et al.*, 2007). This indicates that a positive adjustment for dairy breed type would be important in a future European grading system. Moreover, as the breed information is available to the industry, it would cost very little to record. It is important to note that the magnitude of the effect varied by muscle in this study, being up to 7 points for some cuts and nil for others. This may be a result of true variation between muscles or a reflection of differences in the amount of data available for certain muscles, either in the European database or the Australian database. It is important to note that the effect of muscle type on eating quality explains far more of the variation in eating quality than breed, or indeed than any of the other factors discussed in this paper (Jurie *et al.*, 2007). Therefore, further work in both continents to address the limited data available within some muscles would increase the accuracy of the grading system in both Australia and the European Union.

Sex is also a factor known to influence the eating quality of meat (Boccard *et al.*, 1979; Seideman *et al.*, 1989; Chriki *et al.*, 2013), yet in the Australian MSA system young bulls are not represented as they are rare in Australia. By contrast, in the European Union, young bulls are an important production class (De Roest, 2015), highlighting the need to establish the eating quality of this class of cattle. The work of Bonny *et al.* (2016b) demonstrated that bulls had a slightly lower eating quality than females after correction for other carcass measurements. Similar to breed, this information is readily available at slaughter, thus costing relatively little to incorporate this information and achieve the gains in accuracy in an eating quality-based grading system. Eating quality price signals that differentiate between sexes would also allow producers to make informed production decisions regarding management practices such as castration. In addition, leaving males entire increases carcass yield via their 'natural' level of growth promotion, and aligns with improved animal welfare practices which are likely to reduce the practice of castration in future years (Stafford and Mellor, 2005).

The final item of information uniquely available within the European production system is chronological age. This is important because as animals mature, the tenderness of their meat decreases, particularly due to collagen cross-linking (Bailey, 1985). On this basis, it is vital that an estimate of physiological maturity is included in any system predicting eating quality. At present, the MSA system uses a proxy for animal maturity called ossification score, which is a measure of bone maturity (Watson *et al.*, 2008b). This is not recorded within the European Union, yet could be replaced by animal age which is routinely collected by farmers and reported to processors within the EU (Anonymous, 2009). One potential strength of this is that in contrast to chronological age ossification score increases with age before reaching a plateau when animals reach their physiological maturity (Figure 2). Therefore (Bonny *et al.*, 2016d), explored chronological age as an alternative descriptor of maturity and demonstrated that it has no relationship with eating quality for carcasses <3 years old. In contrast, in older skeletally mature cattle, animal age had a stronger relationship with eating quality than ossification score. This represents an important consideration within the European Union because different

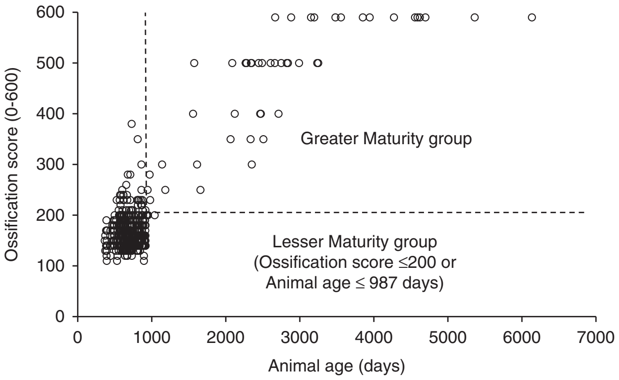

Figure 2 Relationship between animal age and ossification score (an indicator of physiological maturity). As a consequence of the plateau in ossification score for the more mature animals, animal age is more appropriate for carcasses with greater maturity. However, for the animals with lesser maturity ossification score is a better predictor of eating quality. Adapted from Bonny *et al.* (2016d).

countries make far greater use of older animals. Indeed, mature cattle comprise ~60% of the cattle slaughtered annually in the European Union (De Roest, 2015). While young cattle are more commonly associated with prime beef production, classifying older cattle is still relevant. Bonny *et al.* (2016d) showed that carcases from extremely mature cows, above 10 years of age, still produced some cuts of beef with acceptable eating quality. Therefore, correctly evaluating the eating quality of beef from all carcasses, including young and mature ones, will require knowledge of both animal age and ossification score. This will ensure that all quality beef is identified and delivered to the consumer at a price reflecting eating quality, maximising value and reducing waste in the industry. However, further investigation is required to evaluate the eating quality of beef from mature carcasses as there were only limited numbers in this study (Bonny *et al.*, 2016d).

Potential for new measures of eating quality in Europe

For the implementation of an eating quality-based grading system in the European Union, it is likely that a number of new carcass measurements would be needed. If the MSA system is taken as a starting point, then the major additions to data already recorded at slaughter in the European Union would be marbling score, ossification score, and finally, ultimate pH, which is already recorded by some abattoirs (Watson *et al.*, 2008b). The introduction of these new grading scores would require extensive training of carcass graders, the development of technologies to automate the grading process, or more likely a combination of the two. In addition, as technologies improve and new discoveries emerge, the inputs to the grading system should continuously evolve to ensure that relevance to the industry is maintained and to improve the precision and the accuracy of the prediction of eating quality, as has occurred with the MSA system (Watson *et al.*, 2008a).

However, not all measures previously studied are relevant to consumers. Thus, within muscles, there were small or no relationships between biochemical measurements of IMF, collagen, moisture and haem iron content with untrained consumer scores for beef quality (Bonny *et al.*, 2015b). Alternatively, when compared between muscles, these measures had strong relationships with eating quality, explaining a large proportion of the well-known differences in beef eating quality between cuts. Therefore, biochemical profiling of muscles may reduce the need for expensive consumer testing, by allowing the extrapolation of results to other muscles of similar biochemical profile (Seggern *et al.*, 2005). However, within muscles, these measurements are likely to provide little extra predictive power for determining eating quality as previously shown with trained panellists (Chriki *et al.*, 2013).

Research is also currently underway looking into automated carcass grading technology (Ferguson, 2004; Craigie *et al.*, 2012; Prieto *et al.*, 2014). Automated grading technologies also have the potential to record other carcass measurements that have the potential to improve the accuracy of a quality-based meat grading system. Investment into automated grading would reduce the costs of individual carcass measures, such as marbling and ossification, when compared with the labour intensive visual grading currently used in Australia. With automated grading, these measures would be more feasible in new markets and more easily integrated into the beef industry in the European Union. For example, the majority of processors are, at present, already utilising Video Image Analysis systems to grade carcasses for the European fat and muscling scores (Craigie *et al.*, 2012).

Possibilities for genetics and breeding for eating quality

The mean heritability coefficient (h^2) for the tenderness score is around 0.24, while for juiciness and flavour scores, heritability is as low as 0.11 and 0.09, respectively (reviewed by Hocquette *et al.*, 2006). Therefore, it seems that only small genetic gains would be achieved by selecting on these traits alone. Phenotypic traits such as IMF, carcass weight and ossification score (which combined form a proxy for growth rate) have a large impact on the palatability score in the MSA grading scheme (Watson *et al.*, 2008b). These traits also have a moderate to strong genetic component with heritabilities of ~0.32 to 0.93 (mean of 0.50 for IMF) and 0.18 to 0.31 (mean of 0.25 for growth rate), respectively, depending on the cohort studied (Shackelford *et al.*, 1994). This implies that eating quality can be improved indirectly through targeted breeding programmes and genetic selection in favour of traits that are easier to assess routinely (such as marbling), have a high h^2 value and a large impact on sensory quality. Indeed, both IMF content and marbling score have high genetic correlations with tenderness (r_G is around 0.4 to 0.5). However, the effect of selection on these factors must be considered. For example, selection on the basis of IMF or marbling without considering carcass fatness will have counterproductive effects on lean meat yield due to a positive genetic correlation between marbling and carcass fatness (r_G between these two traits being around 0.4) (Hocquette *et al.*, 2006).

In recent decades, many research programmes have searched for genetic markers, such as single nucleotide polymorphisms (SNPs) in specific genes known to be related to beef sensory qualities. Early programmes aimed at detecting genome regions called quantitative trait loci (QTL) which harbour mutations related to quality traits via the joint analysis of phenotype variability and marker polymorphisms located on the whole genome. The detection and fine mapping (3 to 4 cM) of numerous QTLs has been performed with association analyses looking at SNPs and phenotypes in a large number of animals in France and Australia. These studies were performed first by gene candidate approaches and then by genome-wide analysis, which is limited by the significant proportion of false positives. Nevertheless, the discovery of SNPs associated to QTLs known to be related to beef sensory qualities (Allais *et al.*, 2011 and 2014) can be used to implement marker assisted selection or genomic selection, once the set of markers were validated in independent populations. However, it is important to note that with selection pressure, the apparent associations between SNPs and phenotypic traits are likely to be weakened with time. This is due to the natural recombination between genetic markers used in the genomic selection and causal mutations on specific genes which are biologically associated with beef sensory qualities. This problem can be minimised by using a high density array to increase the numbers of SNPs utilised for selection. The higher the density, the higher is the probability that the SNP's used are in close association with actual causal mutations (reviewed by Picard *et al.*, 2015).

The MSA grading scheme offers new potential opportunities. In Australia, the beef industry has responded to the potential for genetic gain in the area of eating quality with the creation of the MSA index (McGilchrist *et al.*, personal communication). This index combines the MSA grading results for individual muscles from carcasses, multiplied by the proportion of that cut within the carcass, to provide a single score of potential eating quality for the entire carcass (Figure 3). The most common cooking method for each cut is used, and for the calculation of the index, a hypothetical 5 days ageing and Achilles suspension is applied to the whole carcass.

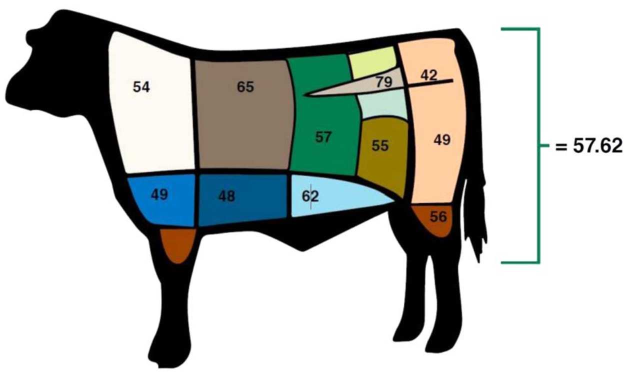

Figure 3 (colour online) An illustration of the Meat Standards Australia (MSA) carcass index. The quality score of each cut, for the best cooking method, and a standard 5 days ageing and Achillies hanging method is calculated. This score is multiplied by the proportion of that cut within the carcass, and summed with all the others to form the final index score. Adapted from McGilchrist *et al.* (personal communication).

Preliminary work in Australia has indicated that higher heritabilities can be achieved for this carcass index with untrained consumers and MSA taste panel protocols than for sensory scores alone. As a result, research in Australia is currently underway to link MSA eating quality scores with estimated breeding values, which is essential to enable producers to include eating quality as part of their breeding strategy. The MSA index is also affected by management prior to slaughter through nutrition and associated growth paths and decisions regarding the use of hormonal growth promoters. The producer is consequently provided with an indicator of his total contribution to eating quality reflecting his choice of genetic material and subsequent management to slaughter. The Index is additional to other mandatory data for all grading inputs used in MSA-graded carcasses in Australia.

Economic impact

Review of added value in Australia

The success of the Australian MSA system has come from the economic benefits related to supplying better quality beef to consumers (Polkinghorne *et al.*, 2008; Griffith and Thompson, 2012). As consumers were willing to pay more for a better quality product, the price differential enabled the industry to use premiums to reward processors and producers, thereby encouraging the production of better quality beef. The last extensive review of the MSA system was performed in 2011. At that stage, the cumulative benefit of the system to the Australian beef industry (producers, processors, retailers, etc.) was AUD$ 523 million (Griffith and Thompson, 2012). After accounting for the costs of research and development and implementation, the net benefit up to 2011 was AUD$ 200 million. In 2016, there was an average price premium for MSA compliant carcasses of AUD$ 0.24/kg, and an average retail premium of AUD$ 4.33/kg for tenderloin (Figure 4). For the

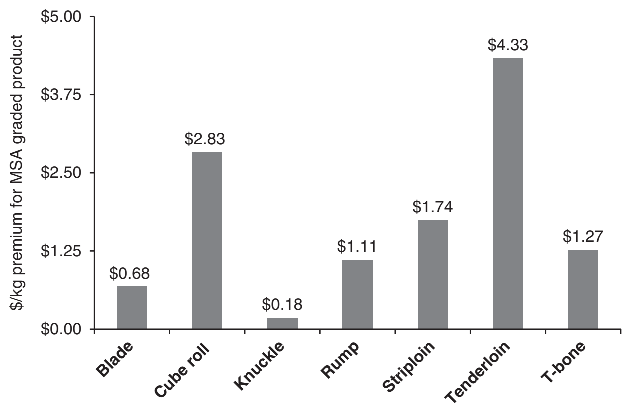

Figure 4 Average price differentials (AUD$) for Meat Standards Australia (MSA)-graded beef by cut in the 2015/16 financial year in Australia (from MLA, 2016). As reported by Meat Livestock Australia in their reports (MLA, 2016), 1100 independent butcher surveys were conducted during one financial year by Millward Brown. Then, differences between the average prices for MSA-cuts and non-MSA cuts were calculated for cube roll, knuckle, rump, striploin, tenderloin, T-bone and blade.

2015/16 financial year, there was an estimated additional AUD$ 153 million returned to the farm gate from retail premiums for 3.1 million MSA-graded carcasses (MLA, 2016). This can be further broken down to an average of AUD$ 66/head for grass fed and AUD$ 45/head for grain fed cattle.

Expected added value in Europe

Consumer surveys (Bonny *et al.*, 2017a) suggest that Europeans are willing to pay similar premiums for better quality beef to Australian consumers for better quality beef (Figure 5). We have also shown that a grading system based on eating quality would perform well for European consumers, allowing price differentials for different quality grades of beef at the point of sale (Bonny *et al.*, 2017a and 2017b). The combination of these two factors would imply that there would be a similar price premium in abattoirs for carcasses complying with the grading system in both Australia and the EU. This price premium for carcasses would then be expected to encourage the production of quality beef, as has been seen in the Australian domestic cattle industry.

If we say that the average wholesale price per kg is AUD$ 5.50 from Australian sources (MLA website, 2017) then a AUD$ 0.30 premium is 5.5% over the standard non-MSA carcass price. Assuming that the average price per kg in the European Union is €3.80, a 5.5% premium is €0.21 (EuroSTAT website). To extend this to the whole of the European market, it is noted that the EU produced ~7.5 million tonnes of beef in 2015. If we make a conservative estimate that half of the beef produced is graded and meets specification, then the total value of a quality-based grading system that would flow through the farm gate to producers would be €787.5 million. For only one-quarter of the total volume of beef produced, the value for producers would be €393.75 million. As such, the value of a system to the industry as a whole, including processors and retailers, would be expected to be even higher.

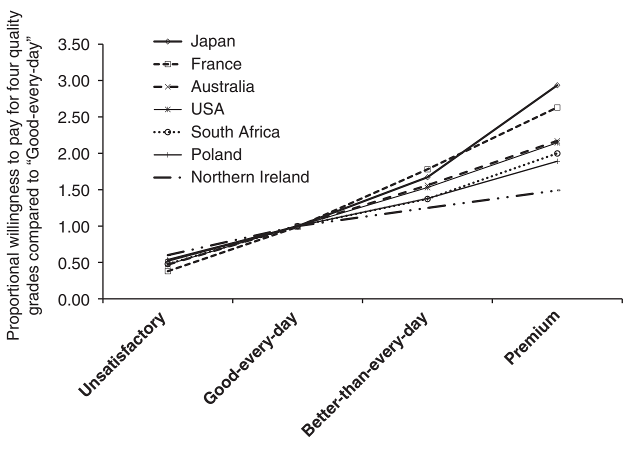

Figure 5 Proportional willingness to pay of consumers for four quality grades of beef for seven countries. Adapted from Bonny *et al.* (2017a), Thompson *et al.* (2010), Smith *et al.* (2008) and Polkinghorne *et al.* (2011).

Conclusion

There is limited information on the eating quality of beef available to the European consumer at the point of sale. This is particularly relevant for the mass market, which is not supported by existing quality labels. All the key factors identified in the MSA system have been examined in this review, in addition to other factors specifically relating to the European industry. The major technical barrier to the implementation of an eating quality-based grading system for beef within the European Union is the need for additional carcass measurements. This could be mitigated by designing a system using measures which are currently available, and then phasing-in additional information over several years, with support from governments and industry bodies.

In addition, further work is currently underway to improve the prediction of eating quality in France and Poland, with plans to undertake consumer testing in other European counties. It is important that both cattle and consumers from all participating countries are evaluated as the European Union contains a diverse array of cultures and practices which may influence the production and evaluation of beef quality.

Becoming more consumer-focussed and meeting consumer demands for quality is essential as the global beef industry faces a changing market and competition from emerging sectors. The results described in this review indicate that an MSA-style grading system would function well with European cattle and would predict eating quality as experienced by European consumers with reasonable accuracy. By identifying quality beef before sale, it can be priced appropriately for its purpose, as determined by the quality grades: unsatisfactory, good-every-day, better-than-every-day and premium. This then encourages farmers to change their practices to improve average beef quality while simultaneously increasing demand for beef by reducing the variability in eating quality experienced by consumers and allowing them to choose beef of a desired quality level. Finally, grading beef on the basis of eating quality would provide an additional framework to encourage and facilitate the genetic improvement of eating quality with financial rewards for quality and a whole-carcass eating-quality index for genetic selection.

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Declaration of interest

The authors have declared to have no conflict of interest.

Ethics statement

No approval of the presented work by an ethics committee or no compliance with national legislation are required for this review article.

Software and data repository resources

Data mentioned in this review article and previously described in previous publications have not be deposited in an official repository.

References

Allais S, Journaux L, Levéziel H, Payet-Duprat N, Raynaud P, Hocquette JF, Lepetit J, Rousset S, Denoyelle C, Bernard-Capel C and Renand G 2011. Effects of polymorphisms in the calpastatin and μ-calpain genes on meat tenderness in three French beef breeds. Journal of Animal Science 89, 1–11.

Allais S, Levéziel H, Hocquette JF, Rousset S, Denoyelle C, Journaux L and Renand G 2014. Fine mapping of quantitative trait loci of meat sensory quality traits in three French beef breeds. Journal of Animal Science 92, 4329–4341.

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. Beef Carcass Classification regulations. In Commission of the European communities, Brussels, Belgium.

Anonymous 2009. Identification of bovine animals. In Health and Consumers European Commission. Retrieved on 19 February 2018 from http://ec.europa.eu/food/animal/identification/bovine/index_en.htm

Anonymous 2017. EU agricultural product quality policy. In Agriculture and Rural Development European Commission. Retrieved on 19 February 2018 from http://ec.europa.eu/agriculture/quality/

Bailey AJ 1985. The role of collagen in the development of muscle and its relationship to eating quality. Journal of Animal Science 60, 1580–1587.

Boccard RL, Naudé RT, Cronje DE, Smit MC, Venter HJ and Rossouw EJ 1979. The influence of age, sex and breed of cattle on their muscle characteristics. Meat Science 3, 261–280.

Bonny SPF, Gardner GE, Pethick DW and Hocquette J-F 2015a. What is artificial meat and what does it mean for the future of the meat industry? Journal of Integrative Agriculture 14, 255–263.

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

Bonny SPF, Gardner GE, Pethick DW, Legrand I, Wierzbicki J, Allen P, Farmer LJ, Polkinghorne RJ and Hocquette JF 2016a. The variability of European beef can be reduced by predicting consumer satisfaction. Book of abstract of the 67th European Association for Animal Production, 29th August to 2nd September, Session 05, Theatre 10, Belfast, UK, p. 133.

Bonny SPF, Hocquette J-F, Pethick DW, Farmer LJ, Legrand I, Wierzbicki J, Allen P, Polkinghorne RJ and Gardner GE 2017a. Untrained consumer assessment of the eating quality of beef: 2. Demographic factors have only minor effects on consumer scores and willingness to pay. Animal 11, 1399–1411.

Bonny SPF, Hocquette J-F, Pethick DW, Farmer LJ, Legrand I, Wierzbicki J, Allen P, Polkinghorne RJ and Gardner GE 2016b. The variation in the eating quality of beef from different sexes and breed classes cannot be completely explained by carcass measurements. Animal 10, 987–995.

Bonny SPF, Hocquette JF, Pethick DW, Legrand I, Wierzbicki J, Allen P, Farmer LJ, Polkinghorne RJ and Gardner GE 2017b. Untrained consumer assessment of the eating quality of beef: 1. A single composite score can predict beef quality grades. Animal 11, 1389–1398.

Bonny SPF, Pethick DW, Legrand I, Wierzbicki J, Allen P, Farmer LJ, Polkinghorne RJ, Hocquette J-F and Gardner GE 2016c. European conformation and fat scores have no relationship with eating quality. Animal 10, 996–1006.

Bonny SPF, Pethick DW, Legrand I, Wierzbicki J, Allen P, Farmer LJ, Polkinghorne RJ, Hocquette JF and Gardner GE 2016d. Ossification score is a better indicator of maturity related changes in eating quality than animal age. Animal 10, 718–728.

Charal 2013. Charal High Quality Standards. In Charal Corporation, France. Retrieved on 19 February 2018 from http://www.charal.com/en/high-quality-standards.html

Chriki S, Renand G, Picard B, Micol D, Journaux L and Hocquette J-F 2013. Meta-analysis of the relationships between beef tenderness and muscle characteristics. Livestock Science 155, 424–434.

Codron J-M, Giraud-Héraud E and Soler L-G 2005. Minimum quality standards, premium private labels, and European meat and fresh produce retailing. Food Policy 30, 270–283.

Craigie CR, Navajas EA, Purchas RW, Maltin CA, Bünger L, Hoskin SO, Ross DW, Morris ST and Roehe R 2012. A review of the development and use of video image analysis (VIA) for beef carcass evaluation as an alternative to the current EUROP system and other subjective systems. Meat Science 92, 307–318.

Cuvelier C, Cabaraux JF, Dufrasne I, Clinquart A, Hocquette JF, Istasse L and Hornick JL. 2006. Performance, slaughter characteristics and meat quality of young bulls from Belgian Blue, Limousin and Aberdeen Angus breeds fattened with a sugar-beet pulp or a cereal-based diet. Animal Science 82, 125–132.

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, Session 21, Theatre 8, Warsaw, Poland, p. 230.

Dransfield E, Martin JF, Bauchart D, Abouelkaram S, Lepetit J, Culioli J, Jurie C and Picard B 2003. Meat quality and composition of three muscles from French cull cows and young bulls. Animal Science 76, 387–399.

FAO 2015. OECD-FAO Agricultural Outlook 2015–2024. OECD Publishing, Paris. Retrieved on 19 February 2018 http://dx.doi.org/10.1787/agr_outlook-2015-en

Farmer LJ, Devlin DJ, Gault NFS, Gee A, Gordon AW, Moss BW, Polkinghorne R, Thompson J, Tolland ELC and Tollerton IJ 2009. Prediction of eating quality using the Meat Standards Australia system for Northern Ireland. In Proceedings of the 55th International Congress of Meat Science and Technology (ed. S Støier, AG Koch, N Oksbjerg, A Karlsson, SE Sørensen, H Wegener, L Skibsted, A Gunvig and L Nannerup) Copenhagen, Denmark, 16 to 21 August 2009, Meat Science 84(2), 227–313.

Ferguson DM 2004. Objective on-line assessment of marbling: a brief review. Australian Journal of Experimental Agriculture 44, 681–685.

Field T, Lemenager R, Long B, Gardiner H and Suttee H 2007. The future of information dissemination to the beef cattle industry. Journal of Animal Science 85, 156–157.

Griffith GR and Thompson JM 2012. The aggregate economic benefits to the Australian beef industry from the adoption of meat standards Australia: updated to 2010/11. Australasian Agribusiness Review 20, 11–38.

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.

Hocquette J-F, Legrand I, Jurie C, Pethick DW and Micol D 2011. Perception in France of the Australian system for the prediction of beef quality (Meat Standards Australia) with perspectives for the European beef sector. Animal Production Science 51, 30–36.

Hocquette J-F, Jacquet A, Giraud G, Legrand I, Sans P, Mainsant P and Verbeke W 2013. Quality of food products and consumer attitudes in France. In Consumer attitudes to food quality products: emphasis on Southern Europe (ed. M Klopčič, A Kuipers and J-F Hocquette), pp. 67–82. Wageningen Academic Publishers, Wageningen, the Netherlands.

Hocquette JF, Renand G, Levéziel H, Picard B and Cassar-Malek I 2006. The potential benefits of genetics and genomics to improve beef quality. Animal Science Papers and Reports 24, 137–189.

Hwang IH, Polkinghorne R, Lee JM and Thompson JM 2008. Demographic and design effects on beef sensory scores given by Korean and Australian consumers. Australian Journal of Experimental Agriculture 48, 1387–1395.

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

Jurie C, Picard B, Hocquette J-F, Dransfield E, Micol D and Listrat A 2007. Muscle and meat quality characteristics of Holstein and Salers cull cows. Meat Science 77, 459–466.

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.

Lizaso G, Beriain MJ, Horcada A, Chasco J and Purroy A 2011. Effect of intended purpose (dairy/beef production) on beef quality. Canadian Journal of Animal Science 91, 97–102.

MLA 2016. Meat Standards Australia, Annual Outcomes 2015–2016. Meat Standards Australia, Sydney, Australia. Retrieved on 20 March 2018 from https://www.mla.com.au/globalassets/mla-corporate/marketing-beef-and-lamb/documents/meat-standards-australia/msa-aor-2016_2017-lr.pdf

Morgan JB, Savell JW, Hale DS, Miller RK, Griffin DB, Cross HR and Shackelford SD 1991. National beef tenderness survey. Journal of Animal Science 69, 3274–3283.

Normand J, Rubat E, Evrat-Georgel C, Turin F and Denoyelle C 2014. A national survey of beef tenderness in France. Viandes et produits carnés VPC-2014-30-5. Retrieved on 20 March 2018 from http://www.viandesetproduitscarnes.fr/phocadownload/vpc_vol_30/3052_normand_enquete_nationale_tendrete.pdf

Oliver A, Mendizabal JA, Ripoll G, Albertí P and Purroy A 2010. Predicting meat yields and commercial meat cuts from carcasses of young bulls of Spanish breeds by the SEUROP method and an image analysis system. Meat Science 84, 628–633.

Peel MC, Finlayson BL and McMahon TA 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 11, 1633–1644.

Picard B, Lebret B, Cassar-Malek I, Liaubet L, Berri C, Le Bihan-Duval E, Hocquette JF and Renand G 2015. Recent advances in omic technologies for meat quality management. Meat Science 109, 18–26.

Polkinghorne R, Philpott J, Gee A, Doljanin A and Innes J 2008. 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, 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.

Prieto N, López-Campos O, Zijlstra RT, Uttaro B and Aalhus JL 2014. Discrimination of beef dark cutters using visible and near infrared reflectance spectroscopy. Canadian Journal of Animal Science 94, 445–454.

Seggern DDV, Calkins CR, Johnson DD, Brickler JE and Gwartney BL 2005. Muscle profiling: characterizing the muscles of the beef chuck and round. Meat Science 71, 39–51.

Seideman SC, Cross HR and Crouse JD 1989. Carcass characteristics, sensory properties and mineral content of meat from bulls and steers. Journal of Food Quality 11, 497–507.

Shackelford SD, Koohmaraie M, Cundiff LV, Gregory KE, Rohrer GA and Savell JW 1994. Heritabilities and phenotypic and genetic correlations for bovine postrigor calpastatin activity, intramuscular fat content, Warner-Bratzler shear force, retail product yield, and growth rate. Journal of Animal Science 72, 857–863.

Smith GC, Tatum JD and Belk KE 2008. International perspective: characterisation of United States Department of Agriculture and Meat Standards Australia systems for assessing beef quality. Australian Journal of Experimental Agriculture 48, 1465–1480.

Stafford KJ and Mellor DJ 2005. The welfare significance of the castration of cattle: a review. New Zealand Veterinary Journal 53, 271–278.

Thompson J, Polkinghorne R, Gee A, Motiang D, Strydom P, Mashau M, Ng'ambi J, deKock R. and Burrow H 2010. Beef palatability in the Republic of South Africa: implications for niche-marketing strategies. In ACIAR Technical Reports, Australian Centre for International Agricultural Research ACIAR, Canberra, ACT, Australia, pp. 1–56.

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

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