CSIRO PUBLISHING

www.publish.csiro.au/journals/ajea *Australian Journal of Experimental Agriculture*, 2008, **48**, 1351–1359

Evolution of the Meat Standards Australia (MSA) beef grading system

R. Polkinghorne[A,F], *J. M. Thompson*[B], *R. Watson*[C], *A. Gee*[D] *and M. Porter*[E]

[A]Marrinya Agricultural Enterprises, 70 Vigilantis Road, Wuk Wuk, Vic. 3875, Australia.
[B]Cooperative Research Centre for Beef Genetic Technologies, School of Environmental and Rural Sciences, University of New England, Armidale, NSW 2351, Australia.
[C]Department of Mathematics and Statistics, University of Melbourne, Vic. 3010, Australia.
[D]Cosign, 20 Eleventh Avenue, Sawtell, NSW 2452, Australia.
[E]2 Oliver Street, Ashburton, Vic. 3147, Australia.
[F]Corresponding author. Email: rod.polkinghorne@gmail.com

Abstract. The Australian Beef Industry identified variable eating quality as a major contributor to declining beef consumption in the early 1990s and committed research funding to address the problem. The major issue was the ability to predict the eating quality of cooked beef before consumption. The Meat Standards Australia (MSA) program developed a consumer testing protocol, which led to MSA grading standards being defined by consumer score outcomes. Traditional carcass grading parameters proved to be of little value in predicting consumer outcomes. Instead a broader combination of factors forms the basis of an interactive prediction model that performs well.

The grading model has evolved from a fixed parameter 'Pathway' approach, to a computer model that predicts consumer scores for 135 'cut by cooking method' combinations for each graded carcass. The body of research work conducted in evaluating critical control points and in developing the model predictions and interactions has involved several Australian research groups with strong support and involvement from the industry.

Introduction

Variable beef eating quality was a major concern to many in the Australian beef industry in the early 1990s. During this period consumers were recording their dissatisfaction with Australian beef products by decreasing consumption. Consistency of beef eating quality was also seen as a key problem for the Australian beef trade (Bindon 2001). Domestic beef consumption fell and attitudinal research indicated that consumers were hesitant regarding the product. Concerns regarding health risks had received strong publicity, knowledge of cuts and cooking was declining, product appearance failed to identify quality, consumers were time-poor and demanding convenience, competing products were performing better (Yann *et al*. 1993; McKinna 1995).

Two of the key strategic imperatives of the Australian meat industry strategic plan were to supply a more consistent product and to accurately describe palatability (Centre for International Economics 1996). The Meat Research Corporation advanced funding to further develop and coordinate an Eating Quality Standards (EQS) program overseen by an Industry Steering Committee. Several active eating quality and consumer testing research projects were combined under the new structure. This program became known as Meat Standards Australia (MSA) when continued under the newly formed Meat and Livestock Australia (MLA).

This paper provides an overview of the issues addressed and parameters utilised in developing consumer standards as a target for grading and the consequent development of the MSA prediction model as the grade delivery mechanism.

Key issues

Delivering against the established strategic imperatives required several key issues to be addressed. Did consumers actually agree when assessing eating quality? If they did not, then any attempt to guarantee quality would fail. If they did, then how should consumer standards be set and product measured? There was considerable debate regarding the relative merits of objective testing, trained panels and untrained consumers. Did existing grading systems perform? How could they be improved?

The Australian beef industry produces from a diverse base of climatic extremes, breed and animal management systems and processing facilities. Cattle range from young calves slaughtered directly at weaning, to old animals; there are a large number of breeds and crosses, including a proportion of high *Bos indicus* content cattle. The climatic differences are also extreme, ranging from southern snowfields to northern tropics and from desert to irrigated pasture. Feedlots are used extensively in many areas. These combinations of different cattle type, age and production system all contribute to extreme variability in carcass quality (Bindon and Jones 2001). There is further variation between cuts within any carcass which, in turn, is affected by processing techniques, aging periods and cooking method. This background placed heavy demands on the proposed eating quality system. A simple industry blueprint, such as that adopted by the Meat and Livestock Commission in the UK (Red Meat Industry Forum 2005), was unlikely to produce consistency from such a diverse base.

A major requirement was to identify and quantify factors that could improve quality and consistency. To improve quality, one

 10.1071/EA07177 0816-1089/08/111351

must first be able to measure it. The concept of identifying, quantifying and applying systematic control to a series of critical control points was first advanced by Morgan (1992) and described as a 'Palatability Critical Control Point' (PACCP) approach. A related critical objective was to accurately identify beef of equal eating quality from the diverse pool presented, in order to deliver a consistent guaranteed consumer product.

These issues have been the focus of the MSA research effort since its inception in 1996. A key principle has been that any system developed had to deliver consistent palatability to the consumer. A grading system which simply described carcasses of similar appearance was not an acceptable option, with preliminary studies concluding that it would be dangerous to introduce a branding approach to the meat industry unless tenderness could be guaranteed within reasonable limits (SMART 1994). The MSA approach was in contrast to traditional grading system objectives which aimed to facilitate trade by describing the commercially important attributes of the carcass (Price 1995).

Understanding consumers

Every piece of beef produced is ultimately judged by the consumer when eaten. No amount of product promotion can counter the direct experience at this point. It is therefore necessary to understand the perception of consumers as a group, and the relative differences between individual consumers, to develop and assess a grading system that is focussed on describing eating quality. In the past, consumer data were often regarded as too noisy to be used effectively as a research measurement tool. However, the alternatives (either trained panels and/or objective measurements) were found to lack validity, particularly over extreme ranges in quality (Hwang *et al*. 2003). In deciding the form of evaluation to be used, consumer data had a downside in terms of reliability, however, this was more than compensated by gains in credibility. A detailed description of the development of the consumer testing protocol and subsequent palatability score is described by Polkinghorne *et al*. (1999) and Watson *et al*. (2008*c*).

The MSA program has been built on the premise that the grade should reflect only the consumer-assessed result, without being prescriptive in regard to the combination of factors that might affect the result. This provides for total flexibility in production systems, with the end product benchmarked against consumer satisfaction levels.

Factors related to eating quality

Having agreed on a consumer testing methodology to measure palatability, the MSA research program concentrated on evaluating all possible factors, or critical control points, against the consumer test benchmarks. Factors found to be correlated with eating quality were initially combined as fixed 'pathway' parameters and later utilised as interactive inputs in the series of grading prediction models developed.

The differential effect and range of interactions found between grading input parameters for various muscles as related to eating quality presented a major challenge to the notion of carcass grading and led to the conclusion that if a grading system aimed to assist consumers, it had to successfully grade individual cuts within a cooking method framework. The difference in ranking and extreme differences in relative importance between various identified control points or prediction variables also challenged the possibility of using an indicator or index muscle to predict other muscles.

This is in agreement with a study of 10 muscles by Shackelford *et al*. (1995), who reported that systems that accurately predict the tenderness of striploin (*M. longissimus lumborum*) of a carcass will likely do little to predict the tenderness of other muscles. Shorthose and Harris (1990), in a study of 12 muscles, also suggested that the *M. longissimus lumborum* was unsuitable as an index muscle, proposing instead the *M. semitendinosus* as more appropriate, partly due to it being restrained under tenderstretch and Achilles hanging systems and accessible from the carcass or cut.

While initial MSA trial work addressed only grilled striploins (*m. longissimus lumborum*), the program was expanded to include a range of muscles prepared by a variety of different cooking techniques (roast, stir-fry, slow-cook, corn, thin-slice and yakiniku). Contributing research activity has progressed in all areas from farm to plate over time. The detailed findings of specific MSA studies are covered in associated papers (see Colditz *et al*. 2007; Ferguson *et al*. 2007*a*, 2007*b*; Warner *et al*. 2007; Hwang *et al*. 2008; Park *et al*. 2008; Polkinghorne *et al*. 2008; Thompson *et al*. 2008*a*, 2008*b*, 2008*c*; Thomson *et al*. 2008; Watson 2008; Watson *et al*. 2008*a*, 2008*b*, 2008*c*; R. Polkinghorne, J. Thompson and R. Watson, unpubl. data). Considerable use has also been made of published data and several international scientists have assisted generously. As knowledge has improved, the level of detail and form of calculation within different versions of the MSA Grading Model has been modified accordingly.

Preslaughter issues

Preslaughter issues such as breed, feed and management effects have been at the forefront of industry interest and debate.

Breed

Early commercial benchmarking studies of grilled striploins (*M. longissimus lumborum*) indicated a negative relationship between eating quality and levels of *B. indicus* content. Similar results have been reported by others (see review by Burrow *et al*. 2001). No significant difference in consumer-assessed eating quality has been evident between British and continental breeds or their crosses, after adjusting for carcass weight, ossification and fatness traits that are influenced by breed type. This was in accordance with results reported by Koch *et al*. (1976), Adams *et al*. (1977), Cuthbertson (1994) and Wheeler *et al.* (1996, 2001) amongst others. Therefore, the grading model incorporated an adjustment for *B. indicus* percentage, which was applied differentially by muscle (Thompson *et al*. 1999). No other direct breed adjustments have been incorporated in the model at this stage.

A similar eating quality effect was found in some tropically adapted *Bos taurus* breeds, such as the Belmont Red which also had some visual *B. indicus* characteristics, including a hump. A factor relating hump height (*M. rhomboideous*) and carcass weight was developed as an estimator of equivalent *B. indicus* content and also incorporated as a cross check in the grading model. The relationship of hump as a phenotypic measure to tenderness scores was previously proposed by Sherbeck *et al.* (1996) in a study utilising cattle of varying Hereford and Brahman percentage.

Weight for age and growth rate

The literature is not clear on the effect of growth path on palatability. Fishell *et al.* (1985) reported that faster growing animals were more tender than slower growing animals. This was in contrast to others (Calkins *et al.* 1987; Moloney *et al.* 2000) who found no relationship between growth rate and a measure of tenderness. As discussed by Perry and Thompson (2005), variation in growth rate can be exhibited as both between- and within-group variation. They concluded from analysis of growth path data collected on ~7000 animals that between-group variation in growth rate was likely to be driven by intake. They also found that, as long as comparisons were not confounded by age, there was unlikely to be large differences in eating quality. However, this contrasted to within-group, where all animals had access to the same feed resource and differences in growth rate were likely to be driven by the individual's genetic potential for growth. They found that within a group the faster growing animals were more tender (i.e. higher tenderness scores and lower shear force). This was consistent with Shackelford *et al.* (1994) who showed that, within a group, faster growing animals had lower calpastatin activities and their meat was more tender. Perry and Thompson (2005) concluded that the small effect of growth rate on palatability within a group could be exploited by a grading scheme such as MSA which rewarded individual carcasses with a higher palatability score.

The use of dentition, ossification and actual age in relation to carcass weight were also investigated as potential tools to assist in predicting consumer scores. Actual age and ossification aided prediction slightly and similarly, but age was seldom available for commercial cattle; dentition demonstrated much poorer correlation. Recent analysis by Park *et al.* (2008) showed that ossification had a small but consistent negative effect on palatability, indicating its usefulness as a predictor of palatability.

The exception to this general approach is for calves slaughtered before weaning. These animals are typically 10 months old or less, with low ossification and carcass weights from 170 to 220 kg. In southern Australia, they are often referred to as 'milk fed vealers' (MFV). When compared with weaned calves of equivalent weight and ossification an unexplained, predominantly positive, eating quality difference was found in various muscles (Watson *et al.* 2008*a*). The Committee overseeing the development of the MSA system suggested that a method of including this in the grading model was to create a separate category for 'MFV', which would segregate calves of genuinely very young age from older calves with equivalent ossification.

Hormonal growth promotants

Several model inputs were found to be influenced by hormonal growth promotant (HGP) implant use. In most instances, HGP use was found to increase carcass weight and ossification score, and to reduce rib fat and marbling (Thompson *et al.* 2008*a*, 2008*c*; Watson *et al.* 2008*b*). Studies by Roeber *et al.* (2000) and Samber *et al.* (1996) have also reported increased ossification associated with some HGP regimes, while Tipton *et al.* (2002) found little effect. MSA data indicates a greater effect on ossification with increased days between initial implant and slaughter and with increased number of implants (Watson *et al.* 2008*b*, Thompson *et al.* 2008*c*). This trend is also seen in a study on repetitive implant use by Platter *et al.* (2003*b*). Studies by Roeber *et al.* (2000), Platter *et al.* (2003*a*) and Tipton *et al.* (2002) all report an increase in carcass weight and decrease in marbling score with various implant strategies. No significant effect on rib fat was reported in any of these studies, which was at odds with the MSA data.

Changes to carcass weight, ossification, marbling or rib fat modify the grading model prediction score, suggesting the possibility that the model would account for any consumer score differences relating to HGP use without a direct additional HGP model adjustment. However, they did not; greater accuracy was obtained by adding a separate HGP adjustment in addition to the changes in carcass weight, ossification, marbling and rib fat. The impact was found to be detrimental to eating quality, to vary by muscle and to be reduced, but not eliminated, with increased aging.

The MSA trials used to develop the grading model HGP calculation have been reported by Thompson *et al.* (2008*a*, 2008*c*), Watson *et al.* (2008*a*, 2008*b*), R. Polkinghorne, J. Thompson and R. Watson (unpubl. data). They included *B. indicus* cross and British breed cattle from grassland and feedlot production systems. Several cuts were tested with alternate cooking methods and aging periods applied in various combinations. A range of alternative implants and implanting strategies was also incorporated in both commercial and research cattle.

Marbling and fatness

Marbling and external fat levels are also common components of industry trading specifications and grading systems. Both are affected by genetic and animal management factors. Marbling scores in AUSMEAT (Anon. 2005) and USDA (Romans *et al.* 1994) scales, both measured at the quartering site, were recorded for a majority of carcasses used to source consumer test samples. Fat depth was also recorded at the P8 (Rump) and 12/13th rib sites for a majority of carcasses. Analysis of the consumer data confirmed a relationship between marbling and consumer scores which varied widely among cuts. While contributing to the consumer score, marbling alone explained only some of the differences between the same cut from different carcasses and very few of the differences between cuts from the one carcass (Watson *et al.* 2008*a*).

This was consistent with results reported by Koohmaraie *et al.* (1995) which stated that connective tissue and marbling only accounted for 20% of the observed variation in meat tenderness. It was also consistent with the findings of Thompson (2004), who stated that marbling accounted for ~15% of the variation in beef tenderness. Miller *et al.* (2000) also reported similar findings but noted that, while the relationship between marbling and consumer palatability was low, it did appear to be consistent. Thompson (2004) reported a curvilinear relationship between marbling score and flavour, although this was not apparent in later analyses (Park *et al.* 2008). A muscle dependent linear marbling adjustment was developed as a component of the grading model.

Gender

Differences between heifers and steers (neutered males) were also evaluated across the full range of samples tested by consumers. While the direct eating quality effect of gender was found to be small, some improvement in prediction accuracy was obtained by including gender in the prediction process. The effect is applied differentially by muscle and is further adjusted according to ossification (Watson *et al.* 2008*a*). Only females and castrated males have been tested to date.

Stress and management practices

Several studies (Butchers *et al.* 1998; Ferguson *et al.* 2007*a*, 2007*b*) have evaluated the impact of stress and various management practices on eating quality. These experiments have analysed MSA eating quality scores in relation to flight speed, mixing of stock at various periods before slaughter, differing feeding and curfew practices before slaughter and application of severe stress immediately before slaughter. Significant results have been reported in several studies, with consumer evaluation often detecting differences to a greater degree than laboratory shear and compression tests. This appears to relate to the sensory experience, including a juiciness component, and is a more complex judgement than shear value alone.

Findings from the studies have been used to set guidelines for animal management and to establish minimum standards for grading eligibility. These include criteria for supply of cattle through saleyards, time off feed before slaughter and time restrictions for mixing of groups before slaughter.

Postslaughter issues

The relative importance of pre- and postslaughter issues has long been a source of debate within both the commercial industry and scientific community. MSA research suggests that both are important with interaction and interdependence for delivering consistent and predictable eating quality. This highlights the importance of viewing industry segments as inter-related elements of a single production chain and the value of cooperation and clear communication between all segments.

pH and temperature

The obvious point of interface is represented by carcass changes, reflected by pH and temperature relationships between knocking and completion of rigor mortis. Animal feeding, temperament and handling on farm, during transport and in lairage all combine to influence blood glycogen level at slaughter. Subsequent abattoir interventions including electrical inputs from restrainers, stimulation systems and rigidity probes interact to determine the rate of pH decline. Time and temperature relationships have major implications for eating quality and for eating quality after aging, due to influences on both myofibrillar shortening and enzyme activity.

The importance of understanding and controlling prerigor conditions in beef carcasses to improve tenderness has been discussed in detail by Marsh (1954) and Marsh *et al.* (1987) and others for a considerable period. Dransfield (1994) states that the conditions during rigor development are the most important factors controlling tenderisation and aging for most commercial meats.

Early MSA efforts towards developing approved PACCP pathways mandated electrical stimulation of all carcasses. However, an early trial produced the unexpected result of decreased eating quality with stimulation. Further analysis and follow-up trials (Hwang and Thompson 2001*a*, 2001*b*) indicated that, whilst the excessive use of stimulation eliminated the risk of cold shortening, it created a new problem of heat shortening, with an associated eating quality decline due to increased moisture loss and reduced aging potential from enzyme autolysis. Product sourced for consumer testing from a range of cattle types and suppliers and slaughtered at different abattoirs utilising high voltage, low voltage and no stimulation after slaughter also demonstrated conflicting results depending on circumstances. These effects have also been reported by Marsh *et al.* (1989) and Takahashi *et al.* (1984). Martin *et al.* (1983) reported a positive association between tenderness and glycolytic rate. Further work by Simmons *et al.* (1996) reported interactions with pH, time and temperature in relation to sarcomere length, μ-calpain and calpastatin activity and shear force, which again indicated an optimum relationship between detrimental extremes of glycolysis. More recently, Thomson *et al.* (2008) demonstrated that extreme temperatures at rigor caused a crossover in toughness; soon after rigor heat-shortened product was more tender but because of autolysis of the calpain system, it did not age as much as muscle that went through rigor at 15°C.

The conclusion drawn by the MSA Pathways team was that, rather than prescribe a stimulation regime which could have a positive or negative impact depending on circumstances, it was better to prescribe a defined pH–temperature relationship. This was in agreement with Tornberg *et al.* (2000), who stated that not only does the temperature fall, in itself, influence the pH decline, but an early attainment of low pH at elevated temperatures (>15°C) can also cause denaturation and/or autolysis of the enzymes and therefore a decreased tenderness. They concluded that this provided a plausible explanation for an optimum pH decline during rigor in relation to tenderness. Wahlgren *et al.* (1997) also reported that a combination of low pH and high temperature during rigor development could detrimentally affect meat tenderness measured by both shear-force and sensory techniques. In their study, they found an intermediate rate of pH fall produced more tender beef than a fast or slow rate, which is also consistent with studies reported by Marsh *et al.* (1987).

Thompson *et al.* (2006) reviewed the factors that impacted on glycolytic rate in carcasses. Studies by Daly *et al.* (2002) showed that higher initial glycogen concentration resulted in a faster rate of pH decline. Similarly, Daly (2005) showed that heavier carcasses exhibited a faster glycolytic rate, which was largely driven by the decreased cooling rate of larger carcasses. They suggested that the problem of very rapid pH decline often seen in long fed beef carcasses may simply reflect the decreased cooling rate of these fatter heavier carcasses and that the problem may not require a metabolic solution but rather something as simple as increasing temperature loss from the carcass during the development of rigor. Thompson *et al.* (2006) proposed that any effect of genotype on glycolytic rate was likely to be driven through differences in muscle fibre type, with anaerobic type IIB fibres having a faster rate of pH decline.

Based on the literature, an MSA standard (described as an 'abattoir window') was established, requiring temperatures to be above 12°C and below 35°C at the point that pH reached 6.0 measured in the loin. The degree of stimulation required to produce this relationship was found to vary widely, from none in the case of many heavy grain fed cattle, to 40 s for light, lean grass-fed cattle.

Hanging and aging

Carcass side suspension effects on eating quality were described by Smith *et al*. (1971), Hostetler *et al*. (1970) and Bouton and Harris (1972). The factors which impact on the tenderstretch response were reviewed by Thompson *et al*. (2006). Depending upon the chiller conditions, tenderstretch generally results in an improvement in palatability and also a substantial reduction in variance of palatability scores. Thompson *et al*. (2005) considered that tenderstretch provided insurance for palatability scores, particularly where the carcasses were likely to be exposed to extremes in processing (e.g. hot or cold rigor temperatures).

Inclusion of tenderstretch within the MLC Blueprint in the United Kingdom has encouraged widespread adoption of tenderstretch by major British retailers. The blueprint recommendation resulted from trial work that demonstrated substantial improvement in comparison to Achilles suspension (Cuthbertson 1994). While utilised widely in the UK, tenderstretch, or pelvic suspension, had not been adopted widely within the Australian industry.

Several MSA trials were conducted to quantify the potential to upgrade cuts by utilising the technique. Following encouraging initial results, the trials were broadened to include a full range of cattle types, a variety of carcass weights and all major cuts. Aging periods were also varied and, when analysed, indicated an interaction between muscle and suspension method (Watson *et al.* 2008*a*).

To counter industry concerns regarding rail space in chillers, some testing was also done on an alternative 'Tendercut' method described by Wang *et al*. (1994). Differences were also evaluated between two commercial variations of tenderstretch, suspending by the pelvic ligament *v.* suspension from the aitch bone (obturator foramen). The differential effect of each hanging method was incorporated into the MSA grading model with the effect varied by muscle. A specific aging estimate was also developed and implemented on a muscle by hang basis.

Development of reasonable aging estimates proved difficult, due to considerable variation in the data. This is not surprising given the strong influence of temperature and pH inter-relationships in the prerigor period, found by Hwang and Thompson (2001*b*). Differences between aging potential of various muscles have also been reported by Shorthose and Harris (1990).

Dransfield (1994) and Bouton and Harris (1972) reported that aging rate differences between muscles were related to muscle type, with calpain and calpastatin levels also differing between red and white fibre muscle types. Those authors indicated that this was consistent with very low aging in *M. psoas major* and lower aging in *M. biceps femoris* than in *M. longissimus lumborum*, which was also consistent with MSA consumer results.

Shorthose and Harris (1990) and Bouton and Harris (1972) have documented changes in toughness with animal age, due to differences in connective tissue strength which varies considerably between cuts. As proteolysis is thought to relate predominantly to changes in myofibrillar toughness, the variation in connective tissue quantity and strength between muscles, with further variation in animal age at slaughter, could be expected to influence postmortem aging.

There appear to be few studies reporting interaction between carcass suspension method and aging rate of specific muscles, although these are strongly evident in the MSA data. Bouton and Harris (1972) reported differences in aging rate between muscles and between the same muscles under different suspension treatments. They reported that the aging effect as measured by shear force was greater for muscles from Achilles hung carcasses than from tenderstretched carcasses and greater for *M. longissimus* than for the *M. semimembranosus*. They also report a decline in aging rate over time. These findings are confirmed by the MSA data and hence are part of the MSA model.

Cooking method

The cooking method used was also found to directly influence eating quality outcomes. The effect differed widely between muscles, both in extent and as to which cooking methods were most favourable to the cooked outcome. A pertinent finding was that, while selection of the most appropriate cooking method might improve the result for an individual muscle, it did not remove differences between muscles.

In light of these results, it was considered necessary to link the consumer grade to a cooking method. For some muscles the grade would often vary according to the cooking method chosen. Accordingly, the model output and estimation process was developed to provide a 'muscle by cooking method' outcome. This was described by Watson *et al*. (2008*a*). It was believed that the beef retailer could use this information to select and prepare muscles for their most appropriate use, thereby assisting the consumer obtain the best result.

Prediction of eating quality

Efforts to predict beef eating quality are not new. Neither is the aim of consistently meeting consumer expectations. A wide range of government and private grading schemes, industry blueprints, supplier specifications and day-to-day specifications have all been used without fully delivering on the aim. Even the USDA quality grading system, which has a major commercial impact in the USA and international markets, only accounts for 10–30% of the variability in beef tenderness (Miller *et al*. 1996).

Early trials which preceded the MSA program attempted to grade beef by a mix of conventional grading parameters. Hearnshaw *et al*. (1995) concluded that the NSW gold branding scheme had little value, based on consumer supermarket studies. It was concluded that at low-fat levels, visual carcass appraisal and slaughter floor data could not reliably categorise eating quality (Australian Meat Standards 1997). Initial MSA efforts to provide a more consistent product to consumers centred on construction of production 'Pathways', each pathway consisting of a set of criteria that had to be met in order for a cut to receive a grade. This approach was similar in concept to the MLC blueprint (Cuthbertson 1994) and strategic alliance project of the American NCA (1994), which linked several critical control points to reduce variation. In the MSA situation, the steps were mandatory rather than best practise recommendations. Typical criteria included maximum *B. indicus* content, minimum marbling levels and minimum days aging. From consumer testing, several successful pathways were formulated. Product which met the criteria also achieved the determined levels of satisfaction confirmed by consumer test.

This was a significant achievement for the industry, in that it then had a means to provide a consumer guarantee. The downside was that a large percentage of product failed to grade, by falling outside one or more of the pathway criteria. Despite failing to meet one criterion, however, the failed product also often met consumer standards because it exceeded minimum standards for other criteria. Additional criteria combinations were tested to provide multiple pathways to attain a common grade.

The number of pathways required to cover all options and then to accurately predict multiple cuts or muscles is very large, however, making management of a developed system complex. After evaluating a range of approaches including construction of decision trees, the concept of an interactive model was formulated and developed (Polkinghorne *et al*. 1999). Under the model approach, all factors are considered interactively, allowing full compensation (positive or negative) rather than imposing rigid threshold levels. If the data are sufficient to provide an understanding of each effect and any interactions, the model approach can provide a high level of consumer protection and satisfaction, while reducing the proportion of acceptable product rejected. A significant benefit is that each muscle can be independently estimated by utilising alternative input factors or different weightings for common factors. This removes the inherent weakness of attempting to apply a common grade to a carcass known to comprise a collection of very different consumer products.

Development of the MSA model has evolved since the release of the original 12-cut version (Polkinghorne *et al*. 1999). The current model is the fourth commercial version, now predicting 135 'cut by cook' combination consumer outcomes for each graded carcass. The statistical processes used in developing the models have been reported by Watson *et al*. (2008*a*). Prediction accuracy and the inputs used have progressed from analysis as additional research data have been accumulated.

Research priorities have also been set or refined to rectify deficiencies in available data or to examine additional issues. Much of the research has been conducted in collaboration with several institutions, with MSA also providing consumer score data for many experiments established to examine a wide variety of production issues. A Pathways committee comprising principal Australian researchers and industry representatives has overseen the research program from the outset, with further input and review from several international meat scientists.

At its current stage of development, the model is providing commercially useful accuracy across all major carcass muscles cooked by most common methods. As such, it has gone a considerable distance towards providing the industry ideal of a rapid, automated, tamper-proof, noninvasive, accurate instrument as expressed by Koohmaraie *et al*. (2005).

Commercial application

The model estimates for individual cuts have provided a strong base from which to simplify retail description systems, while reducing the need for consumer beef knowledge and enhancing satisfaction with the cooked product. A commercial trial reported by Polkinghorne (2006) and Polkinghorne *et al*. (2008) elaborated on advanced practical application of these principles.

Industry interest in the program has been strong at all times. This has provided a high degree of scrutiny and, at times, challenge. The judgement delivered by consumers has, however, been well accepted and many practises have been modified across all industry sectors in response. A major program benefit has been the provision of a consumer view to most aspects of beef production.

In many cases, MSA grading has not been adopted in full due to perceptions of required change or available commercial benefit. Even in these situations there has still been strong uptake of many elements of the program. MLA commissioned survey results suggest that consumer satisfaction has substantially improved over the period of the program (Millward Brown 2007). Whilst this cannot all be attributed to MSA, it is believed to be a major contributing factor.

It is estimated that 40% of all eligible carcasses destined for the domestic market are now graded by MSA. Grading numbers have grown continually to over 700 000 carcasses in 2007. A major impact has been in training with over 20 400 training modules delivered to 8447 processing and retail industry personnel. Producers also receive training as part of the registration process and there are over 10 000 registered MSA members, the majority producers (C. Dart, pers. comm.). This has led to a dramatic increase in the level of understanding of eating quality issues at all points of the production chain. Grading numbers are increasing steadily and adoption now appears to be growing at an increasing rate, as growing capability in the model output is matched by increased industry awareness of commercial opportunities.

Despite accelerated use in the wholesale trade, visibility of MSA at retail is generally low. It is being used predominantly to support private brand initiatives or to underpin existing channel partner offers, rather than as a retail brand in its own right. Growth has been particularly marked in the food service area leading to substantial premiums for MSA graded product at wholesale and farm level (Dart *et al*. 2008).

Conclusion

The MSA program has acted as a catalyst for substantial change in all sectors of the Australian beef industry. Provision of a defined consumer target and testing protocol has served to focus the industry and research efforts on the eating quality result of production, processing and retail presentation alternatives. The program has also served to encourage and facilitate research and commercial industry cooperation, to the benefit of both sectors.

Eating quality is now integral to beef industry operation and planning.

The sensory response of the Australian consumer to beef is now much better defined and understood, enhancing the ability to define and provide superior value. The industry's ability to deliver a consistent quality product of known eating quality has dramatically improved with a commensurate opportunity to modify traditional description and pricing regimes, simplifying the retail offer and reducing the need for consumers to have any background knowledge of beef cuts and cooking relationships. The eating quality cause and effect relationships of practices, from farm to retail, and their interdependent nature are now better defined, providing a base for development of accurate value based pricing systems for each segment.

The program is ongoing, with continuing research to further extend and improve the predictive accuracy of the model across the full range of livestock, production environments and processing practises. There is also growing interest in the potential to utilise the same or modified approaches in export markets and in collaborating with other countries to test the response to local consumers and product.

References

Adams NJ, Smith GC, Carpenter ZL (1977) Carcass and palatability characteristics of Hereford and crossbred steers. *Journal of Animal Science* **46**, 438–448.

American NCA (1994) 'Full report of the national beef tenderness conference. April 22–23, 1994.' (National Cattleman's Association: Denver, CO)

Anon. (2005) 'Handbook of Australian meat.' 7th edn. (AUSMEAT: Brisbane)

Australian Meat Standards (1997) EQS consumer testing protocol. Report to Meat Research Corporation.

Bindon BM (2001) Genesis of the Cooperative Research Centre for the Cattle and Beef Industry: integration of resources for beef quality research (1993–2000). *Australian Journal of Experimental Agriculture* **41**, 843–853. doi: 10.1071/EA00067

Bindon BM, Jones NM (2001) Cattle supply, production systems and markets for Australian beef. *Australian Journal of Experimental Agriculture* **41**, 861–877. doi: 10.1071/EA01052

Bouton PE, Harris PV (1972) The effects of some post-slaughter treatments on the mechanical properties of bovine and ovine muscle. *Journal of Food Science* **37**, 539–543. doi: 10.1111/j.1365-2621.1972.tb02687.x

Burrow HM, Moore SS, Johnston DJ, Barendse W, Bindon BM (2001) Quantitative and molecular genetic influences on properties of beef: a review. *Australian Journal of Experimental Agriculture* **41**, 893–919. doi: 10.1071/EA00015

Butchers ADM, Ferguson DF, Devine CE, Thompson JM (1998) Interaction between pre-slaughter handling and low voltage electrical stimulation and the effect on beef quality. In 'Proceedings of the International Congress of Meat Science and Technology, Barcelona, Spain, Vol. 44'. pp. 1050–1052.

Calkins CR, Seideman SC, Crouse JD (1987) Relationship between rate of growth, catheptic enzymes and meat palatability in young bulls. *Journal of Animal Science* **64**, 1448–1457.

Centre for International Economics (1996) 'Meat industry strategic plan to the year 2001.' (Meat Research Corporation: Sydney)

Colditz IG, Ferguson DM, Greenwood PL, Doogan VJ, Petherick JC, Kilgour R (2007) The effect on meat quality of mixing unfamiliar *Bos taurus* feedlot cattle in the weeks prior to slaughter. *Australian Journal of Experimental Agriculture* **47**, 763–769. doi: 10.1071/EA05114

Cuthbertson A (1994) Enhancing beef eating quality. Digest No. 49, Winter conference. British Cattle Breeders Club, Cambridge.

Daly BL (2005) Factors affecting rate of pH decline in bovine muscle post-mortem. PhD Thesis, University of New England, Armidale.

Daly BL, Richards I, Gibson PG, Gardner GE, Thompson JM (2002) Rate of pH decline in bovine muscle post-mortem – a benchmarking study. In 'Proceedings of the International Congress of Meat Science and Technology, Vol. 48'. pp. 560–561.

Dart C, Griffith G, Rodgers H, Thompson JM (2008) The aggregate economic benefits at the wholesale level from the adoption of Meat Standards Australia. First estimates. *Australian Agribusiness Review* **16**, in press.

Dransfield E (1994) Optimisation of tenderisation, ageing and tenderness. *Meat Science* **36**, 105–121. doi: 10.1016/0309-1740(94)90037-X

Ferguson DM, Shaw FD, Stark JL (2007*a*) The effect of reduced lairage duration on beef quality. *Australian Journal of Experimental Agriculture* **47**, 770–773. doi: 10.1071/EA05212

Ferguson DM, Warner RD, Walker PJ, Knee B (2007*b*) Evaluation of the effect of cattle marketing method on beef quality and palatability. *Australian Journal of Experimental Agriculture* **47**, 774–781. doi: 10.1071/EA05213

Fishell VK, Aberle ED, Judge MD, Perry TW (1985) Palatability and muscle properties of beef as influenced by preslaughter growth rate. *Journal of Animal Science* **61**, 151–157.

Hearnshaw H, Shorthose WR, Melville G, Rymill S, Thompson JM, Arthur PF, Stephenson PD (1995) Are carcass grades a useful indication of consumer assessment of eating quality of beef? In 'Meat 95: Australian Meat Industry Research Conference'. pp. 7A-5–7A-9. (CSIRO: Brisbane)

Hostetler RL, Landmann WA, Link BA, Fitzhugh HA (1970) Influence of carcass position during rigor mortis on tenderness of beef muscles: comparison of two treatments. *Journal of Animal Science* **31**, 47–50.

Hwang IH, Thompson JM (2001*a*) The effect of time and type of electrical stimulation on the calpain system and meat tenderness in beef longissimus dorsi muscle. *Meat Science* **58**, 135–144. doi: 10.1016/S0309-1740(00)00141-8

Hwang IH, Thompson JM (2001*b*) The interaction between pH and temperature decline early postmortem on the calpain system and objective tenderness in electrically stimulated beef Longissimus dorsi muscle. *Meat Science* **58**, 167–174. doi: 10.1016/S0309-1740(00)00147-9

Hwang IH, Park BY, Cho SH, Lee JM, Kim YG, Kim JH, Thompson JM (2003) Relationships between WB-shear force and sensory tenderness scores for three muscles prepared using different cooking methods in tenderstretch and normally hung sides. In 'Proceedings of the International Congress of Meat Science and Technology, Vol. 49'. pp. 266–267.

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

Koch RM, Dikeman ME, Allen DM, May M, Crouse JD, Campion DR (1976) Characterization of biological types of cattle. III. Carcass composition, quality and palatability. *Journal of Animal Science* **43**, 48–62.

Koohmaraie M, Wheeler TL, Shackelford SD (1995) Beef tenderness: regulation and prediction. In 'Meat 95: Australian Meat Industry Research Conference'. pp. 4A-1–4A-20. (CSIRO: Brisbane)

Koohmaraie M, Shackelford SD, Wheeler TL (2005) Biological bases that determine beef tenderness. In 'Proceedings of Eighth Annual Langford Food Industry Conference, British Society of Animal Science'. pp. 21–26.

Marsh BB (1954) Rigor mortis in beef. *Journal of the Science of Food and Agriculture* **5**, 70–75. doi: 10.1002/jsfa.2740050202

Marsh BB, Ringkob TP, Russel RL, Swartz DR, Pagel LA (1987) Effects of early postmortem glycolytic rate on beef tenderness. *Meat Science* **21**, 241–248. doi: 10.1016/0309-1740(87)90061-1

Marsh BB, Ringkob TP, Russel RL, Swartz DR, Pagel LA (1989) Mechanisms and strategies for improving meat tenderness. In 'Annual Reciprocal Meat Conference of the American Meat Science Association, Vol. 41'. pp. 113–121.

Martin AH, Murray AC, Jeremiah LE, Dutson PJ (1983) Electrical stimulation and carcass ageing effects on beef carcasses in relation to postmortem glycolytic rates. *Journal of Animal Science* **57**, 1456–1462.

McKinna D (1995) 'Product description and labelling system research summary. Meat Research Corporation Project 360.' (Meat and Livestock Australia: North Sydney)

Miller RK, Taylor JF, Sanders JO, Lunt DK, Davis SK, Turner JW, Savell JW, Kallel F, Ophir J, Lacey RE (1996) Methods for improving beef tenderness. In 'Reciprocal Meat Conference Proceedings, Vol. 49'. pp. 106–113.

Miller RK, Moeller SJ, Goodwin RN, Lorenzen CL, Savell JW (2000) Consistency in meat quality. In 'Proceedings of the International Congress of Meat Science and Technology, 46'. pp. 555–580.

Millward Brown (2007) 'Consumer survey data.' (Meat and Livestock Australia: North Sydney)

Moloney AP, Keane MG, Mooney MT, Troy DJ (2000) Fat deposition and muscle tenderness in steers with different patterns of concentrate consumption. In 'Proceedings of the Agricultural Research Forum, Dublin'. pp. 107–188. (Teagasc: Carlow, Ireland)

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. 180–187 (National Cattlemens' Association: Englewood, CO)

Park BY, Hwang IH, Cho SH, Yoo YM, Kim JH, Lee JM, Polkinghorne R, Thompson JM (2008) The effect of carcass suspension and cooking method on the palatability of three muscles as assessed by Korean and Australian consumers. *Australian Journal of Experimental Agriculture* **48**, 1396–1404.

Perry D, Thompson JM (2005) The effect of growth rate during backgrounding and finishing on meat quality traits in beef cattle. *Meat Science* **69**, 691–702. doi: 10.1016/j.meatsci.2004.10.020

Platter WJ, Tatum JD, Belk KE, Chapman PL, Scanga JA, Smith GC (2003*a*) Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science* **81**, 2741–2750.

Platter WJ, Tatum JD, Belk KE, Scanga JA, Smith GC (2003*b*) Effects of repetitive use of hormonal implants on beef carcass quality, tenderness, and consumer ratings of beef palatability. *Journal of Animal Science* **81**, 984–996.

Polkinghorne R (2006) Implementing a palatability assured critical control point (PACCP) approach to satisfy consumer demands. *Meat Science* **74**, 180–187. doi: 10.1016/j.meatsci.2006.05.001

Polkinghorne R, Watson R, Porter M, Gee A, Scott A, Thompson J (1999) Meat Standards Australia, a 'PACCP' based beef grading scheme for consumers. 1. The use of consumer scores to set grade standards. In 'Proceedings of the International Congress of Meat Science and Technology, Vol. 45'. pp. 14–15.

Polkinghorne R, Philpott J, Gee A, Doljanin A, 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.

Price MA (1995) Development of carcass grading and classification systems. In 'Quality and grading of carcasses of meat animals.' (Ed. SD Morgan Jones) pp. 173–199. (CRC Press: New York)

Red Meat Industry Forum (2005) 'A blueprint for improved consistent quality beef.' (Red Meat Industry Forum: Winterhill, UK) Available at http://www.redmeatindustryforum.org.uk/supplychain/MeatQuality.htm [Verified 18 July 2008]

Roeber DL, Cannell RC, Belk KE, Miller RK, Tatum JD, Smith GC (2000) Implant strategies during feeding: impact on carcass grades and consumer acceptability. *Journal of Animal Science* **78**, 1867–1874.

Romans JR, Costello WJ, Carlson CW, Greaser ML, Jones KW (1994) 'The meat we eat.' (Interstate Publishers, Inc.: Danville, IL)

Samber JA, Tatum JD, Wray MI, Nichols WT, Morgan JB, Smith GC (1996) Implant program effects on performance and carcass quality of steer calves finished for 212 days. *Journal of Animal Science* **74**, 1470–1476.

Shackelford SD, Koohmaraie M, Cundiff LV, Gregory KE, Rohrer GA, 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.

Shackelford SD, Wheeler TL, Koohmaraie M (1995) Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* cattle. *Journal of Animal Science* **73**, 3333–3340.

Sherbeck JA, Tatum JD, Field TG, Morgan JB, Smith GC (1996) Effect of phenotypic expression of Brahman breeding on marbling and tenderness traits. *Journal of Animal Science* **74**, 304–309.

Shorthose WR, Harris PV (1990) Effect of animal age on the tenderness of selected beef muscles. *Journal of Food Science* **55**, 1–8. doi: 10.1111/j.1365-2621.1990.tb06004.x

Simmons NJ, Singh K, Dobbie PM, Devine CE (1996) The effect of pre-rigor holding temperature on calpain and calpastatin activity and meat tenderness. In 'Proceedings of the International Congress of Meat Science and Technology, Vol. 42'. pp. 414–415.

SMART (1994) Sensory analysis to identify consumers' revealed preferences for product description. Report commissioned by the Meat Research Corporation, Sydney.

Smith GC, Arango TC, Carpenter ZL (1971) Effects of physical and mechanical treatments on the tenderness of the beef Longissimus. *Journal of Food Science* **36**, 445–449. doi: 10.1111/j.1365-2621.1971.tb06384.x

Takahashi G, Lochner JV, Marsh BB (1984) Effects of low-frequency electrical stimulation on beef tenderness. *Meat Science* **11**, 207–225. doi: 10.1016/0309-1740(84)90038-X

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. doi: 10.1071/EA02171

Thompson JM, Polkinghorne R, Hearnshaw H, Ferguson DM (1999) Meat Standards Australia: a 'PACCP' based beef grading scheme for consumers. 2. PACCP requirements which apply to the production sector. In 'Proceedings of the international congress of meat science and technology, Yokohama, Japan, Vol. 45'. pp. 16–20.

Thompson JM, Hopkins DL, D'Souza DN, Walker Baud SR, Pethick DW (2005) The impact of processing on sensory and objective measurements of sheep meat eating quality. *Australian Journal of Experimental Agriculture* **45**, 561–573. doi: 10.1071/EA03195

Thompson JM, Perry D, Daly B, Gardner GE, Johnston DJ, Pethick DW (2006) Genetic and environmental effects on the muscle structure response post-mortem. *Meat Science* **74**, 59–65. doi: 10.1016/j.meatsci.2006.04.022

Thompson JM, McIntyre BM, Tudor GD, Pethick DW, Polkinghorne R, Watson R (2008*a*) Effects of hormonal growth promotants (HGP) on growth, carcass characteristics, the palatability of different muscles in the beef carcass and their interaction with aging. *Australian Journal of Experimental Agriculture* **48**, 1405–1414.

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

Thompson JM, Polkinghorne R, Porter M, Burrow HM, Hunter RA, McCrabb GJ, Watson R (2008*c*) Effect of repeated implants of oestradiol-17β on beef palatability in Brahman and Brahman cross steers finished to different market end points. *Australian Journal of Experimental Agriculture* **48**, 1434–1441.

Thomson KL, Gardner GE, Simmons N, Thompson JM (2008) Length of exposure to high post-rigor temperatures affects the tenderisation of the beef *M. longissmus dorsi*. *Australian Journal of Experimental Agriculture* **48**, 1442–1450.

Tipton NC, Paschal JC, De La Zerda MJ, Savell JW (2002) Effect of seven different implant combinations on carcass quality and yield characteristics of *Bos indicus* breed influence steers. In 'Beef cattle research in Texas, Texas A&M Meat Science report'. pp. 124–128.

Tornberg E, Wahlgren M, Brondum J, Engelsen SB (2000) Pre-rigor conditions in beef under varying temperature and pH falls studied with rigometer, NMR and NIR. *Food Chemistry* **69**, 407–418. doi: 10.1016/S0308-8146(00)00053-4

Wahlgren NM, Devine CE, Tornberg E (1997) The influence of different pH courses during rigor development on beef tenderness. In 'Annual international congress of meat science and technology, 43'. pp. 622–623.

Wang H, Claus JR, Marriot NG (1994) Selected skeletal alterations to improve tenderness of beef round muscles. *Journal of Muscle Foods* **5**, 137–147. doi: 10.1111/j.1745-4573.1994.tb00526.x

Warner R, Ferguson DM, Cotrell JJ, Knee B (2007) Acute stress induced by the use of electric prodders pre-slaughter causes tougher beef meat. *Australian Journal of Experimental Agriculture* **47**, 782–788. doi: 10.1071/EA05155

Watson R (2008) Meta-analysis of the published effects of HGP use on beef palatability in steers as measured by objective and sensory testing. *Australian Journal of Experimental Agriculture* **48**, 1425–1433.

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

Watson R, Polkinghorne R, Gee A, Porter M, Thompson JM, Ferguson D, Pethick D, McIntyre B (2008*b*) Effect of hormonal growth promotants on palatability and carcass traits of various muscles from steer and heifer carcasses from a *Bos indicus–Bos taurus* composite cross. *Australian Journal of Experimental Agriculture* **48**, 1415–1424.

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

Wheeler TL, Cundiff LV, Shackelford SD, Koohmaraie M (1996) Characterization of biological types of cattle (Cycle IV): carcass traits and longissimus palatability. *Journal of Animal Science* **74**, 1023–1035.

Wheeler TL, Cundiff LV, Shackelford SD, Koohmaraie M (2001) Characterization of biological types of cattle (Cycle V): carcass traits and longissimus palatability. *Journal of Animal Science* **79**, 1209–1222.

Yann M, Campbell A, Hoare W, Wheeler A (1993) The role of nutrition in the consumption of red meat. Australian Meat and Livestock Corporation, Sydney.

Manuscript received 12 June 2007, accepted 20 June 2008