MANAGING MEAT TENDERNESS

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Abstract

This paper discusses the management of meat tenderness using a carcass grading scheme which utilizes the concept of total quality management of those factors which impact on beef palatability. The scheme called Meat Standards Australia (MSA) has identified the Critical Control Points (CCPs) from the production, pre-slaughter, processing and value adding sectors of the beef supply chain and quantified their relative importance using large-scale consumer testing. These CCPs have been used to manage beef palatability in two ways. Firstly, CCPs from the pre-slaughter and processing sectors have been used as mandatory criteria for carcasses to be graded. Secondly, other CCPs from the production and processing sectors have been incorporated into a model to predict palatability for individual muscles. The evidence for the importance of CCPs from the production (breed, growth path and HGP implants), pre-slaughter and processing (pH/temperature window, alternative carcass suspension, marbling and ageing) sectors are reviewed and the accuracy of the model to predict palatability for specific muscle x cooking techniques is presented.

Keywords: tenderness, palatability, grading, breed, growth path, HGP implants, pre-slaughter, pH/temperature window, alternative carcass suspension, marbling, ageing

Introduction

Meat tenderness is a function of production, processing, value adding and cooking method used to prepare the meat for consumption by the consumer. Failure of one or more links in the beef supply chain increases the risk of a poor eating experience for the consumer. A guarantee for eating quality can only be given if the links that most affect tenderness are controlled along the meat production chain.

An example of a 'paddock to plate' quality assurance system which manages meat quality along the entire length of the meat production chain is the new grading scheme called Meat Standards Australia (MSA), which is presently being implemented for the Australian domestic beef market by Meat and Livestock Australia (MLA). This paper will use the example of MSA to describe the development and implementation of a quality assurance system which manages and describes the palatability of meat for the consumer.

A total quality management approach (TQM) to meat quality

A TQM approach to meat quality was suggested by Tatum, Belk, George, and Smith (1999) as a means of addressing the incidence of poor tenderness in beef. In a pilot programme they showed that, by implementation of best practice genetics, pre-harvesting cattle management, early post-mortem processing and post-mortem ageing, the incidence of tough beef was reduced, as assessed by shear force. The MSA grading scheme also uses a TQM approach to identify critical control points (CCPs) and to predict the quality of the final product. From the literature and an on-going research program, MSA has identified those CCPs from the production, processing, value adding and cooking sectors of the meat supply chain in Australia that impact on eating quality and combined these into a workable quality assurance or grading system.

Much of the research undertaken by MSA was not new. The new component was the use of a large-scale consumer testing system that allowed the effects of the CCPs to be quantified using a standard evaluation procedure. This allowed the CCPs to be ranked on their potential impact on palatability and incorporated into a predictive model. Given the variety of meat quality measurements used by scientists around the world, it was not previously possible to integrate results into a general model capable of operating at a commercial level (i.e., a model that predicted palatability using traits that could be measured in a commercial environment). Other prediction models have generally focused on a specific sector of the beef supply chain, whilst MSA incorporated CCPs from production through to cooking the beef.

MSA has had a rapid evolution, initially developing a 'carcass pathways' approach similar to that described by Tatum et al (1999), whereby carcass grades were defined by a series of threshold parameters which had to be met before the carcass was graded (Thompson, Polkinghorne, Watson, Gee and Murison, 1999b). The need for a cuts-based-grading system was predicated on the need to improve the accuracy of predicting palatability in beef and the need to grade all muscles in the carcass. Analysis of the MSA database showed that the variation in palatability explained by muscles was approximately 60 times greater than that explained by the variation between animals for the same muscle.

The consumer testing system

At the commencement of MSA the decision was made to use sensory results from consumer testing as the means to describe palatability of beef. Although objective measurements (such as shear force) have the advantage of being relatively cheap, they are rather simplistic one dimensional measures of a complex set of interactions which occur when cooked meat is chewed and masticated in the mouth. Perry, Thompson, Hwang, Butchers and Egan (2001) examined the relationship between objective and sensory measurements and concluded that whilst shear force was a useful indicator of sensory tenderness, it did not account for all the improvement in sensory scores when meat was aged. In addition, it was difficult to predict the sensory juiciness scores from objective measurements of meat texture or cooking loss.

Sensory assessment of meat can be undertaken using either trained or untrained consumer panels. A trained taste panel is generally skilled in scoring the specific attributes of eating quality, independently of the other sensory dimensions. Trained panels will generally have a smaller variance, but the training procedure can lead to biased results. By comparison a consumer panel is unbiased, but has a larger variance. The MSA decision to use consumer taste panels was based on the need to have a reliable, transparent, system of testing samples that would engender confidence with both the beef industry and consumer sectors. It would also allow the final assessment of palatability to be determined by the target consumer market for the product. The consumer sensory testing protocol used by MSA was based on existing protocols in use by Australian sensory groups and the American Meat Science Association protocols (AMSA 1995).

The consumer tasting protocol has been described by Polkinghorne, Watson, Porter, Gee, Scott and Thompson (1999). Briefly, untrained consumers were screened to include only those who ate beef a at least once per week. At each tasting, consumers were presented with a total of 7 warm samples over a 35 minute period and asked to score tenderness, juiciness, flavour and overall acceptability. They also graded the sample on the following word associations; unsatisfactory, good everyday (3 star), better than everyday (4 star), or premium quality (5 star). To combine the 4 sensory dimensions into a single palatability or meat quality score (MQ4), weightings were formulated from a discriminant analysis (0.4, 0.1, 0.2 and 0.3 for tenderness, juiciness, flavour and overall acceptability, respectively). Although all sensory dimensions were positively correlated the highest correlation was between tenderness and overall acceptability, suggesting that these two dimensions essentially were describing similar variation. This effectively meant that the palatability score was weighted toward description of tenderness. The palatability scores were then used to calculate the optimum boundaries for the grades assigned by the consumers. A linear discriminant analysis was used to produce a maximal separation of the grade means to the within-grade variance. The boundaries between these grades were consistent between weeks, with 45.5 separating ungraded and 3 star categories, 63.5 for 3 and 4 star, and 76.5 and above for 5 star.

Development of a model to predict palatability

The MSA prediction model was developed using a multiple regression approach whereby input variables from the production, processing and value adding sectors were included in a model to predict palatability of individual muscles for a range of cooking techniques. From over 30 parameters initially available only 13 have been incorporated into the final model. The model building was undertaken by Dr Ray Watson of the Department of Mathematics and Statistics at Melbourne University, in conjunction with the Pathways team from MSA. Models were developed for individual muscle/cook combinations.

The regression approach allowed changes in palatability to reflect the estimated effects of the input variables, rather than using the approach of non-negotiable cut-offs as used by most other grading schemes, although there are still cut-offs for ultimate pH, fat depth and ossification score. An important feature of the model approach was that there was now a large number of combinations that could be used to achieve a specified outcome. This was desirable, as consumers are not concerned by how palatability scores are derived, rather, that palatability matches its description.

The initial the model was developed using production, processing and sensory data from 12,700 samples contained in the MSA database (Thompson et al 1999a). The next iteration of the model in February 2000 used data from 23,000 samples. The MSA data base presently contains over 55,000 samples which have been tested by consumers.

Components of the MSA model

The specifications for producers and processors to supply carcasses which are eligible for grading by MSA include compliance with a set of conditions aimed at reducing pre-slaughter stress and optimizing processing conditions. Producers need to be registered and must adhere to MSA Cattle Handling Guidelines to minimize stress. They must declare the *Bos Indicus* % content of their cattle, and whether the cattle can be classed as milk fed calves. The time of loading must be supplied, the cattle trucked direct to slaughter, not mixed in lairage, and killed the day after dispatch.

Abattoir procedures are audited within a QA system to ensure pH and temperature relationships are within the prescribed window to achieve optimal palatability. To minimise variation in cooling rates carcasses must have an even distribution of fat with at least 3mm of fat at the rib site. All carcasses must have an ultimate pH below 5.7 and a USDA ossification score (Romans, Costello, Carlson, Greaser and Jones, 1994) below 300. As more samples are tested from older cattle it is intended to extend this limit so that a greater proportion of the Australian domestic cattle kill are eligible for grading.

A sample output from the MSA model is shown in Figure 1. The prediction parameters used in the model include :

- *Bos indicus* %: This is specified on the producer declaration. In addition, hump height is measured at grading and related to carcass weight. Where the hump height is outside a specified range for the declared *Bos indicus* %, a higher *Bos indicus* adjustment is applied. This provides improved accuracy for some adapted *Bos taurus* breeds, such as Belmont Reds. The magnitude of the *Bos indicus* effect varies with muscle (see Table 1).
- Sex: A sex adjustment is applied in two ways. One adjustment is by muscle, with various muscles showing a slight difference between sexes. The second adjustment is applied differentially in conjunction with the ossification score across all muscles. The magnitude of the sex adjustment varies with muscle and is relatively small, being of the order of 2 palatability units.
- Carcass weight: This is used in conjunction with ossification score to estimate the effect of growth rate on palatability. The change in palatability with increased carcass weight differs for each ossification range and tends to decline as ossification increases. An increase in USDA ossification score from 120 to 200 would increase palatability by approximately 3 palatability units. At this stage a common adjustment is made for all muscles and cooking techniques, although this is under review.
- Milk Fed Veal (MFV): Muscles from calves weaned immediately prior to slaughter receive a higher score than from earlier weaned cattle of equivalent ossification score. The magnitude of the MFV effect varies with muscle and ranges from 0 to 6 palatability units. The mechanism by which this effect occurs is currently under investigation.
- Carcass Hanging Method: This effect is applied on an individual muscle basis, with different values for each muscle and hang combination. Hanging methods are AT (Achilles tendon), TS (Tenderstretch from the ligament), TX (Tenderstretch from the aitch bone) and TC (Tendercut). Differences in palatability between AT and TS carcasses are shown in Table 3.
- Marbling: As marbling score and rib fat were positively correlated, both parameters are used to assess the impact of marbling on palatability of individual cuts. An increase in USDA marble score from 250 to 550 (equivalent to an increase from 0 to 3 marble score on the AUSMeat system) results in an increase of 8 palatability units for the striploin. The adjustment made for marbling depends on the muscle.
- Ultimate pH: A small improvement in eating quality occurs as pH declines from the threshold of 5.7 (ca. 1 palatability unit).
- Ageing: The rate of ageing is estimated differently for each muscle within each hanging option. Ageing muscles from 5 to 21 days increases the palatability score by up to 4 palatability units.
- Cooking Method: Palatability for individual muscles is predicted for a specific cooking method. Larger muscles generally have several cooking options. Grilling low connective tissue cuts resulted in the highest palatability scores. Roasting low connective cuts gave similar scores to grilling, whereas for the high connective cuts roasting gave higher palatability scores than did grilling. Stir frying and thin slicing gave similar results to grilling for low connective muscles, but relatively high scores in the high connective tissue muscles. The magnitude of the effect of cooking technique on palatability varies with muscle but can be of the order of 30 palatability units.

The following sections review the evidence from the literature for the major CCP's from the production, processing and value adding sectors used in the MSA model.

hang (AT, TC, TS)	AT
sex (M, F)	M
epbi (est %)	0
hump (cm)	0
cwt	260
uoss	160
MFV? (Y, N)	N
umb	250
d.aged	7
ribfat	12
pHu	5.60
AMC (1a, 1b, ..., 6)	1b
Saleyard? (Y, N)	N
calculated wam	0.72

cut	muscle	d.aged	GRL	RST	SFR	TSL	SC1	SC2	CRN
spinalis	SPN081		74 4	66 4	74 4	75 4			
tenderloin	TDR034				74 4				
tenderloin	TDR062		78 5	76 4	80 5				
cube roll	CUB045		62 3	62 3	62 3	64 4			
striploin	STR045a		56 3	54 3	58 3	58 3			
striploin	STR045p		53 3	53 3	56 3	57 3			
oyster blade	OYS036		63 3	61 3	66 4	69 4			
blade	BLD095				44 x				
blade	BLD096		53 3	57 3	59 3	63 3	52 3	56 3	
chucktender	CTR085			49 3	50 3	57 3	51 3	54 3	
rump	RMP131		50 3	59 3	57 3	58 3			
rump	RMP231		54 3	62 3	63 3	68 4			
rump	RMP005				66 4	69 4			
rump	RMP032				63 3				
rump	RMP087				60 3				
knuckle	KNU066		48 3	60 3	56 3	61 3	37 x	46 3	
knuckle	KNU098				54 3	59 3	46 3	55 3	
knuckle	KNU099		36 x	58 3	45 x	56 3	41 x	50 3	
knuckle	KNU100				62 3	64 4	51 3	56 3	
outside flat	OUT005			42 x	45 x	53 3	41 x	51 3	52 3
outside flat	OUT029				56 3	62 3	50 3	52 3	
eye round	EYE075		41 x	51 3	48 3	50 3	43 x	48 3	41 x
topside	TOP001		41 x		50 3	56 3	41 x	43 x	
topside	TOP033		34 x		52 3	57 3	50 3	55 3	
topside	TOP073		35 x	44 x	43 x	56 3	32 x	46 3	
chuck	CHK068''				49 3	49 3			
chuck	CHK074				61 3	66 4			
chuck	CHK078			56 3	58 3	60 3	57 3	63 3	
chuck	CHK081				59 3				
chuck	CHK082''				53 3				
thin-flank	TFL051				60 3		57 3	61 3	
thin-flank	TFL052				64 4				
thin-flank	TFL064				63 3		54 3	58 3	
rib-blade	RIB041				51 3				
brisket	BRI056				40 x	51 3	39 x	48 3	28 x
brisket	BRI057				38 x	50 3	36 x	51 3	
shin	FQshin						46 3	54 3	
shin	HQshin						54 3	59 3	
intercostal	INT037				56 3				

Figure 1. A sample output from the MSA cuts based model model, showing the inputs used to predict palatability (hanging technique, sex, estimated *Bos indicus* content, hump height, carcass weight, ossification score, milk fed vealer classification, USDA marbling score, days aged, rib fat depth, ultimate pH, AUSMeat muscle colour and selling method) and the outputs which comprise predicted palatability scores and star rating (ungraded, 3, 4 or 5 star grade) by individual muscle and cooking technique. Those cells which are blank represent muscle/cooking techniques combinations that have not been tested.

Production factors that impact on palatability

Between breed effects: Most reported breed differences in beef palatability have centred around the *Bos indicus* breed (Dikeman 1990, Burrow, Moore, Johnston, Barendse and Bindon 2001). This is particularly relevant to Australian production systems where *Bos indicus* derived cattle comprise almost 40% of the Australian cattle herd (Bindon and Jones 2001). A number of researchers (Crouse, Cundiff, Koch, Koohmaraie and Seideman 1989; Wheeler, Cundiff and Koch 1994; Hearnshaw et al. 1998) have reported that cattle with high *Bos indicus* content tend to have lower marbling scores and produce less tender and more variable striploin steaks than *Bos taurus* breeds. The magnitude of the *Bos indicus* effect tends to vary between studies with some experiments showing that greater than 25% *Bos indicus* content can have an impact on palatability (eg Morgan, Savell, Hale, Millar, Griffin, Cross, and Shackelford, 1991), although others have considered 50 (Sherbeck, Tatum, Field, Morgan, and Smith, 1995), or even 75% (Rymill 1997) *Bos indicus* content is required before consumers can detect a decline in palatability.

As MSA moved towards the cuts-based-grading system there was a large research effort to quantify the impact of *Bos indicus* content on individual muscles in the carcass. Earlier work by Shackelford, Wheeler, and Koohmaraie, (1995) examined the effect of the interaction between *Bos indicus* content and cut on palatability. They showed that the *Bos indicus* effect was significant for the *mm. triceps brachii, longissimus dorsi, supraspinatus, biceps femoris* and *quadriceps femoris* and not for a number of other muscles that were tested. For MSA the interaction between *Bos indicus* content and cut palatability was initially examined in an experiment using cuts from 50 milk-fed vealers and 40 heavy pasture-fed steers, which ranged in *Bos indicus* content from 0 to 100% (Thompson, Polkinghorne, Hearnshaw and Ferguson, 1999a). At slaughter, carcasses were stimulated using a low voltage system, and one side tenderstretched by the aitch bone. Ten cuts were collected from each side and sensory tested using a range of cooking techniques (Polkinghorne et al. 1999). Table 1 shows the regression coefficient for the palatability score of different muscles as a function of percentage *Bos indicus* content after ageing for 14 days. These results clearly demonstrate a *Bos indicus* x muscle interaction, with a decline in palatability with increased % *Bos indicus* content most evident for the muscles surrounding the spinal column (ie *Mm. longissimus* and *psoas* which make up the cube roll, striploin and tenderloin cuts). These muscles showed nearly a 10 point decrease in palatability over the range of 0 to 100% *Bos indicus* content. The concentration of *Bos indicus* effect in the loin muscles was more evident in the MSA study than in the experiment conducted by Shackelford et al (1995), as their study reported little difference in the *m. psoas major* muscle. They also reported a breed x cut x cooking interaction which was not evident in the MSA study. These results indicated that it would not be appropriate to incorporate a single *Bos indicus* adjustment across all muscles, as the magnitude of the *Bos indicus* effect was muscle dependent. The quantification of the *Bos indicus* effect has been expanded to test more muscles using a wider range of cooking techniques.

Table 1 Regression coefficients for the effect of *Bos indicus* content on the MSA palatability score of different muscles, ranked in order of the magnitude of the effect after adjustment for cooking, hanging, US marbling and ossification scores and their interactions. (Thompson et al 1999a)

Primal Cut	Muscle	Regression coeff (b)	se of b	Significance
Tenderloin	*m. psoas major*	-0.09	0.020	P<0.0001
Cube roll	*m. longissimus thoracis*	-0.08	0.021	P<0.0001
Striploin	*m. longissimus lumborum*	-0.08	0.020	P<0.0001
Brisket	*m. pectoralis profundus*	-0.05	0.038	ns
Spinalis	*m. spinalis dorsi*	-0.05	0.036	ns
Eye Round	*m. semitendinosus*	-0.04	0.022	P<0.10
Knuckle	*m. rectus femoris*	-0.03	0.019	P<0.10
Rump	*m. gluteus medius*	-0.03	0.020	ns
Blade	*m. triceps brachii*	-0.02	0.020	ns
Topside	*m. semimembranosus*	-0.01	0.018	ns
Oyster blade	*m. infraspinatous*	-0.01	0.026	ns
Outside flat	*m. biceps femoris*	0.01	0.018	ns

Breed effects on palatability tend to be restricted to contrasts between *Bos indicus* and *Bos taurus* genotypes. Breed is therefore an important CCP in Australia, where *Bos indicus* genotypes comprise a large proportion of the national herd, but would not be applicable in countries where *Bos indicus* genotypes are not used.

Growth path effects: Rapid growth over the lifetime of the animal is often cited by industry as resulting in more tender and palatable beef. Oddy, Harper, Greenwood and McDonagh (2001) reviewed the possible mechanisms by which changes in growth rate could impact on tenderness. They concluded that there was evidence that variation in growth rate could impact on the structure and cross-linking of the collagen matrix and also the proteolytic activity and potential rate of glycolysis of the myofibre component of the muscle. However, the literature is divided on the importance of the effect of growth rate on palatability, with some studies reporting no difference in tenderness or palatability due to growth rate (eg Calkins, Seideman and Crouse, 1987), whilst others have reported a positive association (eg Fishell, Aberle, Judge and Perry, 1985).

The early results from MSA found that, in commercial cattle, there was a weak but positive correlation between palatability score and growth rate (r=0.23), where growth rate was calculated from a ratio of estimated live weight gain and age was estimated by ossification score (Thompson et al 1999a). In the subsequent development of the cuts-based-grading model, palatability score was adjusted for carcass weight nested within ossification score (Thompson et al 1999a) to provide a more stable adjustment. Whilst the contribution of growth path to final palatability was not large, it was essentially additive to the impact of other CCPs identified in the model.

More recently, a detailed analysis of the Beef Quality Co-operative Research Centre (Beef CRC)/MSA database has been completed by Perry, Thompson, Reverter and Johnston, (2002). The cattle comprised both temperate and tropically adapted breeds finished to a range of slaughter weights on different finishing systems. At slaughter, striploin samples from 2,631 carcasses collected from 61 kills were submitted for testing to the MSA consumer taste panel.

Sensory data were analysed on both a within and between group basis, with separate analyses for the tropical and temperate breed groups. The within group analyses described the relationship that existed between growth rate and palatability within cohorts of animals that had been exposed to the same environmental conditions. Variation in growth rate described by this analysis can be likened to an animal expressing its potential for growth whether under ad libitum, or restricted food availability. As growth rate in the MSA model is calculated for each animal, rather than for groups, it is this relationship that is of interest here. Under this scenario, Perry et al (2002) showed a curvilinear relationship between finishing growth rate and palatability which appeared to plateau at a growth rate of approximately 1.2 kg/day. The similarity in the shape and points of inflexion of the curvilinear relationships for both the temperate and tropical breeds would suggest that the results were transportable between breed types and across environments. Within a cohort of animals an increase in growth rate from 0.6 kg/day to 1.0 kg/day resulted in an increase in palatability of approximately 4 units, which is similar to the magnitude of the growth path response described in the MSA model. Even though the growth rate effect is relatively small compared with other CCPs it is important and remains a critical control point that impacts on the production sector of the beef supply chain.

Hormonal growth promotants (HGPs): Hormonal growth promotants are widely used in the Australian beef industry as a means of increasing productivity in both the grass and grain fed sectors (Hunter, Burrow and McCrabb, 2001a). However, whilst there are clear benefits in terms of liveweight gain and efficiency, a number of studies have reported that HGP implants were responsible for reductions in marbling scores and an increased incidence of dark cutters (Duckett, Owens, Andrae, 1997, Hunter, McCrabb and O'Neill, 2001b). There is also a trend for HGP treatment to increase meat toughness, although to date the results have been variable, with a number of studies showing no impact on objective (Huck, Brandt, Dikeman, Simms and Kuhl, 1991), or sensory (Hunter et al 2001a) measurements, whilst others have indicated that HGP implants may have a detrimental effect on both objective and sensory measures of quality (eg Roeber, Cannell, Belk, Millar, Tatum and Smith, 2000). Published data on HGP effects generally refer to the striploin and have not included evaluations of other muscles.

HGP's were not initially included as a predictor in the MSA model, although recent results from both US studies and Australian studies suggest that this should be reviewed. The study by Roeber et al (2000) evaluated a number of different compounds used in different implant strategies and showed there was a trend for 14 day aged striploin steaks from implanted animals to be tougher when evaluated using a consumer panel. A similar trend was evident for objective measurements, although the differences failed to reach significance.

More recently a large study has been undertaken as part of the Beef CRC/MSA research program (B.M. McIntyre, *unpublished data*) to investigate the effect of a strong HGP implant (Revalor-S and –H) on palatability of samples from a variety of muscles. The experiment used a total of 80 Angus yearlings which were finished in a domestic feedlot. Half the steers and heifers were implanted with Revalor-S and Revalor-H, respectively. Animals were slaughtered 60 and 70 days later, whilst still within the payout period for the implants, and the striploin, rump, blade and oyster blade cuts collected for both objective and sensory evaluation. Samples were aged for 5 and 21 days prior to testing, as grills or roasted samples, by consumer taste panels.

Table 2 Predicted MSA palatability scores from grilled and roasted samples from 4 primal cuts from HGP and control animals after ageing for 5 or 21 days (B. McIntyre, unpublished data)

Cut		5 days aged		21 days aged		
	Position	HGP	Control	HGP	Control	Av se
Striploin (*m. longissimus dorsi*)	Anterior	44.6	54.4	61.6	67.1	*2.2*
	Posterior	38.0	51.2	51.8	56.3	*2.3*
Rump *(combined muscles)*		55.6	62.5	62.4	64.6	*2.0*
Oyster Blade (*m. infraspinatous*)		65.9	66.6	66.7	66.6	*2.0*
Blade (*m. triceps brachii*)		54.4	53.3	59.1	60.2	*1.9*

The rump muscles comprised the *mm. gluteus medius* and the proximal portion of the *biceps femoris* which is included in the rump cut.

To date a total of 577 samples have been sensory tested. This comprised 70% of the striploin samples and between 50 and 60% of the rump, oyster blade, and blade muscles. Despite the imbalance in sample numbers there are some clear trends. The striploin showed the largest HGP effect, with the HGP treated striploins having a 10 point lower palatability score than the controls at 5 days of ageing (Table 2). The magnitude of this HGP effect in the striploin decreased to about 5 palatability units after 21 days ageing. The HGP effect was also evident in the rump muscles, although the magnitude of the effect was less than in the striploin. An intriguing result was the clear interaction of the HGP treatment with muscle, with little evidence of the HGP effect in the blade and oyster blade muscles.

It is an MSA priority to quantify the magnitude of various HGP implants on palatability, along with guidelines for their use in terms of repeated implantation and time of slaughter relative to the payout period of the implant. When incorporated into the MSA model the HGP effect will simply quantify the magnitude of the effect in terms of palatability. The extent to which HGP's are used will depend upon the value placed by producers on the penalty for palatability relative to the advantages of increased weight gain and feed efficiency. It is likely that the size of the palatability penalties will vary considerably between markets. As the magnitude of the HGP effects decreased with ageing there is an opportunity in some markets to age the product for sufficient time to minimise the HGP effect. Other alternatives may include accelerating the ageing effect by tenderstretching HGP implanted carcasses.

Management of animals in lairage

The MSA criteria for supplying cattle are focused on minimising stress on farm, during transport, and in lairage, and therefore minimising depletion of muscle glycogen reserves prior to slaughter. Typically cattle which are well fed up until dispatch for slaughter will have muscle glycogen concentrations in the range from 60 to 120 *u*moles/g (Pethick et al 1999). To achieve an ultimate pH ca. 5.5 in the post-slaughter muscle there needs to be at least 57 *u*moles/g of glycogen in the muscle pre-slaughter to form sufficient lactic acid to lower pH (Tarrant, 1989). If glycogen reserves have been depleted below this threshold then an elevated ultimate pH will result and the meat will have a dark colour, which is typically referred to as dark cutting or dark firm dry (DFD) meat. As ultimate pH increases the meat appears to be less juicy, lacks visual appeal and has reduced shelf life (Shorthose 1989). Up to a pH of 6.0, dark cutting meat is also tougher (Purchas and Aungsupakorn 1993). MSA chose a maximum ultimate pH of 5.7, primarily because of the impact on palatability, but also due to the effect of high pH on degree of doneness, consumer appeal and shelf life.

Stress in a number of forms will deplete glycogen reserves. Ferguson, Bruce, Thompson, Egan, Perry and Shorthose (2001) concluded that the emotional state of the animal was probably more critical in mobilizing glycogen reserves than was activity that was not physically demanding (eg during transport). The effect of transport on glycogen mobilization and ultimate pH post-slaughter is not well documented and tends to vary with the type of animal, nutritional status and the conditions during transport (Tarrant 1990). The review by Ferguson et al (2001) concluded that, given ideal conditions, transport distances of less than 400 km were unlikely to deplete glycogen reserves sufficiently to impact on ultimate pH.

In Australia almost half of all prime cattle are marketed through saleyards. This method of selling is more popular in the southern states and also with small lots of cattle. Initially MSA required direct consignment of cattle to the abattoir in an effort to minimise stress and the subsequent depletion of glycogen reserves. Warner, Walker, Eldridge, and Barnett (1998) found that the combination of low nutrition and saleyard selling depleted glycogen levels in the muscle. More recently, a comparison between direct consignment and best practice saleyard selling showed a small penalty in terms of palatability (D.M. Ferguson, *unpublished data*). The best practice saleyard option required animals to be well handled, not mixed, have water available and be slaughtered the day after dispatch from the farm. Based on these results MSA has introduced a saleyard option with a 5 point palatability penalty, relative to direct consignment, for all muscles.

Mixing has been shown to cause mobilization of glycogen and should be avoided at all costs (Grandin 1993). Certainly, the data for bulls shows mixing results in high levels of dark cutting. For animals which are consigned direct to the abattoir mixing is seldom a problem, although the same cannot be said of saleyard selling.

Glycogen reserves at slaughter are a function of the initial levels of glycogen and the losses due to stresses placed on the animal during the immediate pre-slaughter period. Feedlot cattle had higher on-farm glycogen concentrations in their muscle and lost less glycogen during the loading, transport and lairage period than pasture fed cattle (D. Pethick, unpublished data). The net result was that feedlot animals had a higher buffer of muscle glycogen at slaughter and, therefore, a lower incidence of dark cutting. Other techniques to either boost initial glycogen levels, or to minimise losses during transport and lairage, have been discussed by Pethick et al (1999). Short term grain feeding prior to slaughter has been shown to have a positive response if suitable rumen modifiers are included to control acidosis (Gardner 2001). Supplementation using electrolyte preparations has had limited success in Australia, largely due to variation in intake. Other supplements

such as magnesium oxide, whilst successful in sheep (Gardner, Jacobs and Pethick, 2001a), have not been successful in cattle (G. Gardner 2001). Whilst stress can rapidly deplete muscle glycogen reserves, repletion takes considerably longer and depends upon how severely animals were depleted and upon access to and the quality of the feed during the repletion phase (Pethick et al 1999; Gardner, McIntyre, Tudor, and Pethick, 2001b).
Current research activities of the Beef CRC are aimed at both enhancing the adaptability of cattle to specific stressors and developing alternative pre-slaughter management strategies to minimise stress.

Optimising the slaughter process for palatability

pH/temperature window: The pH/temperature window was one of the initial specifications for the MSA 'carcass pathways' grading scheme. The concept of the window originated from the results of Locker and Hagyard (1963) who showed that myofibrillar shortening occurred when pre-rigor muscle was held at either low or high temperatures. At low muscle temperatures extensive shortening occurred and the subsequent increased toughness was termed 'cold shortening'. Pearson and Young (1989) considered that for cold shortening to occur the muscle pH had to be greater than 6.0 with ATP still available for muscle contraction and the muscle temperature to be less than 10°C. At high muscle temperatures some shortening also occurred, in some cases (but not all) leading to increased toughness (Uruh, Kastner, Kropf, Dikeman, and Hunt, 1986, Simmons, Cairney, and Daly, 1997). This effect was termed rigor or heat shortening and was considered to be due to the combination of high temperature and low pH in the muscle causing early exhaustion of proteolytic activity (Dransfield 1993; Simmons, Singh, Dobbie, and Devine, 1996) and increased drip loss (Denhertogmeischke, Smulders, Vanlogtestijn and Vanknapen, 1997). These studies lead to the development of the MSA pH/temperature window, whereby electrical inputs during processing were managed to achieve a pH/temperature relationship of greater than pH 6 for muscle temperatures greater than 35°C, and a pH of less than 6 for muscle temperatures less than 12°C (see Figure 2).

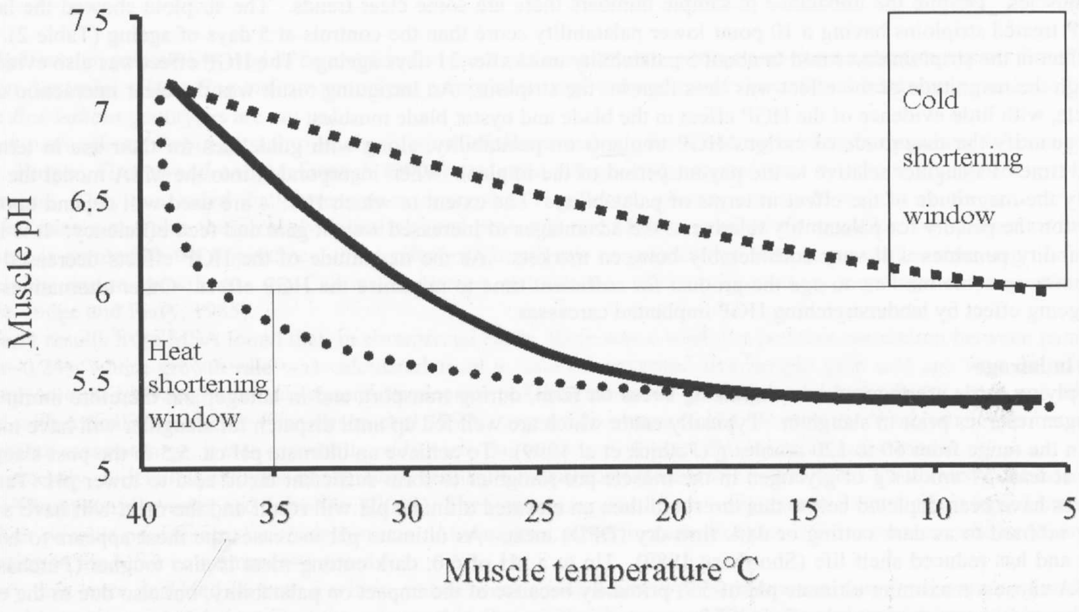

Figure 2 The pH/temperature window used by MSA to optimise the decline in pH relative to the temperature of the muscle. The solid line represents an optimal rate of decline, the dashed line a cold shortening, and the dotted line, a heat shortening scenario.

More recently, Hwang and Thompson (2001a) examined the effect on glycolytic rate, protease activity and subsequent meat quality of applying stimulation either immediately after slaughter, or just prior to entry into the chiller. They confirmed that early application of stimulation was associated with a very rapid decline in pH, which led to exhaustion of the protease system (ie lower *u*-calpain and higher calpastatin activities) and higher peak force. In a subsequent study a combination of stimulation and chilling treatments were used to cause independent variation in pH and temperature decline (Hwang and Thompson 2001b). The results showed that, *in situ,* the rate of pH decline had the largest effect on eating quality. Striploins which had a rapid decline in pH showed a smaller decrease in shear force with ageing, compared with carcasses with a much slower rate of pH fall (Figure 3). These results showed that the main penalty of a rapid pH fall was reduced ageing, and increased drip loss. Changes in *u*-calpain activities indicated that the rapid fall in pH accelerated and ultimately exhausted the activity of the *u*-calpains, which led to the reduced ageing potential in heat shortened meat. Their study also showed that the optimum pH decline to produce the most tender meat after 14 days of age was achieved with a temperature of 29 to 30°C at pH 6. This was higher than estimates of the optimal rigor temperature of 15 to 18°C obtained from *in vitro* studies (Locker and Hagyard 1963; Devine, Wahlgren, and Tornberg 1996), but could reflect the differences between the constant temperature regimes used in the *in vitro* studies, and declining temperature gradient in muscle samples *in situ.*
When the MSA pH/temperature window was implemented as part of the abattoir audit it was found that many abattoirs were effectively over-stimulating, with carcasses clearly entering the heat shortening region (ie achieving pH 6 at temperatures greater than 35°C). This was due in part to other electrical inputs being installed in the slaughter chain (eg immobilisers and rigidity probes) which, along with electrical stimulation, accelerate glycolytic rate (Petch and Gilbert 1997). It is clear that differences between abattoirs in the positioning of the stimulator, effectiveness of contact electrodes, and speed of the chain make it impossible to recommend a uniform protocol for stimulation. The approach taken by MSA is to regularly audit individual abattoirs and then adjust the electrical inputs to match the window specifications.

However, despite constant monitoring by MSA, there is still variation in glycolytic rate both between and within lots of carcasses. Abattoir audits by MSA indicate that grain fed carcasses require less stimulation than grass fed carcasses to achieve a similar glycolytic rate, as do heavy compared with light carcasses. As part of a benchmark study to quantify the sources of variation in glycolytic rate Daly, Richards, Gibson, Gardner, and Thompson, (2002) found that glycogen reserves at slaughter were positively related to glycolytic rate. However, within grain or grass fed carcasses the variance in temperature at pH 6 was of the order of 4.5°C, although the study did not identify any production factors, such as transport distance or time, that were associated with this variation. In addition, the benchmark study showed that glycolytic rate varied widely within groups of carcasses. The average within lot variance for temperature at pH 6 was 4.2°C, but ranged from 1.3 to 8.3 °C. This indicated that, in groups with a high variance, the mean glycolytic rate for a group may be within the optimal pH/temperature window, but individual carcasses within the group may be at risk of heat or cold shortening. This large variation both between and within groups of carcasses makes it difficult to optimize eating quality. In the longer term, better control of electrical inputs, in conjunction with a prediction model to allow the stimulation requirements to be specified for different classes of cattle being processed at specific abattoirs, may minimize this variation.

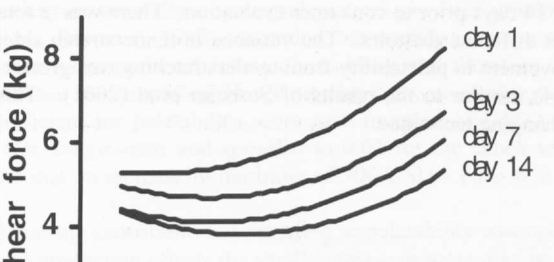

Figure 3. Shear force as a function of pH at 1.5 hours *pm*, adjusted to a temperature of 28 °C at 1.5 hours *pm* (Hwang and Thompson 2001b).

Alternative carcass suspension: Tenderstretch, or pelvic hanging, has been used to underpin a number of carcass quality assurance schemes focused on eating quality (MLC 1991; Ferguson, Thompson, and Polkinghorne, 1999). Tenderstretching is done by suspending the side by the pelvis as it comes off the slaughter chain, thereby placing increased tension on the major leg and loin muscles before the muscles pass through rigor. This increased tension is aimed at either minimising shortening, or stretching the muscles with subsequent improvement in tenderness (Hostetler, Link, Landmann, and Fitzhugh 1972; Bouton, Fisher, Harris and Baxter, 1973; O'Halloran, Ferguson, Perry and Egan, 1998).

The mechanisms by which tenderstretching pre-rigor impacts on eating quality is thought to occur via the stretching effect on both the myofibrils and connective matrix (Hostetler et al. 1972, Bouton et al. 1973). Tenderstretching increases sarcomere length, thereby reducing the overlap between actin and myosin. However, as shown by Hopkins and Thompson (2001), there was no relationship between the energy required to dissociate the actomyosin complex and tenderness in muscle samples subjected to different levels of stretching pre-rigor and therefore different levels of actin/myosin overlap. This suggested that mechanisms other than actin/myosin overlap were responsible for the improvement in palatability with tenderstretching, possibly associated with more rapid degradation of structural proteins at the junction of the Z disk and intermyofibre filaments.

Table 3 Palatability scores for muscles from electrically stimulated tenderstretched and achilles hung sides after adjustment for cooking, hanging, US marbling and ossification scores and their interactions (Ferguson et al 1999).

Muscle	Tender Stretch	Achilles	Sign
Forequarter			
Pectoralis profundus	32	35	ns
Triceps brachii	55	56	ns
Infraspinatous	61	62	ns
Longissimus thoracis	65	63	$P<0.05$
Spinalis dorsi	75	76	ns
Hindquarter			
Longissimus lumborum	61	55	$P<0.001$
Psoas major	71	74	$P<0.01$
Gluteus medius	64	57	$P<0.001$
Semimembranosus	45	38	$P<0.001$
Biceps femoris	50	47	$P<0.001$
Semitendinosus	48	47	ns
Rectus femoris	50	48	$P<0.001$

Significance levels $P<0.05$ and $P<0.001$, ns not significant

The magnitude of the tenderstretch effect in the MSA model was reported by Ferguson et al (1999). Their results (Table 3) demonstrated that the palatability of most hindquarter muscles was improved following tenderstretching. Exceptions included the *M. poas major* which was subjected to less tension pre-rigor in the tenderstretched compared with the normally hung side. Also the eye round (*m. semitendinosus)* was stretched to a similar degree in both the tenderstretched and normally hung sides and therefore showed no difference in palatability. Since this report the tenderstretch effect in the MSA model has been extended to more muscles and cooking techniques. Previously most studies have compared tenderstretched and normally hung sides in carcasses which were not stimulated. An interesting feature of the results by Ferguson et al (1999) was that the improvement due to tenderstretch was obtained in stimulated carcasses, suggesting that stimulation and tenderstretch were, to a degree, additive in their effects on palatability.
Sorheim, Idland, Halvosen, Froystein, Lea and Hildrum, (2001) reported that in unstimulated carcasses the magnitude of the tenderstretching effect interacted with chilling temperature. The greatest difference between tenderstretch and normally hung sides occurred when sides were rapidly chilled, presumably because the normally hung sides cold shortened. Sorheim et al (2001) also commented that, within chilling temperatures, the greatest response to tenderstretch occurred in carcasses with the poorer eating quality. In matched sides the variance in tenderstretched sides was approximately half that in normally hung treatments.
The MSA database was used to examine the magnitude of the tenderstretch response in matched carcasses where grilled striploin steaks from tenderstretched and normally hung sides had been aged for 14 days prior to consumer evaluation. There was a total of 195 carcasses drawn from 14 different tenderstretch experiments conducted in 8 different abattoirs. The variance in tenderstretch sides was 9 palatability units compared with 12 in the normally hung sides. The improvement in palatability from tenderstretching was greater in those carcasses with a low palatability score in the normally hung side (Figure 4), similar to the results of Sorheim et al (2001). This suggests that there is a maximum potential palatability for a muscle, regardless of hanging technique.

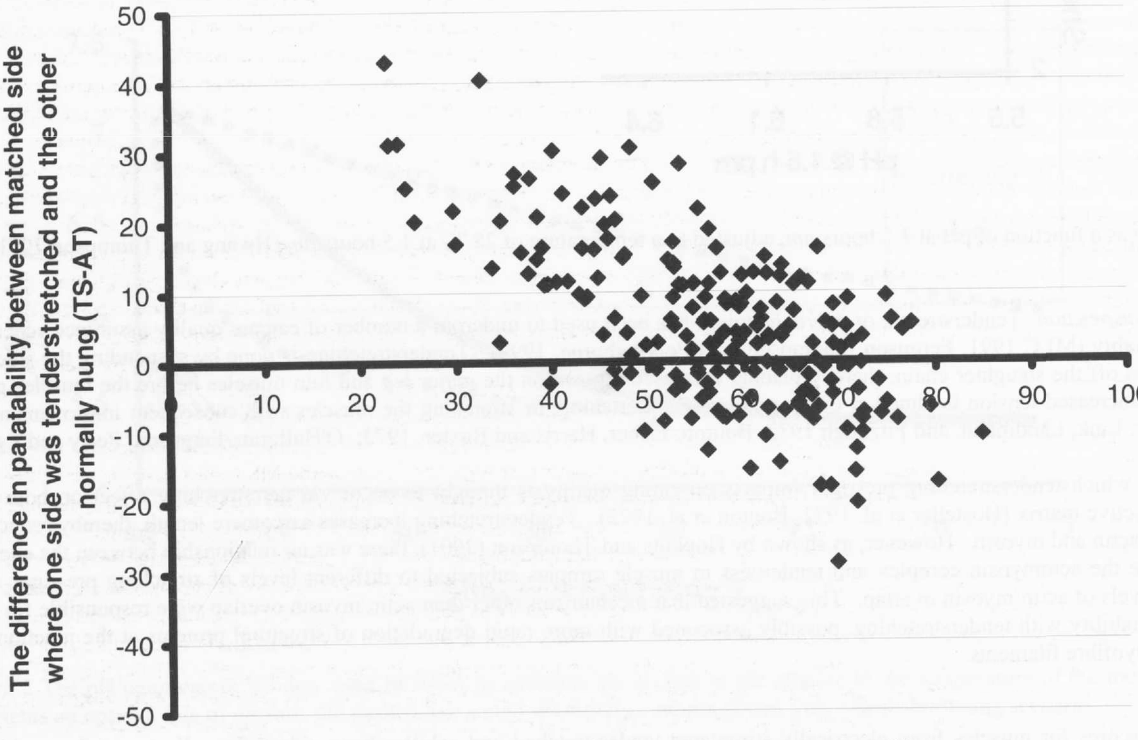

Figure 4 The relationship between the increment in striploin palatability resulting from tenderstretching one side, as a function of the palatability score of the normally hung side Striploins had been aged for 14 days.

Commercially, carcasses can be tenderstretched by suspending either through the aitch bone (obturator foramen) or through the pelvic ligament. As the suspension fulcrum is not the same for these two methods, different tension is placed on individual muscles in the leg and loin. Hwang, Gee, Polkinghorne, and Thompson, (2002) examined the effect of differences in the fulcrum point on palatability and showed that, whilst both techniques placed increased tension on the major muscles of the loin and leg, there were differences in the tension placed on different muscles and some of the minor muscles showing degrees of shortening. The impact of the shortening was variable, with some muscles appearing not to toughen even at very short sarcomere lengths (*m. gluteus profundus*), while others toughened at longer sarcomere lengths (the *m. tensor fascia latae* toughened at sarcomeres greater than 2.0 *u*m). This suggested that the relationship between shortening and palatability varied with muscle, and that the threshold length of less than 2.0 microns at which toughness starts (Bouton et al., 1973) may not be applicable to all muscles. In addition they showed that the position effect in the striploin in normally hung carcasses, whereby the anterior portion had a higher palatability score than the posterior section, was lessened by suspending carcasses by the aitch bone and ameliorated by suspension by the ligament. The comparison of tenderstretch methods was more subtle, in that it showed that for the larger muscles in the hindlimb there was a trend for suspension by the ligament to result in longer sarcomeres, although this was not reflected in either shear force or palatability score. When pooled across the hindquarter and loin muscles, suspension by the aitch bone resulted in an increase of 3.2 palatability units, relative to suspension by the ligament.

Tendercut is a more recent alternative to tenderstretching, whereby the backbone is cut and the connective tissue and other minor muscle attachments severed to allow the weight of the forequarter to place tension on the *M. longissimus* muscle (Wang, Claus and Marriot, 1994). In addition, the ischium can be broken to allow increased tension on the hindquarter muscles. The MSA results have found that, when all hindquarter and loin muscles are taken into account, the impact of tendercut on palatability was less than tenderstretching. Therefore, given that the tendercut procedure is more difficult than tenderstretching, it is unlikely that abattoirs will use this option in the MSA model.

Tenderstretching obviously provides a very cheap and effective means of managing palatability in beef and is being adopted widely by the Australian industry. The disadvantages of tenderstretching in terms of increased labour (to both tenderstretch the sides as they enter the chiller and to rehang them by the achilles tendon when exiting the chiller for boning) and decreased chiller capacity are a small price to pay for the increased palatability. The smaller tenderstretching effect in highly palatable sides is offset by the added insurance against problems in processing.

Other post-slaughter factors that impact on palatability

Marbling: Although marbling is generally an integral part of any beef grading scheme the literature suggests that it has only a minor association with palatability. Dikeman (1987) concluded that marbling accounted for only 10 to 15% of the variance in palatability. Many markets have large premiums for increased levels of marbling and therefore in many carcass grading schemes it is given a very high weighting. The MSA data base has quantified the relationship between marbling score recorded on the striploin and palatability in a range of cuts. The regression coefficient for palatability score as a function of USDA marbling score ranges from ca. 0.03 for cuts such as the striploin and cube roll (*Mm. longissimus* and *spinalis)* to 0.01 for the chuck tender (*m. infraspinatus*) and eyeround (*m. semitendinosis*). These coefficients indicate that an increase in marbling of 300 USDA units will increase palatability by ca. 6 and 3 units in these muscles, respectively.

The MSA model showed that the contribution of marbling to palatability was not high, but as this factor tends to be additive to other chiller assessment, processing, and production effects the small increase in score may be sufficient to lift the palatability score into the next grade.

Ageing: Ageing refers to the improvement in palatability that occurs as meat is held post-mortem. The mechanisms by which ageing occur have recently been reviewed by Hopkins and Thompson (2002). They concluded that ageing was a largely a function of the calpain system, even though the mode of action is not fully understood. Certainly, the body of evidence does not support the role of cathepsins as contributing to proteolysis in the early post-mortem period.

Bouton et al (1973) examined the effect of tenderstretch and ageing rate on the striploin, outside and rump muscles. They found an initial advantage due to tenderstretch relative to achilles hung sides for the all three muscles, although the subsequent ageing rate was lower in the tenderstretch samples. O'Halloran et al (1998) achieved a similar result for striploin samples.

For simplicity, calculations in the MSA model assume the ageing curve for muscle samples is linear from 5 to 21 days ageing and thereafter declines exponentially. Ageing rates for individual muscles are higher for the low connective cuts relative to high connective cuts. From 5 days the ageing rate for muscle from the hindquarter and loin of a tenderstretch side are approximately 66% of that in the normally hung side. Given that MSA testing has shown that hindquarter cuts from tenderstretch sides were more palatable at the commencement of the ageing period and had a lower ageing rate, the palatability of muscles from the hindquarter of tenderstretch and normally hung sides would converge with extended ageing.

The accuracy of the MSA model

The ability of the MSA cuts based model to accurately describe palatability grade has been tested using the MSA data base. Over 19,000 cut x cook combinations were available in the data base, after discarding those samples which did not comply with the basic criteria (ie had a fat depth less than 3mm or pH > 5.7 or ossification score > 300).

Table 4 shows that the model correctly classified between 50 to 70% of the samples, with 95 to 97% of the predicted scores being within one grade of their consumer rating. If a muscle was predicted by the cuts based model to be 'ungraded' then there was ca. a 70% chance that this agreed with the consumer panels. If the model was incorrect, it was generally only 1 grade out, ie if the model said it was 'ungraded' then there was only ca. a 30% chance it was a '3 star', but essentially little chance it was a '4 star' or '5 star'. Similarly for muscles that graded '3' or '4 star', the model was correct about 50% of the time and again, if it was wrong, it was only by one grade. At the top and bottom grades the accuracy was of the order of 60 to 70%. This is an order of accuracy greater than is possible by just using carcass measurements of fat depth, carcass weight, marbling and dentition measured in the chiller (Hearnshaw, et al 1995).

Table 4. The ability of the MSA cuts based model to correctly classify samples into consumer grades. The bolded cells represent the percentage of samples which were graded correctly according to the consumer taste panel results.

	Grade given by Consumer panel				
Predicted grade using the MSA model	Ungraded	3 star	4 star	5 star	Total
Ungraded	**68**	29	3	0	100
3 star	24	**50**	23	4	100
4 star	3	25	**49**	23	100
5 star	0	5	32	**63**	100

Conclusion

The MSA grading system is an example of a quality assurance system capable of managing palatability. CCPs which impact on palatability have been quantified using large scale consumer taste panels. For the Australian production system *Bos indicus* is an important CCP. Whilst the magnitude of the growth rate effect on palatability is smaller it is additive to breed. HGP implantation is not currently incorporated into the MSA scheme, although it can have a substantial impact on palatability and its incorporation into the model is being reviewed. Pre-slaughter and processing effects can have a large impact on palatability and the MSA system has made compliance with these CCPs mandatory. Other post-slaughter CCPs include tenderstretching, marbling and ageing which all have a significant impact on palatability. These CCPs are used as inputs into a model to predict palatability. The model provides a multitude of pathways to achieve a defined quality outcome. The rationale behind this is that, as long as handling the animal/carcass along the beef supply chain meets welfare and food safety standards the consumer is not concerned by the means by which a muscle achieved its palatability score, rather that palatability matched the description.

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