Meeting Domestic and Export Markets for Beef: Research Outcomes of the Cattle and Beef CRC, 1993-2000

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ABSTRACT: The CRC program was designed to understand the genetic and non-genetic factors affecting beef quality. This contract presents an overview of the CRC’s progeny tests for beef quality traits and net feed intake. There is scope for significant genetic improvement of retail beef yield percentage and marbling in temperate and tropically adapted breeds, using crossbreeding and within-breed selection. There is greater scope for genetic improvement of tenderness in tropically adapted breeds than temperate breeds. The CRC’s research on the genetics of feed efficiency and gene marker technologies offer potential benefits, but are yet to be exploited. CRC studies highlight significant non-genetic approaches to improving eating quality of beef. Pre-slaughter management of cattle and pathways developed for the Meat Standards Australia (MSA) grading scheme offer immediate advantages. Tenderstretching of beef carcases enhances tenderness and reduces the need for ageing of some cuts from some genotypes.

Key Words: Beef Quality, Progeny Tests, Gene Markers, Retail Beef Yield, Marbling, Tenderness, Pre-slaughter Stress, Meat Standards Australia, Crossbreeding, Tenderstretch, Electrical Stimulation, Genetic Parameters, Quantitative Trait Loci

INTRODUCTION

The CRC for the Cattle and Beef Industry was formed in July 1993 to carry out research on meat quality to enhance the domestic and international competitiveness of the Australian beef industry. At the time the CRC was formulated (June 1992), there were major challenges for the Australian beef sector. As shown in Figure 1, the period following 1988 saw a 30% growth in beef exports, with major expansion in Japan and Korea and the live cattle trade to SE Asian destinations. Grain-fed beef exports to Japan and Korea grew by 1,300% during this period. At the same time, consumers in Australia and Japan were recording their dissatisfaction with the tenderness of Australian beef products. Consistency of beef eating quality was emerging as a key element of the Australian beef trade.

SCOPE OF CRC

Breeding/Feeding/Slaughter Projects

The CRC has carried out the world’s largest progeny-test program for carcass and beef quality traits and their other genetically related traits such as growth. The straightbreeding project is a within-breed progeny test involving seven breeds from 49 cooperating seedstock herds. The northern cross-breeding project is a progeny test based on 1,000 Brahman females (donated by industry) and nine terminal sire breeds. These are illustrated in Figure 2. Progeny testing is an expensive business because it involves:

- generation of pedigreed progeny;
- purchase of progeny by CRC;
- transport to grow-out properties;
- management and agistment costs during grow out;
- grain versus grass finishing;
- transport to abattoirs;
- slaughter costs and retrieval of carcass sub-samples;
- laboratory measurement and taste panel assessment of meat samples;
- collation, analysis and reporting results.

Figure 1. Trends in beef industry export growth by product, 1988-1995 (source: AMLC (1996)).

The CRC portfolio concentrated on the genetic and non-genetic factors influencing beef quality. This followed many years of emphasis on the genetic improvement of cattle growth and adaptation to stressful northern environments. It was now time to combine our expertise in genetics, meat science and growth and nutrition to address the beef issues of the 1990s. A parallel development in molecular genetics in 1992 provided the opportunity to pursue gene markers and candidate genes for beef quality traits. A third area of endeavour chosen by the CRC was to expand Australian research on the efficiency of feed utilization, in the hope of providing long-term improvement in the economy of beef production in pasture- and grain-fed environments.
Figure 2. Design of CRC progeny tests for meat quality traits.

It is estimated that the CRC has spent nearly $32 million on this process, as shown in Figure 3.

Figure 3. CRC breeding/feeding/finishing/slaughter projects (1993-1998) – proportional funding from CRC, Core Parties and industry.

It is clear that the Commonwealth CRC cash funding accounted for 40% of these resources. But the project could not have been achieved without the generous resources of the CRC Core Parties and our beef industry sponsors. Thirty-two million dollars seems like a lot of money, but to keep this in perspective it must be appreciated that the Australian beef industry is worth some $6 billion annually. If this research guarantees the quality and competitiveness of this important export industry, then it is money well spent.

Carcase and meat quality genetics

The CRC’s breeding projects (progeny tests) have made further progress towards achieving the largest-ever bank of knowledge about carcase and meat quality of Australian beef cattle. In the CRC database there are now records of 9,651 carcasses, comprising 3,958 British breeds, 3,823 tropically adapted breeds and 1,894 crossbred animals. These results will underpin future genetic improvement schemes for meat quality traits in Australian cattle and they are playing a key role in developing growth paths to successful achievement of Meat Standards Australia (MSA) grading targets in different Australian production environments.

The results are derived from the CRC’s integrated research approach involving the Meat Science, Genetics and Growth and Nutrition Sub-programs. They provide the best-ever opportunity to understand the genetic, environmental and meat processing factors contributing to the eating quality of Australian beef.

Tenderness and retail beef yield

- Estimates of heritability ($h^2$) of (objectively measured) tenderness are low in British breeds for different muscles and are only moderate in tropically adapted breeds. Direct selection to improve these traits may not be successful.
- Non-genetic approaches, by controlling growth path and pre- and post-slaughter practices may be a more reliable method of guaranteeing beef tenderness.
- Heritability estimates for marbling, as measured by chemical intramuscular fat percentage are more promising: 43% overall; 38% in British cattle and 33% in tropically adapted cattle.
- By contrast, retail beef yield percentage (RBY%) is an important new trait studied by the CRC (achieved by bone-out of one side of most CRC carcasses). The trait is highly heritable (49 to 52%; Figure 4) in all breeds studied so far, and is of great potential economic value to the Australian beef industry. Genetic differences between extreme animals could be worth up to $100 per carcase. New opportunities for direct measurement of RBY% are becoming available in Australian processing plants. VIAscan® may provide indirect prediction of the trait.
Figure 4. Heritability estimates for tenderness of the striploin and eye-round muscles, chemical intramuscular fat percentage and retail beef yield percentage.

The economic benefits of adopting genetic improvement of retail beef yield are shown in Table 1.

Table 1. Economic evaluation of retail beef yield improvement from CRC outcomes – value to Australian beef industry

<table>
<thead>
<tr>
<th>Basis of estimate</th>
<th>Discounted net present value over 20 years (SM)</th>
<th>Internal rate of return (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base rate</td>
<td>195.0</td>
<td>65</td>
</tr>
<tr>
<td>Lowest estimate</td>
<td>4.2</td>
<td>19</td>
</tr>
<tr>
<td>Highest estimate</td>
<td>37.0</td>
<td>75</td>
</tr>
</tbody>
</table>

Currently, most of this economic benefit would flow to beef processors, but with progress in value-based marketing, cattle producers should be rewarded for using sires whose progeny have higher retail beef yield. Note that these genetic differences are not the result of heavier carcases: they result from genuine differences in body composition.

In trying to improve RBY%, cattle breeders should be aware of possible conflict with fatness traits. If, for example, RBY% is negatively correlated with marbling, then sole selection for RBY% may lead to erosion of economic benefits if marbling levels were to fall. A theoretical example is shown in Table 2.

Table 2. Economic effects of negative genetic correlation between RBY% and marbling

<table>
<thead>
<tr>
<th>Basis of estimate</th>
<th>Discounted net present value (Sm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBY% increase has nil effect on marbling</td>
<td>+195</td>
</tr>
<tr>
<td>RBY% increase 2% gives 40¢/kg loss in marbling</td>
<td>+85</td>
</tr>
<tr>
<td>RBY% increase of 1.5% gives 40¢/kg loss of marbling</td>
<td>-35</td>
</tr>
</tbody>
</table>

Genetics of marbling

The CRC has a strong commitment to marbling research. The objective is to understand how intramuscular fat can be regulated by genetic and non-genetic techniques. This would create opportunities to either increase or decrease marbling, depending on the market specifications for the trait. CRC studies of marbling cover:

- progeny testing sires for intramuscular fat percentage (IMF%);
- measurement of marbling by real-time ultrasound (RTUS) in bulls, steers and heifers to arrive at correlations with IMF%;
- analysis of the possible conflict between marbling and RBY%;
- comparison of sire progeny on grain versus grass finishing to arrive at the genetic correlation between the two nutritional environments (are the "genes" for grain and grass performance the same?);
- development of gene markers and candidate genes for marbling;
- the relationships between marbling, tenderness and eating quality;
- investigation of apparently lower marbling levels in cattle finished in northern versus southern feedlots.

Good information is now available on the heritability of marbling when measured by different methods. This is shown in Figure 5 (Johnston et al., 1999).
Figure 5. Estimates of heritability of marbling in the same cattle when measured as IMF%, or as marble score using AusMeat or Meat Standards Australia (MSA) graders (n=4,000).

Intramuscular fat percentage is moderately to highly heritable. AusMeat marble score is less heritable, meaning that this measure may be influenced by environmental factors such as chiller conditions or inconsistencies between assessors. Heritability of marbling assessed by MSA graders, however, is closer to the heritability of intramuscular fat percentage. These results highlight a significant industry issue: we need to find a more reliable way to measure intramuscular fat percentage, perhaps “on-line” in the abattoir. It must be closely calibrated to marble score while ever this measure is the “accepted” trait on which carcase payment is based.

Genetics of feed efficiency

The CRC has invested substantial resources to measure individual feed intake of groups of cattle fed a standard feedlot diet.

Net feed efficiency refers to actual feed intake adjusted for an animal’s weight and growth rate. The idea is to identify cattle that eat less feed for the same gain. The CRC now has data on some 1,200 British and tropically adapted steers, shown in Figure 6. Here Robinson et al. (1999) estimated the heritability estimates for feed intake, liveweight, net feed efficiency, P8 fat depth and marbling measured as IMF%. Net feed efficiency in these data has low to moderate heritability (~30%), lower than that for feed intake. Figure 6 also presents the genetic correlations between net feed efficiency and fatness measures of P8 fat depth, IMF% and the 12/13 rib fat depth. These are all slightly negative. This means direct selection for net feed efficiency is likely to lead to small reductions in these fatness traits.

So far we have identified significant between-sire differences in net feed efficiency within each of the Hereford, Angus, Murray Grey, Shorthorn, Belmont Red, Brahman and Santa Gertrudis breeds. In the near future, we will release EBVs for sires studied by the CRC, initially to cooperating breeders, then to the industry in general.

Figure 6. Heritability estimates for feed intake, liveweight, net feed efficiency, P8 fat and IMF% (and genetic correlations between net feed efficiency and P8 fat, IMF% and 12/13 fat depth) – CRC cattle, feedlot diet (n=1,165).

Superior sires identified

Estimated Breeding Values (EBVs) for meat quality traits have been released to co-operating breeders, breed societies and now to the cattle breeding industry in general. In some cases, these results have had significant immediate impact on the seedstock industry.

CRC analyses have examined sire EBVs for traits thought to be antagonistic. This approach (“Sire Solutions”), for example, compared sires on the basis of RBY% and marbling, traits normally thought to be negatively correlated. In all breeds studied, there is, in general, a negative association between the traits. Sires with high RBY% generally have lower fatness, including marbling (see Figure 7, as example). However, there are sires with high genetic merit for both traits.

Figure 7. Sire rankings for IMF% and RBY% in the tropically adapted breeds.

Gene marker technology

The present difficulty with this technology is to work out how to test enough sires for net feed efficiency to ensure that enough steer progeny by high net feed efficiency sires are available for feedlot use. We must also ensure that such progeny have acceptable merit for other traits such as growth, marbling and beef quality.
The CRC has invested heavily in the search for gene markers and candidate genes for beef quality traits. Specialized gene marker families were set up to facilitate this work (Hetzel et al., 1997) and promising quantitative trait loci (QTL) then evaluated in the CRC’s progeny test population. Promising linked markers exist for growth, carcase yield, fatness, marbling, beef tenderness and meat/fat colour. Candidate genes with promising predictive value for marbling and tenderness are being further evaluated in a consortium involving CSIRO, Meat and Livestock Australia and the CRC. Licensing arrangements with an Australian company are close to completion. The CRC’s database, comprising genotype information and the matching growth, carcase and meat quality phenotypes, is regarded as an invaluable asset for the Australian beef industry.

Industry adoption of CRC outcomes

Results from the CRC projects have now been released to industry. Molecular genetics outcomes are being commercialized through an Australian spin-off company. Adoption of results from the CRC’s genetics research has been facilitated by publishing EBVs for all meat quality traits measured on CRC sires from the seven breeds in the progeny test. Northern crossbreeding results will not be finalized until early 2000.

As already identified in this paper, the genetic improvement of retail beef yield offers handsome economic returns. Economic benefits for the Australian beef sector from CRC outcomes depend on serious industry adoption of:

- improved RBY%
- improved beef tenderness via genetic and meat processing technologies
- improvement in Japanese B3/B4 exports through CRC results on genetic and nutritional manipulation
- genetic improvement of net feed intake in Australian feedlot cattle
- improved management of cattle during backgrounding
- improved northern cattle growth through enhanced hormonal growth promotant
- improved economies of feedlot cattle via CRC’s novel bovine respiratory vaccines
- enhanced markets for Australian cattle as a result of reduced antibiotic residues
- improved precision of genetic selection from linked gene markers and candidate genes
- a more skilled meat industry work force

ACHIEVING BEEF QUALITY BY QUANTITATIVE AND MOLECULAR GENETIC TECHNIQUES

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Genetic variation in quantity and quality of beef is evident through differences between breeds and crossbreeds and sires within breeds. Within-breed variation includes direct genetic effects and also the correlated impacts of direct genetic effects on other economically important productive and adaptive traits. Over the past decade, there has been an increasing emphasis on development of molecular tools such as genetic markers, to improve beef production and quality through marker-assisted selection (MAS).

Australian beef producers are faced with the challenge of using vastly different production environments and marketing systems to produce cattle that are both productive and profitable. A particular challenge for beef producers in harsh northern Australian environments is that cow herds must remain well adapted to the environment, whilst their slaughter offspring must meet increasingly more stringent requirements of beef markets and feedlots in more benign environments. To do this, knowledge of genetic and non-genetic factors that affect adaptation and beef production and quality is required. The purpose of this paper is to summarize results from the CRC for the Cattle and Beef Industry (Meat Quality) cattle breeding projects, particularly with respect to the improvement of carcase and beef quality attributes using both quantitative and molecular genetic tools.

Northern crossbreeding project

The CRC’s northern crossbreeding project was based on ~1,000 Brahman females, joined over three breeding periods between 1995/96 and 1997/98. Sire breeds used in the project were selected to represent different biological types and included Bos indicus (Brahman - purebred control); Bos taurus - British (Angus, Hereford, Shorthorn); Bos taurus - European (Charolais, Limousin); Brahman x British-derived (Santa Gertrudis); Brahman x European-derived (Charbray); and Sanga-derived (Belmont Red). Experimental progeny were finished to one of three target carcase weights (domestic market ~220 kg; Korean market ~280 kg; or Japanese market ~340 kg) either on grain or at pasture in central Queensland or in the CRC’s experimental feedlot near Armidale in NSW.

Measurements recorded on all animals included growth from weaning to slaughter, repeated ultrasound scans for carcase attributes recorded at least at six-monthly intervals between weaning and slaughter and complete carcase and meat quality measurements. As
well, since July 1998, samples of striploin of every carcase generated in the project have been evaluated by consumer taste panel as part of Meat and Livestock Australia’s Meat Standards Australia (MSA) scheme. A description of the CRC’s research facilities is given by Bindon (2000). Details of the northern crossbreeding project and measurements recorded on the live animals are described by Upton et al. (2000). Details of carcase and beef quality measurements are described by Shorthose et al. (2000).

Preliminary project results are reported by Newman et al. (1999a,b). The majority of carcases represented in the preliminary results were derived from animals finished on grain and those targeted for domestic- and Korean-market weights. It is likely that results will change as more data accrue from animals finished at pasture and those slaughtered at heavier carcase weights. Main results from these analyses were:

- European sire breeds produced progeny that were heavier, leaner and had higher yielding carcasses than the other sire breeds. Progeny of Charolais sires had carcases that were 21% heavier than purebred Brahman controls.
- Angus, Belmont Red and Shorthorn sires produced progeny, at export market weights, with the highest IMF%.
- Purebred Brahman progeny had less tender meat than progeny of all other sire breeds, although differences between sire breeds for compression measurements were not as great as for other indicators of beef toughness. Compression is believed to be a better indicator of toughness due to collagen content than shear force measurements, suggesting that collagen content is not an issue with respect to toughness in these animals, although all animals were less than 2.5 years of age at slaughter.
- Crossbred progeny finished at pasture in central Queensland were considerably older and leaner, had larger eye muscle areas, higher RBY%, greater weight of retail primal cuts and had tougher beef than progeny finished in either the northern or the southern feedlot environments.
- Animals of high Bos indicus content are failing to achieve MSA 3-star grades without the use of special processing techniques such as tenderstretch.

To determine whether some sire breeds were more suited to particular market endpoints than others, data were analyzed within markets. Notable results from preliminary analyses include:

- European and British sire breeds over Brahman cows produced carcases that were consistently heavier at all market weights than progeny of tropically adapted sire breeds. This may change as more animals are finished at pasture and to older ages.
- Differences between sire breeds were relatively small for yield traits at domestic market weights, but increased from domestic to export market weights.
- Differences between sire breeds for IMF% were not expressed at domestic market weights, where IMF% values were very low.
- P8 fat depth in progeny by European sire breeds was adequate for domestic market specifications and was similar to that of progeny of British breed sires at the lighter carcase weights.
- At Korean and Japanese market weights, progeny of European sires were leaner and had greater RBY% than the other crossbred genotypes.
- Purebred Brahman progeny had less tender meat than Brahman-crossbred progeny at all market endpoints.

**CRC straightbreeding project**

The CRC’s straightbreeding project was a large progeny test for carcase and beef quality attributes, based on seven breeds in which pedigreed calves, generated in industry herds, were purchased by the CRC at weaning and were managed through a complex research protocol until slaughter. Breeds included in the project were from diverse biological types and from environmentally diverse properties of origin. Bos taurus breeds included four British breeds (Angus, Hereford, Murray Grey and Shorthorn) and the Sanga-derived Belmont Red breed. The Brahman breed represented Bos indicus breeds. The Santa Gertrudis breed represented the Bos indicus x British stabilised breeds. Belmont Red, Brahman and Santa Gertrudis breeds are all tropically adapted breeds. British cattle for the project were bred only in temperate areas and tropically adapted cattle were bred only in tropical and subtropical areas of Australia.

All sires in the project were performance recorded through GROUP BREEDPLAN to allow evaluation relative to industry standards. Genetic linkages were generated between herds of the same breed by use of common sires in all herds.

Experimental progeny were allocated within sire and property of origin to either pasture- or grain-finish and to domestic-, Korean- and Japanese-market carcase weights, and followed the same experimental protocol that was applied to the CRC’s crossbred calves. Full details of the experimental design are given by Robinson (1995), whilst descriptions of the experimental facilities, measurements in live animals and carcase and beef quality measurements are given by Bindon (2000), Upton et al. (2000) and Shorthose et al. (2000).

Main outcomes from the CRC’s straightbreeding project include:

- CRC results have provided the basis for new Estimated Breeding Values (EBVs) for carcase and beef quality traits in Australia’s national beef genetic evaluation scheme, BREEDPLAN. EBVs for carcase traits are now expressed on a 300 kg carcase weight basis and include new EBVs for carcase weight, RBY% and IMF% (marbling).
Gene markers for carcase and beef quality

Gene markers for carcase and beef quality attributes in breeding cattle is generally difficult and expensive. Use of real-time ultrasound scanning for eye muscle area and fat thickness as a predictor of RBY% is an effective tool for genetic evaluation of carcase quantity in young animals and is also potentially useful for genetic evaluation of IMF% in young animals. The only other tool currently available to genetically evaluate carcase and beef quality attributes is by obtaining abattoir data from designed progeny tests, a long-term and expensive option. The development of MAS could potentially allow direct evaluation of breeding animals for these traits and substantially reduce the time needed for evaluation. Preliminary data from genome-wide screening of DNA markers through the CRC’s program have revealed a number of putative QTL associated with carcase and beef quality attributes.

Hetzel et al. (1997) and Hetzel and Davis (1999) reported outcomes from three large half-sib families of about 200 progeny/sire that were bred from F₁ Charolais x Brahman bulls mated to unrelated tropically adapted composite breed dams. The progeny were finished on pasture in central Queensland and slaughtered at about three years of age. Details of design, measurements and genotyping are reported by Hetzel et al. (1997). More than 100 QTL associated with variation in growth, carcase and beef quality were detected (Hetzel and Davis, 1999). Table 1 shows the size of effects of some of the QTL detected for carcase and beef quality attributes.

Main outcomes from the project include:

- **Growth**: An average of 4.1 QTL per growth trait were detected. Quantitative trait loci were located on eight different chromosomes, with a concentration on five chromosomes (5, 6, 14, 19 and 21.) Sizes of effect ranged from 0.5 to 1.6 s.d., with a relatively high frequency of large QTL in excess of 1 s.d. The QTL will allow selection for combinations of early and late growth.

- **Retail yield**: On average, three QTL per beef yield trait were detected. The effects were smaller than for growth, being in the range of 0.5 to 0.7 s.d. and accounting for <30% of phenotypic variance within sires. A large QTL of almost 1 s.d. was found for carcase value.

- **Fatness traits**: were analyzed for sexes separately and combined, due to differences in means and variances. Using this approach, an additional QTL was detected in females for rib fat and for marbling in males. Some QTL had effects of >1.5 s.d. Because the distribution of marbling scores was binary rather than normal, estimated sizes are likely to be biased upwards. Different QTL were observed in each sex for both rib and rump fat. Similarly, QTL detected for marbling and IMF% were on different chromosomes. By contrast, the IMF% and moisture loss QTL were in the same region.

- **Beef tenderness**: An average of 2.2 QTL were detected per tenderness trait. Sizes of the effect ranged from 0.5 to 0.8 s.d., accounting for up to 25% of phenotypic variance. QTL for beef tenderness attributes in either of the longissimus dorsi or semitendinosus muscles were often in the same region.

- **CRC data**: In conjunction with seedstock data, have allowed the estimation of the relationship between live animal ultrasound scans of carcase traits (fat depth, eye muscle area and IMF%) and abattoir measures of those traits. Genetic correlations between ultrasound carcase measures in seedstock bulls and heifers with the same trait measured in the CRC slaughter progeny were moderate to high (Reverter et al., 2000). Selection based on scanning in seedstock herds can effectively improve carcase traits of the slaughter animal.

- **Heritability of IMF%**: was moderate in tropically adapted (0.33) and in temperate breeds (0.38). However, the amount of additive genetic variance in the tropically adapted breeds was much lower (Johnston et al., 1999).

- **Retail beef yield percentage**: is highly heritable in both temperate and tropically adapted breeds (Burrow et al., 2000).

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- **Retail beef yield percentage**: is highly heritable in both temperate and tropically adapted breeds (Burrow et al., 2000).

- **A moderate to strong antagonistic genetic relationship exists between RBY% and IMF%**: (Burrow et al., 2000). This relationship needs to be considered in selection programs for RBY%.

- **A comparison of objectively measured tenderness in domestic-, Korean- and Japanese-weight carcases showed no significant difference and was consistent for both grain- and pasture-finished progeny. This finding is also consistent with results from the CRC’s crossbreeding project and confirms the common practice of slaughtering animals at light carcase weights to guarantee beef tenderness is not a valid approach to ensure eating quality.

- **Sires that are genetically superior for RBY%**: IMF% and beef tenderness have been identified in all tropically adapted breeds, including sires that have high genetic merit for both RBY% and IMF%.
chromosomal region. However, there was little commonality in QTL location between the two muscles.

- **Meat and fat colour:** The number of QTL detected for meat and fat colour traits averaged only 1.2. There were no QTL regions in common between meat and fat colour.

- **Quantitative trait loci for carcase and beef quality traits:** were distributed throughout the genome, with a concentration on chromosomes 5, 6 and 14.

**Table 1. Size of effects of QTL for carcase and beef quality traits (from Hetzel et al., 1997)**

<table>
<thead>
<tr>
<th>Trait</th>
<th>Herd mean</th>
<th>Actual units</th>
<th>Standard deviation units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcase weight (kg)</td>
<td>268</td>
<td>9</td>
<td>1.5</td>
</tr>
<tr>
<td>Dressing percentage</td>
<td>50.5</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>RBY1 (kg)</td>
<td>196</td>
<td>8</td>
<td>1.1</td>
</tr>
<tr>
<td>EMA (cm²)</td>
<td>69.8</td>
<td>6.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Marble score (units)</td>
<td>1.2</td>
<td>0.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Peak force (kg)</td>
<td>5.8</td>
<td>0.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Rump fat (mm)</td>
<td>10.5</td>
<td>2.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Fat colour (units)</td>
<td>16.0</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Tend. index1 (units)</td>
<td>8.4</td>
<td>0.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

1RBY = retail beef yield; EMA = eye muscle area; Tend. index = tenderness index where 0 = extremely tender and 15 = extremely tough.

Evidence to date shows that genetic markers can be used to identify specific chromosomal regions where genes constituting QTL are located. However, it is likely that the linkage phases identified from one particular set of families may not apply to other populations. This means that QTL detected using linkage analysis will be difficult to exploit beyond the research population. Before commercial use, markers must be validated in independent populations and ideally, the genes themselves identified and cloned to provide direct tests for the genes of interest.

In the short to medium term, increasingly dense bovine genome maps will facilitate practical application of MAS for major genes and QTL for carcase and beef quality characteristics and other difficult-to-measure traits. In the medium to longer term, development of diagnostic tests will be required for more accurate MAS applications, either through within-breed selection or introgression of economically important genes from one breed grouping to another. There are potential genetic benefits to beef producers from ongoing developments in the molecular genetics field, but producers need to recognize that molecular technologies are unlikely to replace traditional genetic evaluations. Rather, the molecular tools, in conjunction with crossbreeding and within-breed selection will increase the accuracy and rate of genetic progress.

**PRE-SLAUGHTER STRATEGIES TO IMPROVE BEEF QUALITY**

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The process of marketing cattle for slaughter results in inevitable losses in both beef quality and quantity. The magnitude of these losses will depend on the intensity and duration of the various stressors that apply between the farm gate and abattoir and also the susceptibility of the animal to stress. During the pre-slaughter phase, cattle can be exposed to several stressors that include:

- fasting;
- dehydration;
- novel/unfamiliar environments;
- transport;
- increased human contact;
- changes in the social structure (that is, through separation and mixing of cattle);
- sudden climatic changes.

These stressors or stimuli result in a perturbation of the animal’s homeostasis. An adaptive response is then initiated to restore balance and this might involve a simple alteration of behaviour (for example, movement away from an aggressive contemporary) or more complex autonomic and/or neuroendocrinal changes may be invoked. This response is often non-specific, and considerable variability exists between animals in their perception of the stressor and the co-ordination of the physiological response. Both are modulated by several intrinsic factors (for example, genetics, sex, age, and physiological state) and by past experiences and acquired learning (Moberg, 1985).

**The effects of pre-slaughter stress on beef quality**

Sustained efforts by the animal to restore balance with its environment incur inevitable costs. During the pre-slaughter period, one of the most obvious costs is weight loss. Cattle deprived of both feed and water will lose approximately 0.75%/day of initial liveweight (Shorthose and Wythes, 1988). This will vary depending on the treatment of the animals (for example, duration of fast, transport conditions etc.) and their condition. Furthermore, weight loss is not linear with time. The greater part of weight loss, predominately gutfill, is lost within the initial 24 hours post-farm. Further losses will accrue depending upon the duration of feed and water restriction and the level of physical activity. Losses in carcase weight are generally not observed until about 48 hours after feed and water withdrawal, with the latter taking on far greater importance. Dehydrated cattle given access to water will quickly rehydrate with noticeable increases in muscle weight and moisture content after three hours of rehydration (Wythes et al., 1980).
In relation to meat quality, pre-slaughter losses in muscle glycogen reserves are unequivocally the most critical. In healthy well-fed cattle, muscle glycogen concentrations typically range from 60-120 μmol/g muscle (approximately 1-2% of wet muscle weight) (Howard, 1963; Tarrant, 1989; Pethick et al., 1999), although levels as high as 200 μmol/g have been reported for grain-fed cattle (Pethick et al., 1999). Muscle glycogenolysis occurs during pre-slaughter handling of cattle through the combined effects of increased physical activity and adrenal activation. Prior to slaughter, some loss in glycogen can be accommodated without any deleterious effects on meat quality. However, if the pre-slaughter glycogen reserves fall below a threshold of approximately 40-57 μmol/g (Howard, 1963; Tarrant, 1989), then there is insufficient substrate to convert to lactic acid and consequently, the ultimate pH (pHu) of the meat will progressively increase. Meat with a high pHu (>5.8) is typically referred to as dark cutting or dark, firm and dry (DFD). It is characterized by a darker colour, higher water holding capacity and, depending on the pHu, increased toughness (especially between pHu 5.9 to 6.2, see Purchas and Aungsapakorn, 1993). Dark, firm and dry beef therefore lacks both visual and organoleptic appeal and has a predisposition to increased microbial spoilage (Shorthose, 1989).

Within the CRC for the Cattle and Beef Industry, a strict protocol was applied during the pre-slaughter management of progeny from its two large breeding projects. This was enforced to minimize any pre-slaughter stress and therefore any potential for dark-cutting or losses in meat quality. Typically, cattle were mustered and yarded within 24 to 48 hours of slaughter. The cattle were trucked to the abattoir using approved stock carriers, held overnight in lairage in their groups and slaughtered the following morning. At all times either on-farm or during lairage the cattle had full access to water.

Table 1. Percentage of CRC straightbred progeny with longissimus ultimate pH (pHu) >5.8

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Per cent pHu &gt;5.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straightbred Progeny</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pasture finished (CQ)</td>
<td>651</td>
<td>2.6</td>
</tr>
<tr>
<td>Feedlot finished (CQ)</td>
<td>953</td>
<td>1.6</td>
</tr>
<tr>
<td>Pasture finished (NE)</td>
<td>1393</td>
<td>3.7</td>
</tr>
<tr>
<td>Feedlot finished (NE)</td>
<td>2528</td>
<td>0.5</td>
</tr>
</tbody>
</table>

CQ = Central Queensland  
NE = New England Tablelands, NSW

Notwithstanding the lack of any contrasting treatment, it could be argued that this protocol was conducive to minimizing stress given the relatively low incidence of DFD (0.5 to 3 % pHu >5.8) in CRC progeny (see Table 1). In previous Australian surveys, the incidence of DFD (that is, pHu >5.8) in beef carcases was reported at 8 to 10% (Shorthose, 1989; Warner et al., 1988). The results shown in Table 1 also support previous data that in general, feedlot cattle have a lower predisposition to dark cutting (Warner et al., 1988). This can be attributed to their higher muscle glycogen levels (Pethick et al., 1999) and the influence of increased exposure to handling and human contact in feedlots compared to cattle off pasture.

A feature of the management of CRC cattle was the frequency with which they were handled (yarded and weighed every one to two months depending on location) for the purposes of determining growth and productivity. This would be in excess of that received by most commercial cattle. It is likely that this habituation to handling was beneficial during the pre-slaughter phase, as it may have attenuated the animals’ stress response. Research with other meat animals such as pigs and poultry has demonstrated clear benefits in productivity through frequent positive interaction between animal and handler (Hemsworth and Gonyou, 1997). In the context of minimizing pre-slaughter stress, habituating cattle to handling and transport is viewed as a worthwhile strategy, but has yet to be proven scientifically.

Alternative pre-slaughter strategies

The protocol described above is commonly applied during the direct consignment of slaughter cattle. Variations to this procedure such as reducing the time in lairage (Purchas, 1992) and electrolyte supplementation (Schaefer et al., 1997) have been shown to have positive effects through reductions in carcass weight loss and the incidence of dark cutting (pHu >5.8). In a CRC study, Butchers et al. (1998) demonstrated that early rather than late arrival (five days prior to slaughter) at the abattoir and provision of feed to feedlot cattle produced quite dramatic changes in the post-mortem rates of glycolysis and meat quality, notably, tenderness and juiciness scores. Also pertinent here are the results of Jeremiah et al. (1992) who demonstrated the negative effects of feed and water withdrawal prior to slaughter on tenderness, flavour intensity and overall palatability of beef from bulls. Given these results, there would appear to be some scope for further improvement of eating quality through the investigation of alternative pre-slaughter management strategies.

In a second CRC study by Newsome et al. (1999), the effects of time in lairage and lairage feeding were examined. Briefly, 60 feedlot cattle (Brahman and Charolais x Brahman) were trucked to the abattoir four days prior to slaughter and allocated to one of three feeding treatments:

- **Group 1**: Fed a grain ration for four days;
- **Group 2**: Fed a grain ration for three days and fasted for one day;
- **Group 3**: Fed a grain ration for two days and fasted for two days;

A fourth group (Control), representing current practice, was trucked the day before slaughter and...
fasted overnight, but given access to water. All groups were slaughtered on the same day. The results of taste panel tests revealed that consumers rated the steaks from cattle that were fed either four days or three days in lairage significantly better than the other two groups. Interestingly, the differences in sensory tenderness score or shear force measurements were not significantly different. Rather the difference was associated more with improved flavour and juiciness (see Figure 1).

The practice of early arrival and lairage feeding is unlikely to be a viable commercial option. However, the results highlight the fact that there is scope for further improvement in beef eating quality via alternative pre-slaughter management of cattle.

The Eating Quality of Beef: Cooperative Research Centre Contributions to the Meat Standards Australia Beef Grading Scheme

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The Meat Industry Strategic Plan of 1996 identified a total of six strategic imperatives that were considered essential for the longer term sustainability of the industry. Three of these six strategies encompassed the development of better description and marketing systems which would provide a consistent beef eating experience to the consumer. As a means of achieving these strategies the Meat Research Corporation began development of a new meat-grading scheme for Australia.

During the later part of 1996 and early 1997, discussions were held with several interested parties, including the CRC for the Cattle and Beef Industry, to formulate a proposed structure for the new meat grading scheme. The intention was to develop a total systems approach, whereby the critical control points that impacted on palatability were identified and incorporated into a grading scheme focused on delivering beef palatability to the consumer.

Since these initial meetings in 1996, the Meat Standards Australia (MSA) grading scheme has gone through a rapid evolution. Consumer testing for the first pathways commenced in June 1997 and in November 1997, a prototype carcass grading scheme was launched in the Brisbane market. Subsequent to this, there were a number of modifications and additions to the carcass pathway scheme as new results emerged from the consumer testing. In this context, "pathways" refers to a defined set of critical control points between conception and delivery of beef to a consumer. In mid-1998, the concept of extending the carcass-based grading scheme to a cuts-based grading scheme was initiated. Over the next six months, consumer tests on individual muscles from carcases, sourced from a number of experiments, incorporating different cattle breeds from different finishing systems and post-slaughter treatments, were conducted. The results from this research have underpinned the development of a cuts-based grading system, which was launched in Sydney in June 1999, with plans to roll out the scheme nationally by mid-2001.

The CRC has played an important role in the development of the MSA grading scheme. As mentioned, CRC staff were initially involved in formulating the grading concepts. Via the MSA pathways team, CRC staff have an ongoing role in direction of research and model development being undertaken as part of the MSA scheme.

Results from a number of CRC experiments, including the straightbred and crossbred breeding projects, have been used to develop the carcass grading scheme and more recently the cuts-based grading scheme. In addition, a number of the strategic research projects undertaken by the CRC Meat Science Sub-program have had application to particular aspects of the MSA system. This paper will detail some areas of interaction between CRC and MSA.

The "pathways team"

The development of MSA has been under the direction of the pathways team. The role of the pathways team is to both formulate the direction of developments in MSA and to evaluate the results of research with a view to incorporation into the MSA system. This team comprises a number of MSA and CRC staff, plus several other scientists from institutions around Australia. Membership of the Pathways Team has tended to vary depending upon the particular problems at hand, the guiding principle being to draw on the best expertise available.
The MSA database

One of the unique features of MSA is the sensory database it has developed. This database was described briefly by Polkinghorne et al. (1999). To date it comprises over 200,000 consumer responses, on over 20,000 samples of meat from a range of cuts and cooking techniques. The database was initially used to validate the inclusion/exclusion of various grading criteria in the carcase grading scheme. More recently it has been used to develop complex prediction models of palatability of specific muscles, subjected to a range of production and processing treatments. The database is located at the CRC in Armidale with a full-time biometrician supported by MSA.

The CRC straightbred and crossbred breeding projects

Prior to the inception of MSA, the CRC commenced the straightbred and crossbred progeny tests discussed earlier in this contract. These CRC programs were aimed at obtaining genetic variances and breed parameters on meat quality using laboratory measurements. The development of the MSA sensory protocol for testing large numbers of meat samples using consumer taste panels provided an opportunity to obtain genetic variances on the five sensory dimensions (tenderness, flavour, juiciness overall acceptability and the combined CMQ4 score).

Since July 1997, all striploin samples from CRC straightbred and crossbred cattle have been evaluated by the MSA consumer panels. Early analysis of the objective measurements have indicated moderate genetic variance in shear force and compression measurements in the tropically adapted breeds, whilst only limited genetic variance in the temperate breeds (Robinson et al., 1998). Genetic analysis of the MSA palatability scores is currently being undertaken.

The straightbred project involved purchasing pedigreed calves at weaning from commercial co-operators to be placed on various backgrounding and finishing systems prior to slaughter and as such was not designed to estimate direct breed effects. However, the crossbred cattle were generated from Brahman cows managed together on the one property and therefore the MSA palatability scores from these striploin samples were used to estimate breed effects for the MSA scheme. The CRC backgrounding and finishing regimes were ideal to estimate the importance of a number of production effects on palatability. In addition, as CRC only collected samples from one side for analysis, it was possible to overlay some post-slaughter treatments, such as tenderstretch and tendercut on the CRC cattle without compromising the genetic objectives.

CRC strategic research projects

The effects of *Bos indicus* content, tenderstretch and ossification on palatability of cuts

For the development of the cuts-based model, the emphasis of the MSA research program changed from testing the palatability of grilled striploin samples from a large numbers of carcases, to testing specific production, processing and cooking effects on a wide range of cuts within the carcase. To this end, NSW Agriculture (Grafton) crossbreeding program provided an ideal resource for MSA, as both milk fed vealers and heavy grass fed steers were available from genotypes with a range of *Bos indicus* content (Hearnshaw, 1999).

As for the CRC straightbred and crossbred projects, it was possible to overlay post-slaughter treatments (both tenderstretch and tendercut) without compromising the breed comparison objectives. MSA and CRC undertook total cut collections from 120 carcases with more than 3,500 samples sensory tested for a range of cooking and treatment effects. In combination with samples from commercial groups of cattle, these data provided the basis for development of the cuts based model. Tables 1 and 2 provide examples of some of the more important interactions from these analyses.

The *Bos indicus* content x muscle interaction (Table 1) showed that the *Bos indicus* effect varied greatly with muscle and tended to be highest in the low connective tissue muscles which surrounded the spinal column. This suggests that the major part of the *Bos indicus* effect was mediated via the myofibre component. Subsequent CRC studies at CSIRO Cannon Hill laboratory have indicated that part of the breed effect may occur through differences in membrane permeability (D. Ferguson, unpublished data).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Regression coeff (b)</th>
<th>se of b</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psoas major</td>
<td>-0.09</td>
<td>0.020</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Longissimus thoracis</td>
<td>-0.08</td>
<td>0.021</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Longissimus lumborum</td>
<td>-0.08</td>
<td>0.020</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Pectoralis profundus</td>
<td>-0.05</td>
<td>0.038</td>
<td>ns</td>
</tr>
<tr>
<td>Spinalis dorsi</td>
<td>-0.05</td>
<td>0.036</td>
<td>ns</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>-0.04</td>
<td>0.022</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>-0.03</td>
<td>0.019</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>-0.03</td>
<td>0.020</td>
<td>ns</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>-0.02</td>
<td>0.020</td>
<td>ns</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>-0.01</td>
<td>0.018</td>
<td>ns</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>-0.01</td>
<td>0.026</td>
<td>ns</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>0.01</td>
<td>0.018</td>
<td>ns</td>
</tr>
</tbody>
</table>
The pH/temperature window

The pH/temperature window (that is, the optimum change in pH post-slaughter in relation to carcase temperature to achieve favourable beef quality) was one of the initial specifications for the MSA carcase grading scheme. The choice of boundaries was based on literature estimates for the boundaries for heat and cold shortening. The recommendation from the Pathways Team was that the rate of pH fall in the loin be controlled by electrical stimulation and chilling, so that pH was greater than 6.0 when the loin muscle temperature was greater than 35°C and pH was less than 6.0 when the loin muscle temperature was less than 12°C. Although the literature suggested that heat shortening should impact on palatability, when the pH/temperature profiles were examined in the MSA database there was no evidence that a rapid pH decline, relative to temperature, had a detrimental effect on palatability.

Again, as part of a postgraduate program, the effect of the pH/temperature window on the ageing rate and other meat quality traits was examined (Hwang et al., 1999). That study used a combination of electrical stimulation and chilling treatments to cause independent variation in pH and temperature decline. The results in Figure 1 showed that, in situ, the rate of pH decline has the largest effect on eating quality. From Figure 1, striploins which had a rapid decline in pH showed a very small decrease in shear force with ageing, compared with carcases with a much slower rate of pH fall. These results showed that the main penalty of a rapid pH fall was reduced ageing along with increased drip loss. Post-slaughter tenderisation enzyme (calpain) activities indicated that the rapid fall in pH accelerated and ultimately exhausted the activity of the calpains, which led to reduced ageing potential in heat shortened meat.

Figure 1. Shear force as a function of pH at 1.5 hours post mortem, adjusted to a temperature of 28°C at 1.5 hours post mortem (Hwang et al., 1999).

The interaction between carcase hanging treatment and ageing effects on palatability

As part of a postgraduate program the effect of the hanging treatment x ageing interaction on palatability was examined (O’Halloran et al., 1998). In this study, striploin samples from tenderstretched carcases showed an initial improvement in sensory tenderness score, but little further improvement in palatability between 7 and 14 days, compared with the samples from normally hung carcases. This indicated that in terms of palatability, tender-stretching increased the rate of ageing relative to normally hung carcases. This study underpinned the inclusion of the hanging treatment x ageing interaction in the cuts-based model.

Table 2. Palatability scores (CMQ4) 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)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Tender-stretch</th>
<th>Achilles</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forequarter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pectoralis profundus</td>
<td>32</td>
<td>35</td>
<td>ns</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>55</td>
<td>56</td>
<td>ns</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>61</td>
<td>62</td>
<td>ns</td>
</tr>
<tr>
<td>Longissimus thoracis</td>
<td>65</td>
<td>63</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Spinalis dorsi</td>
<td>75</td>
<td>76</td>
<td>ns</td>
</tr>
<tr>
<td>Hindquarter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longissimus lumbrorum</td>
<td>61</td>
<td>55</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Psoas major</td>
<td>71</td>
<td>74</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>64</td>
<td>57</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>45</td>
<td>38</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>50</td>
<td>47</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>48</td>
<td>47</td>
<td>ns</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>50</td>
<td>48</td>
<td>P&lt;0.001</td>
</tr>
</tbody>
</table>
developing systems to optimize processing conditions and ageing potential of beef. Whilst there has been progress in refining the pH/temperature window for the loin muscles, data on the rump muscles indicate that many of the deep muscles are being disadvantaged. Hot boning may be a tool by which the optimum post-slaughter conditions may be achieved over the whole carcase. In the longer term this project will facilitate industry application of CRC outcomes from other CRC programs. These include procedures to reduce pre-slaughter stress and strategies to minimize the negative effect of growth path on palatability.

CONCLUSION

The relative contributions of genetic and non-genetic factors to the ultimate eating quality of beef are now better understood. Australia is well positioned to recommend appropriate combinations of genetic, growth and meat processing strategies to guarantee eating quality for all cuts of the beef carcase. A Meat Standards Australia grading scheme, based on this approach, is being implemented nationally. Further research is required to exploit new developments in bovine genomics research and in growth path technologies and feed efficiency.

From a CRC perspective, MSA has proved to be one of the most useful conduits for technology transfer of CRC outcomes associated with the control of beef eating quality in the meat industry. Traditionally, technology transfer to sectors such as the processing industry have been slow, as it has been difficult to demonstrate the economic advantage in implementing technology to improve eating quality.

The focus on palatability by MSA provides a system by which technology that improves palatability can be rewarded by achieving higher quality grades. Because MSA is a total system approach it is flexible enough to implement technology at any stage of the beef chain from production to value adding. The new CRC for Cattle and Beef Quality will contribute further to this initiative from 2000 to 2006.

ACKNOWLEDGEMENTS

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