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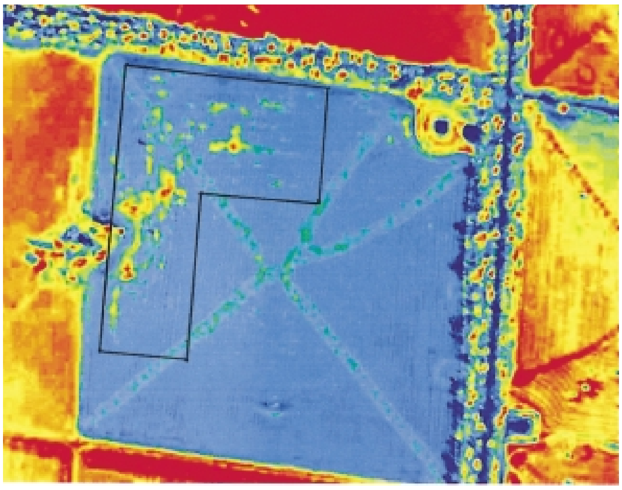

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Genesis of the Cooperative Research Centre for the Cattle and Beef Industry: integration of resources for beef quality research (1993–2000)

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Abstract. The Cooperative Research Centre for the Cattle and Beef Industry (Meat Quality) was formulated in 1992 by CSIRO, the University of New England (UNE), NSW Agriculture and Queensland Department of Primary Industries (QDPI) to address the emerging beef quality issue facing the Australian beef industry at that time: the demand from domestic and export consumers for beef of consistent eating quality. An integrated program of research involving meat science, molecular and quantitative genetics and growth and nutrition was developed. To meet the expectations of the Commonwealth of Australia, additional projects dealing with animal health and welfare and environmental waste generated by feedlot cattle were included. The program targeted both grain- and grass-finished cattle from temperate and tropical Australian environments. Integration of research on this scale could not have been achieved by any of the participating institutions working alone.

This paper describes the financial and physical resources needed to implement the program and the management expertise necessary for its completion. The experience of developing and running the Cooperative Research Centre confirms the complexity and cost of taking large numbers of pedigreed cattle through to carcass and meat quality evaluation. Because of the need to capture the commercial value of the carcass, it was necessary to work within the commercial abattoir system. During the life of the Cooperative Research Centre, abattoir closure and/or their willingness to tolerate the Research Centre's experimental requirements saw the Cooperative Research Centre operations move to 6 different abattoirs in 2 states, each time losing some precision and considerable revenue. This type of constraint explains why bovine meat science investigations on this scale have not previously been attempted. The Cooperative Research Centre project demonstrates the importance of generous industry participation, particularly in cattle breeding initiatives. Such involvement, together with the leadership provided by an industry-driven Board guarantees early uptake of results by beef industry end-users.

The Cooperative Research Centre results now provide the blueprint for genetic improvement of beef quality traits in Australian cattle herds. Heritabilities of beef tenderness, eating quality, marbling, fatness and retail beef yields are now recorded. Genetic correlations between these traits and growth traits are also available. Outstanding sires for beef quality have been identified. Linked genetic markers for some traits have been described and commercialised. Non-genetic effects on beef quality have been quantified. Australian vaccines against bovine respiratory disease have been developed and commercialised, leading to a reduction in antibiotic use and better cattle performance. Sustainable re-use of feedlot waste has been devised.

Introduction

The Cooperative Research Centre (CRC) for the Cattle and Beef Industry (Meat Quality) commenced 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, until 1995, saw a 30% growth in beef exports, with major expansion in Japan and Korea and the live-cattle trade to South-east Asian destinations. Grain-fed beef exports to Japan and Korea grew by 1300% 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.

The CRC portfolio was designed to concentrate 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 Australian 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

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the CRC was to expand Australian research on the efficiency of feed utilisation, in the hope of providing long-term improvement in the economy of beef production in pasture- and grain-fed environments.

Origin of the CRC for the Cattle and Beef Industry (Meat Quality)

The CRC for the Cattle and Beef Industry (Meat Quality) arose out of a Meat Research Corporation (MRC) project proposal called ‘Breeding directions for grain- and grass-fed cattle’ conceived in 1990 by Bernie Bindon, Keith Hammond, Alex McDonald and John Thompson. The $12 million required for the proposal was beyond the scope of the MRC. With the advent of the Australian Government’s CRCs Program, the project was then expanded into a CRC proposal called ‘CRC for Integrated Feedlot and Meat Quality Research and Training’ lodged in 1991. This narrowly missed out on selection. Following advice from the CRC Office, the proposal was revised with the following elements in mind:

(i) The new proposal was to include a significant molecular genetics component. (This recognised the fact that CSIRO’s Molecular Animal Genetics CRC proposal, based at the University of Queensland, also narrowly missed the selection in 1991.)

(ii) The new proposal was to involve a significant northern cattle industry component. (This recognised the reality that no CRC for the cattle industry would succeed without significant Queensland involvement.)

(iii) The new proposal was to include recognised environmental waste management and animal health components. (This reflected the Federal Government’s view that feedlot environmental issues were emerging as concerns of the modern Australian beef industry.)

From December 1992, the degree of difficulty in setting up the CRC became apparent. The CRC’s core business was to be based on large numbers of pedigreed, straightbred and crossbred cattle, grown out under controlled nutrition and then slaughtered to secure a full range of meat quality measurements. The main difficulties were the following: (i) the CRC had not then agreed on the breeds to be involved or the exact numbers required to satisfy the experimental design; (ii) the CRC had no land on which to run the cattle; (iii) the CRC had insufficient funds to finance the breeding, purchase, transport, agistment, feeding and slaughter costs of the project; (iv) the CRC had funds (provided by the NSW Cattle Compensation Fund and UNE) to build a research feedlot, but did not have a location for it, had no idea of the design or construction costs and no staff who understood the technical difficulties in grain-feeding cattle; and (v) the CRC had no Board of Management and no Business Manager to begin serious financial planning.

In most cases, the activities proposed for the CRC could not have been achieved by one of the cooperating institutions working alone. They needed the cooperation of the many scientists from different scientific disciplines and different organisations and they needed industry participation: these are the 2 essential elements of the CRC.

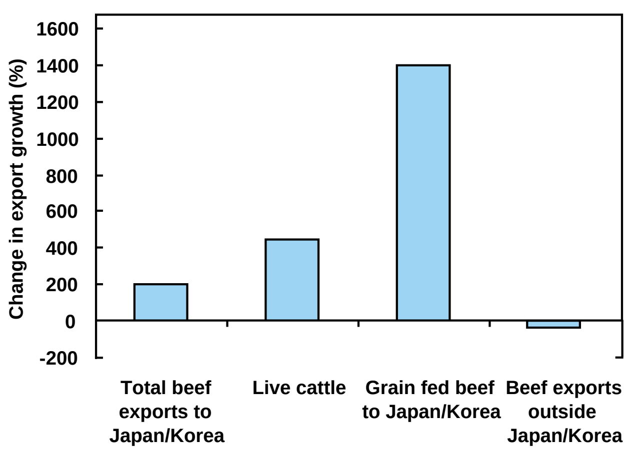

Figure 1. Trends in Australian beef industry export growth, 1988–1995 (source: AMLC cited in Meat and Livestock Industry Reform 1996).

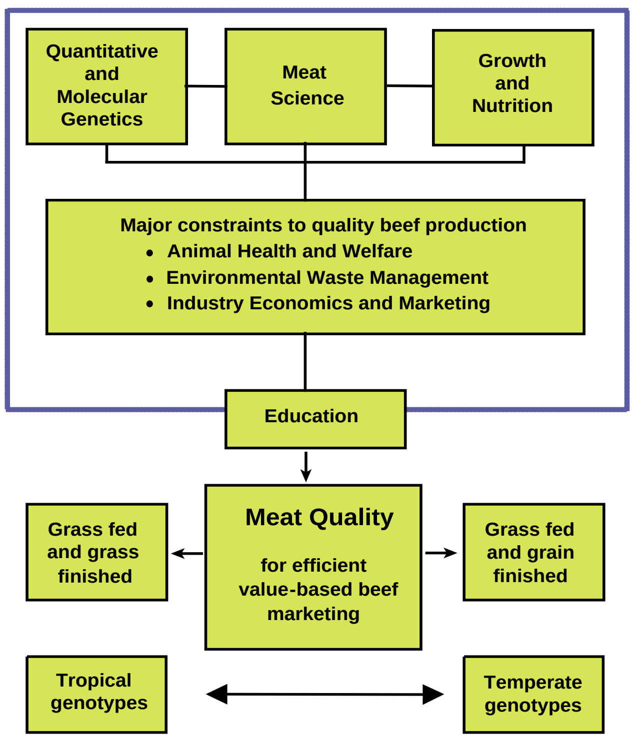

Figure 2. Integrated research program established by the Cooperative Research Centre (CRC) for the Cattle and Beef Industry (Meat Quality). The top half of the diagram refers to the 5 integrated research programs of the CRC. The lower half indicates the Meat Quality outcome of the CRC’s research based on grain-fed and grass-fed cattle from tropical and temperate Australian environments.

Establishing CRC research priorities

The integrated research program had the following 4 objectives: (i) to identify and resolve the key meat science issues that constrain Australia's ability to meet domestic and export market specifications for meat quality, at least cost; (ii) to develop molecular and quantitative genetic technologies to breed cattle suited to existing and new markets; (iii) to design novel feeding and management strategies to meet meat quality objectives in Australia's difficult environments; and (iv) to address and resolve major constraints to intensive beef production by eliminating health and welfare concerns and reducing environmental pollution.

The program structure is illustrated in Figure 2. It addressed both northern and temperate beef industry sectors and grass- and grain-fed production systems. It also initiated the development of new postgraduate diploma and certificate education programs aimed at the meat industry.

This CRC addressed the challenge of the 1990s to improve the quality and reliability of Australian beef products to match the exacting requirements of new markets in Asia and cater for changing preferences in the domestic market, while containing costs. Distinguishing features of the program were the following:

(i) Genetics, nutrition and meat science research was closely coordinated. The genetics program was to establish genetic correlations between grass- and grain-fed productivity and product quality and genetic variability in feed conversion efficiency. This was required to determine whether the existing national cattle breeding programs were suitable for production of the most efficient animals for grass- and grain-fed systems and whether there was a need to develop a separate breeding strategy for the feedlot sector. Molecular genetics was to develop gene markers for key meat quality traits, to position Australia to make rapid changes in breeding direction, as required.

(ii) Growth and nutrition research was to produce strategies for different cattle genotypes to optimise feed efficiency and maximise the production of specified carcase traits. This was to be achieved through novel methods of balancing the key nutrients absorbed by animals, manipulation of microbial digestive efficiency, altering nutrient availability and mobilising peripheral fat.

(iii) Carcase and detailed meat quality assessments were important components of all core research. Emphasis was given to measuring, as well as predicting, marbling and peripheral fat in the carcase. Meat science research was to develop new methods for predicting carcase and meat quality in live animals to speed up genetic manipulation and enable slaughter of cattle at the correct stage of development.

(iv) Animal health and welfare research was to address the most serious respiratory disease problem of feedlot cattle ('shipping fever'), which is likely to be caused by *Pasteurella hemolytica* and pestivirus. Vaccines were to be developed to combat the identified disease-causing agents, which would then allow studies of the interactions of animal health, stress and nutrition in different genotypes to be understood.

Table 1. Representation on the Board of Cooperative Reasearch Centre (CRC) at March 2000, indicating the range of business skills and beef industry experience available to the CRC through this representation

Board member	Business skills and beef industry experience
Mr Dick Austen, AO (Chairman)	Former Chairman Australian Meat and Livestock Corporation; driving force behind major reforms in the Australian coal and beef industries; identified as the Australian Beef Industry Achiever of the Decade (April 2000)
Mr Robin Hart, AM	President, Australian Lotfeeders' Association; Chairman, Kerwee Pastoral Company; specialist expertise as a beef producer, feedlotter, processor and retailer, being an innovator in the development of specialist beef products to Japan over the past decade and more
Mr Johnny Kahlbetzer	Managing Director, Twynam Pastoral Company Pty Ltd, one of the largest specialist beef producers in southern Australia
Mr Keith Lawson (deceased 1998, replaced by Mr Rod Hadwen)	Executive Chairman, Australia Meat Holdings, Australia's largest meat-processing enterprise; the company also has significant production and feedlotting interests
Mr John Mactaggart AM	Past President, Cattle Council of Australia; beef producer from Central Queensland
Mr David Woolrych	Former Managing Director, South Burnett Meat Cooperative; expertise in beef processing and development of novel and/or niche beef markets
Mr David Wright	Former board member, Australian Meat Board and Australian Meat and Livestock Research and Development Corporation; specialist beef producer from southern Australia; developer of novel beef markets and marketing technologies
Mr Edward Wright	Past President, Cattle Council of Australia; specialist beef producer from southern Australia
One representative from each of the core partners (University of New England, CSIRO, Queensland Department of Primary Industries and NSW Agriculture)	Ability to commit resources from their organisations to the CRC's programs; management skills and expertise from within a research environment

Techniques to boost the immune competence of young cattle were to be developed, together with behavioural studies to eliminate stress.

(v) Feedlot waste management was to be addressed by this CRC's strategic science on nutrient cycling and soil and water pollution, to complement the MRC-funded projects in this field, and to provide the basis for a sustainable feedlot sector.

(vi) Training and education initiatives of the CRC were to improve knowledge levels and skills across the industry supplying a high-quality, specified, value-added product destined largely for the discerning, middle-income groups in Asia, Australasia and North America. The CRC appointed the first Professor of Meat Science and Technology in Australia, to take responsibility for degree courses and a newly established postgraduate school. An Australian Meat and Livestock Corporation (AMLC) funded Chair of Meat Marketing and the Twynam Chair of Animal Breeding Technologies were other major education initiatives of the CRC.

An industry-driven board and advisory committee

A feature of the CRC has been the quality of board representation. By careful selection of an independent, industry-dominated board, the CRC has brought significant business skills and beef industry experience into an Research and Development environment previously dominated by the self-interest of scientists (see Table 1).

The foundation board was responsible for the following achievements:

(i) The CRC convinced a broad sector of the beef industry to get involved in an integrated program of research and development, designed to enhance the industry's international competitiveness. This meant cattle breeders, feedlotters, meat processors and exporters working side-by-side with scientists from diverse institutions to address the meat quality issues that threaten Australia's position as the world's largest beef trader.

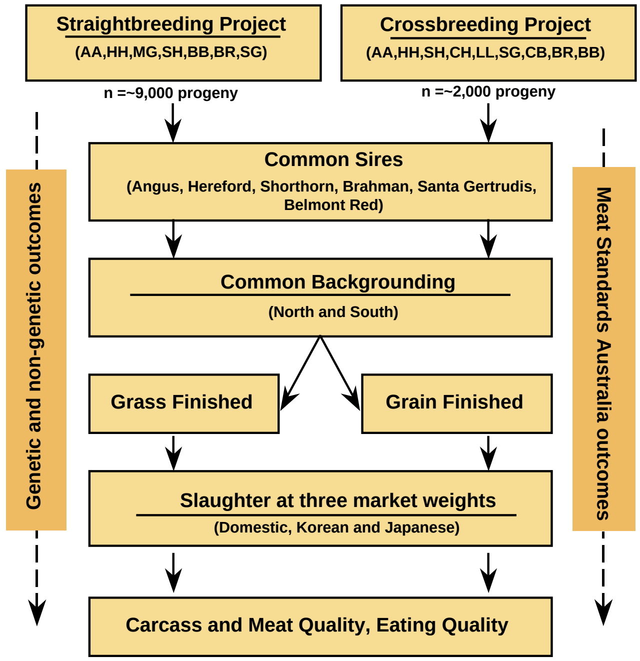

Figure 3. Design of Cooperative Research Centre (CRC) breeding program directed at meat quality traits (AA, Angus; HH, Hereford; MG, Murray Grey; SH, Shorthorn; BB, Brahman; BR, Belmont Red; SG, Santa Gertrudis; CH, Charolais; LL, Limousin; CB, Charbray).

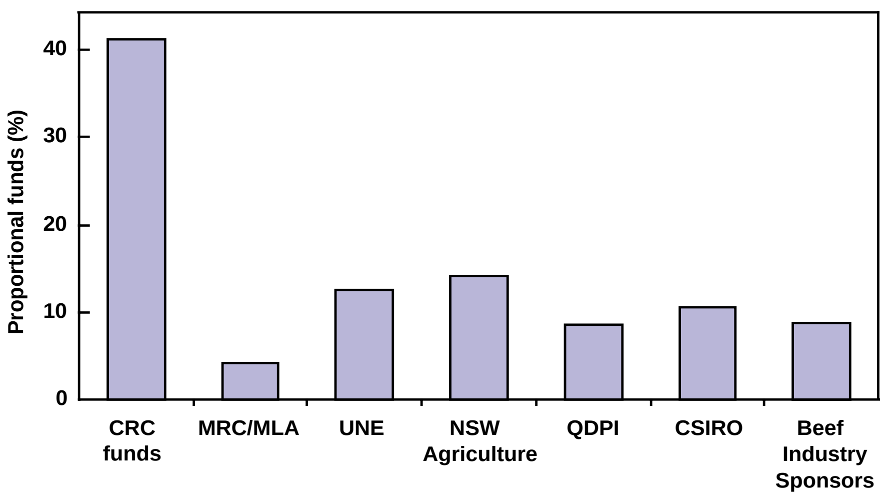

Figure 4. Proportional funding from Cooperative Research Centre (CRC), core partners and industry for the CRC breeding, feeding, finishing and slaughter projects (1993–98) (see Fig. 3). Total expenditure was A$32 million.

Table 2. Significant industry sponsorship achieved as an exclusive result of the program of the Cooperative Research Centre

Agency	Cash sponsorship (1993–1997)
Cattle Compensation Fund of NSW	$2000000
Meat Research Corporation	
Chair of Meat Science and Technology ($100000 p.a.)	$400000
Australian Meat and Livestock Corporation	
Chair of Meat Marketing ($150000 p.a.)	$300000
Twynam Pastoral Company	
Chair of Animal Breeding Technologies ($150000 p.a.)	$450000
NSW Government Science and Technology Foundation	
TAFE teaching modules	$340000
Ridley AgriProducts	$160000
NSW Government State and Regional Development	$180500
Qld Government Department of Business, Industry and Regional Development	$250000
Australian Brahman Breeders' Association	$45000
Australian Limousin Breeders' Society	$20000
Nippon Meat Packers (Australia)	$75000
Mitsubishi Australia	$60000
Northern cattle companies (8 of these)	$400000
Cargill Foods Australia	$51000
Meat Research Corporation — competitive grants in 1997	$1200000
Total	$5936000

(ii) The 4 core partners to the CRC were all previously doing beef research, but in an uncoordinated way and largely without end-user involvement. This CRC achieved collaboration that has not occurred since the time of Federation of Australia.

(iii) The CRC succeeded in achieving cooperation between animal geneticists, meat scientists and ruminant nutritionists who worked together to achieve the common goal of meat quality excellence.

(iv) The CRC's close involvement in cattle trading and production issues (droughts, high grain costs and low beef prices) has won added respect from industry. Beef sectors accept CRC outcomes because they were forged in a realistic commercial environment.

(v) The program was developed by exhaustive consultation between scientists and beef industry sectors, including AMLC, MRC, Australian Lotfeeders' Association, Meat and Allied Trades Federation of Australia, Australian Meat Council, cattle breed societies and agribusiness firms.

(vi) Selection criterion used to prioritise CRC projects was that if the work could be addressed by 1 core partner alone, then it was not compatible with the CRC philosophy.

(vii) Users and researchers combined to design the program. For example, cooperating cattle breeders and breed societies worked with scientists to design the breeding programs. Northern cattle enterprises donated 1000 Brahman cows to make 1 project possible.

(viii) The CRC's Advisory Committee comprised respected industry practitioners from the cattle breeding, production, feedlot, meat-processing and agribusiness sectors. They worked closely with CRC scientists to maintain the industry relevance of the CRC's activities.

Finding resources for CRC activities

Scope of CRC breeding, feeding and slaughter projects

The CRC carried out the world's largest progeny-test program for carcass and beef quality traits and their genetically related traits such as growth. The straightbreeding project was designed as a within-breed progeny test, involving 7 breeds from 48 cooperating seedstock herds. The northern crossbreeding project was designed as a progeny test based on 1000 Brahman females (donated by industry) and 9 terminal sire breeds. These breeding projects are illustrated in Figure 3. These experimental progeny tests were expensive because they involved: (i) generation of pedigreed progeny that met CRC's demanding experimental specifications, (ii) purchase of progeny by CRC, (iii) transport to grow-out properties, (iv) management and agistment costs during grow out and finishing, (v) grain *v.* grass finishing, (vi) transport to abattoirs, (vii) slaughter costs and retrieval of carcase subsamples, (viii) laboratory measurement and taste panel assessment of meat samples, and (ix) collation, analysis and reporting of results.

It is estimated the CRC has spent nearly $32 million (cash) on this process, as shown in Figure 4. 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 partners and 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.

This ambitious undertaking required resources over and above those provided by the Commonwealth CRC allocation. The Board's business contacts made it possible to achieve substantial additional cash resources, as shown in Table 2.

The generous participation of 48 seedstock breeders across eastern Australia provided the pedigreed livestock for the straightbred progeny test. These are listed in Table 3.

Brahman females (1000) for the northern crossbreeding progeny test were generously donated by the northern pastoral companies (**Queensland:** Hillgrove Pastoral Company, Hillgrove Station, Charters Towers; Australian Agricultural Company, Canobie Station, Julia Creek; The North Australian Pastoral Company Pty Ltd, Boomarra Station, Julia Creek; Stanbroke Pastoral Company, Weetalaba Station, Collinsville; Queensland and Northern Territory Pastoral Pty Limited, Lyndhurst Station, Charters Towers; Hughes Grazing Company, Tierawoomba Station, Sarina; Acton Land and Cattle Company, Croydon Station, Marlborough; **Northern Territory:** Consolidated Pastoral Pty Ltd, Newcastle Waters Station, Newcastle Waters; Heytesbury Pastoral Company, Walhallow Station, Tennant Creek) and QDPI's Brigalow Research Station.

Table 3. Cooperating breeders who generated pedigreed straightbred cattle for the experimental Cooperative Research Centre breeding program outlined in Figure 3

Angus (n = 14)	*Murray Grey* (n = 4)
MB and VA Boothby, Wangaratta, Vic.	D and S Gadd, Culcairn, NSW
B Corrigan, Albury, NSW	R Kuhn, Coolah, NSW
A Gubbins, Colac, Vic.	M McDonald, Naracoorte, SA
C Gubbins, Colac, Vic.	R Wythes, Narromine, NSW
Hazeldean Pty Ltd, Corowa, NSW	*Shorthorn* (n = 5)
JA and S Hindson, Casterton, Vic.	P Balderstone, Wannon, Vic.
K and S Jaques, Mulwala, Vic.	K Johnson, Keith, SA
J Litchfield, Cooma, NSW	OR and IE Schwilk, Orange, NSW
K McFarlane, Tailem Bend, SA	A Starling, Kingston, SA
D and S Murray, Walcha, NSW	J and A Williamson, Carisbrook, Vic.
NSW Agriculture, Trangie, NSW	*Belmont Red* (n = 3)
G Reid, Yass, NSW	JM and B Hudson, Moura, Qld
R and S White, Guyra, NSW	EA and G Maynard, Jambin, Qld
A Wilson, Camperdown, Vic.	GW and MC Seifert, Rockhampton, Qld
Hereford (n = 11)	*Brahman* (n = 6)
F Austin, Adelong, NSW	AA Company, Julia Creek, Qld
A Baulch, Coleraine, Vic.	AA Company, Springsure, Qld
C Goode, Naracoorte, SA	C Briggs, Springsure, Qld
JW and MJ Gough, Hotspur, Vic.	GE and J McCamley, Marlborough, Qld
P Gunner, Gilberton, SA	JR McCamley, Dululu, Qld
R Hann, Bellata, NSW	Stanbroke Pastoral Co., Collinsville, Qld
F Kentish, Mt Gambier, SA	*Santa Gertrudis* (n = 5)
S Larsson, Mallanganee, NSW	AA Company, Springsure, Qld
GRT Lord, Moree, NSW	AA Company, Tennant Creek, NT
C and C Winter, Injune, Qld	A and S Coates, Eidsvold, Qld
J Yelland, Milawa, Vic.	B and L Joyce, Theodore, Qld
	de B and M Joyce, Theodore, Qld

The Brahman cows were joined to bulls from 9 breeds representing *Bos indicus* (Brahman), *Bos indicus* × British and European-derived (Santa Gertrudis, Charbray), Sanga-derived (Belmont Red), British (Angus, Hereford, Shorthorn) and European (Charolais, Limousin).

With the exception of the European and Charbray sires, all sires used in the crossbreeding project were used to produce purebred calves for the CRC in the straightbreeding project. A full description of the experimental design and breeding programs in given by Upton *et al.* (2001). Genetic linkages were also created with the CRC's crossbreeding projects and with the experimental crossbreeding programs at Belmont and Grafton Research Stations and with the MRC-funded southern crossbreeding project (i.e. semen from common sires used in all 4 experiments). The assistance of respective breed societies in sourcing semen is gratefully acknowledged by the CRC.

All CRC purebred and crossbred cattle were finished on grass or grain to achieve target weights approximating those of the existing domestic, Korean and Japanese markets. In northern Australia, animals were grown out and finished on grass at the CRC's leased property, 'Duckponds', near Comet in Central Queensland. Arrangements were made with the Australian Agricultural Company, a major collaborator in the CRC breeding projects, to finish all northern grain-fed animals at its newly constructed 20000-head commercial feedlot, 'Goonoo', located about 40 km from 'Duckponds'. In southern Australia, animals were grown out on CSIRO, UNE and NSW Agriculture properties in the New England area of NSW and finished on grass on the same properties or on grain at the CRC's research feedlot, 'Tullimba', near Armidale.

CRC's leased property, 'Duckponds'

In addition to the use of QDPI's Brigalow Research Station, which accommodated about 300 Brahman cows, a property in northern Australia was sought for the management and agistment of the remaining crossbreeding herd of about 700 Brahman cows. These cows would be joined by artificial insemination (AI) and natural mating to produce the CRC's crossbred progeny. Selection criteria for the property were established and expressions of interest sought through the rural press.

Nogoa Pastoral Company's 'Duckponds' property (Fig. 5) was selected and the CRC signed a 5-year lease agreement for agistment of up to 2000 head on approximately 9500 ha of buffel grass pastures. Both the crossbreeding female herd and the crossbred and straightbred progeny allocated for northern grow-out and northern grass finishing were run on the property.

Breeding projects based on the donated Brahman cows at 'Duckponds' and Brigalow Research Station were completed in 1997, with the final crossbred calf crop weaned in July 1998. Final intakes of straightbred calves also occurred at that time. Over the past 6 years, a very intensive breeding and data collection protocol was superimposed on normal commercial operations at 'Duckponds'. In total, about 2000 Brahman cows were used over 3 joining periods for oestrous synchronisation experiments that involved AI and checking for returns to oestrus, scrupulous maintenance of breeding cow records and weighing and recording of calves at birth. In addition, more than 5000 purebred and crossbred calves were weighed and other intensive experimental measurements recorded every 6–8 weeks between weaning and transfer to either 'Goonoo' for feedlot finishing, or to slaughter. Final data collections on CRC calves at 'Duckponds' were completed in March 2000.

Cattle research (feedlot) facility — 'Tullimba'

The property 'Tullimba' was purchased by UNE in 1993 and facilities on the property were constructed with funds provided from the NSW Cattle Compensation Fund and UNE. The property is located 50 km west of Armidale, at an altitude of about 750 m. It consists of 740 ha, mainly grey loam soils, suitable for grazing, with some crops in a pasture rotation. Up to 400 cattle can be grazed on pasture or crop at 'Tullimba' to reach slaughter or feedlot entry weights.

The research feedlot was completed in September 1994. It consists of a 1000-head licensed, registered facility. Varying pen sizes allow research flexibility and variable slopes in pens and individual catchment ponds allow waste management studies. The installation represents a $3.0 million investment by UNE and CRC sponsors (see Fig. 6).

A major feature of the cattle research (feedlot) facility is the measurement of individual feed intake. Sixteen automated 'Tullimba' feeder units incorporate state-of-the-art electronic hardware and unique software to allow measurement and recording of daily feed consumption of a standard feedlot diet on up to 280 head at any given time.

'Goonoo' feedlot, the CRC's northern grain-finishing environment

With the development of a major new feedlot at Comet by the Australian Agricultural Company, a major participant in the CRC's breeding projects, the opportunity arose for the CRC to grain finish a further 1/3 of its northern-bred animals in a fully commercial feedlot in northern Australia. The 'Goonoo' installation is pictured in Figure 7.

Molecular genetics

A key requirement of the CRC molecular genetics project was an automated gene sequencer, acquired in 1994. This was made available by a generous grant of $250 000 from the Queensland Government's Department of Business, Industry

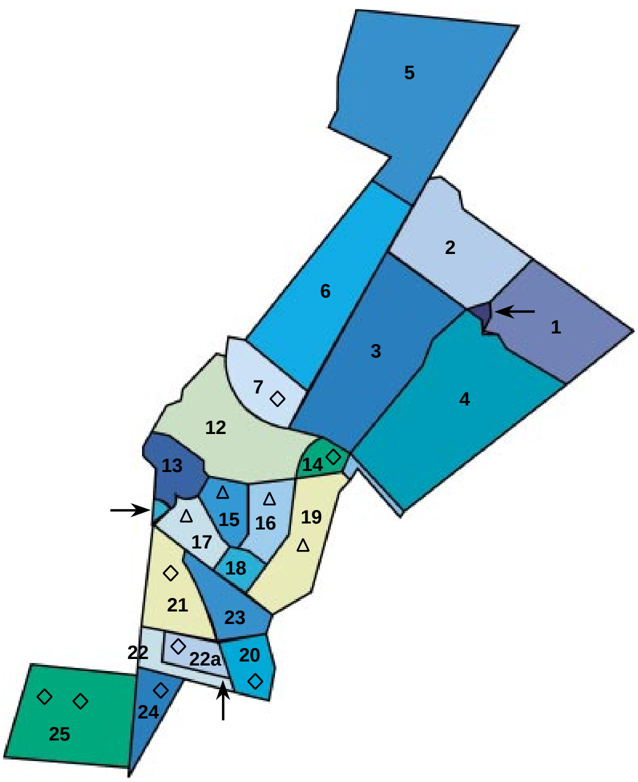

Figure 5. 'Duckponds' property map, showing the location of facilities (⟶ yards; ◇ possible single sire joining paddocks; △ AI paddocks and/or single sire joining paddocks) required for the northern crossbreeding program (see Upton *et al.* 2001).

Figure 6. Aerial view of the cattle research (feedlot) facility, 'Tullimba' Armidale NSW. The facility has 1000-head capacity with 16 pens equipped for individual feed-intake measurement. Purpose-built drainage and sediment ponds designed for feedlot waste management studies. Contours and waste water collection allow for total containment of all effluent.

Figure 7. State-of-the-art Goonoo feedlot, used for the northern grain-finishing strategies at Comet, Central Queensland. Capacity 17500 head (photograph courtesy of Australian Agricultural Company).

and Regional Development. The 373 automated DNA sequencer is able to generate allele sizes up to multiple microsatellite markers using 30 offspring per run. The dedicated software then assembles the sorted data for further gene mapping and quantitative trait loci applications. This enables high throughput of samples, as skilled operators can perform several runs in a day. Sequencing of DNA to determine its specific structure is also possible with the 373 automated sequencer.

Meat science studies

A subset of the demanding set of carcass and meat quality measurements on which the CRC projects were based is shown in Table 4. A complete description of the carcass and beef quality measurements recorded by the CRC is given by Perry *et al.* (2001). Adherence to this experimental protocol has been a major challenge for this program. It has not proceeded perfectly and the difficulties encountered are a lesson in the practicalities of carrying out research in a commercial meat-processing environment.

Commercial abattoirs

Cattle in the CRC projects have been processed at the following plants: (i) Australia Meat Holdings, Guyra — closed June 1995; (ii) Borthwick's, Bowen — arrangement ceased November 1995; (iii) Consolidated Meat Group, Rockhampton — arrangement ceased January 1997; (iv) South Burnett Meatworks, Murgon — closed December 1997; (v) Bindaree Beef, Inverell — arrangement ceased December 1998; and (vi) Stockyard Meats, Grantham — arrangement in place until February 2000.

The underlying difficulty in securing a working arrangement with a meat processor is that the CRC measurement protocol causes disruption to normal commercial through-put. This is especially evident in the boning room, where CRC measurements require more precise bone-out procedures and the weighing and recording of primal cuts, fat trim and bone weights cause serious delays. Despite the fact that the CRC paid additional charges for such disruption, the procedures became untenable at all but Stockyard Meats, where a version of retail meat yield is provided on every carcase as a routine service to all clients.

The closure of Australia Meat Holdings Guyra and South Burnett plants reflect the commercial realities of the 1990s. Inevitably, the changes of slaughter venue of CRC cattle during the life of the project have downgraded the quality of the data for some animals. This is a reminder that maintaining scientific integrity of data in the commercial, industrial environment of a meat-processing plant is fraught with difficulty. In the current project, we may have lost 15% of information from part or all carcases in the project. The idea that we can carry out large-scale, foolproof beef quality investigations in Australian meat processing plants is flawed. The CRC failed to anticipate this difficulty. Australia needs a dedicated meat processing and bone-out facility attached to a commercial abattoir and available for research initiatives involving slaughter of up to 100 head of cattle per day.

Table 4. Subset of the measurements recorded at different sites for meat science studies of Cooperative Research Centre carcases (RTUS, real time ultrasound scanning; VIA, video imaging analysis)

Pre-slaughter	Slaughter floor	Chiller	Boning room	Laboratory
Liveweight	Electrical stimulation	Eye muscle area	Saleable meat yield	Two muscles:
Fat depth (RTUS)	Body weight	Fat depth	Retail beef yield	striploin, eye round
Eye muscle area (RTUS)	Hide weight	Marble score	Lean meat yield	Objective tenderness:
Marbling (RTUS)	Organ weights	Fat colour	Distribution lean:fat	myofibrillar, connective
Muscle score	Carcass weight	Meat colour	Ratio muscle:bone	tissue, intramuscular fat
Temperament	Fat depth (manual + VIA)	Ultimate pH	Weight of trimmed primals	percentage, pH/water
	Fat cover (manual + VIA)	AusMeat chiller		holding capacity
	Muscle score (manual + VIA)	assessment + VIA		Subjective (MSA) panel:
				tenderness, flavour, juiciness,
				overall acceptability

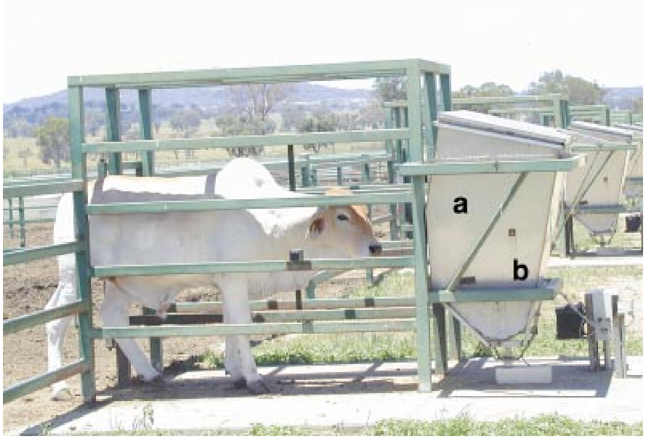

Figure 8. Animal at 'Tullimba' individual feed intake recorder. Note feed hopper (a) and cleaning door (b).

Measurement of feed intake

The CRC invested heavily in technology to measure feed intake in groups of cattle fed a standard feedlot diet. The 'Tullimba' automatic feed-intake monitor consists of a stainless steel hopper in front of a race approximately 2000 mm long and 700 mm wide. It is supported over a high-precision load cell, the output of which is passed through a 20-bit analog–digital converter continuously monitored by a dedicated micro-computer on each monitor (see Figs 8–10). The theoretical precision of this system is less than 30 g in 200 kg. However, in practice, the environmental constraints such as movement from wind and cattle decrease the precision of weighing in each feeding session to about 100 g in 200 kg. This is a very small error given that cattle, on average, eat between 9 and 15 kg per day of a feedlot diet, and the within-animal, between-day coefficient of variation is about 35%, meaning that, on any day, an animal with an average intake of 10 kg could eat as little as 3 and as much as 17 kg.

Figure 9. Side view of 'Tullimba' individual feed intake recorder showing computer (a) and infrared beam emitter (b).

Figure 10. Animal's eye view of individual feed intake recorder showing animal identity reader antenna (a), load cell (b), and infrared beam emitter and reflector (c).

Each animal is identified by a unique electronic disc in its ear. This is interrogated each time the animal puts its head into the feeder. There is a fixed-beam infrared detector placed in the race that indicates when an animal is present. This is used to switch the power on to the electronic identity (ID) reader.

Animal identification and time of entry to, and exit from, the monitor are collated with continuous weighing of the feed hopper. At the end of each feeding session, the stable weight of the hopper is recorded and matched to the animal ID and time. All these operations occur in the self-contained micro-computers which then may pass the information from the feeder to the office, or in the unlikely event of a problem with the line, store the information for up to 2 days. Each feeder has an independent power supply (a standard 12-volt DC car battery), which is automatically charged by a normal 240 V AC-powered battery charger. In the event of a power failure, the monitors are able to operate without AC power for 24 h.

A remote computer in the office interrogates each monitor in turn throughout the day. It builds up a data file from all monitors. Data are automatically consolidated into a complete file of each day's feeding activity at midnight. Each complete day file is then manually extracted into an Excel spreadsheet, where a series of macro command programs are executed to remove monitor maintenance messages and build up a file of each animal's feeding activity per monitor per day. These files are then added to the database of measurements recorded on all CRC cattle. The feeding information recorded on the database for each animal includes daily feed intake, number of feeding sessions and total time spent eating. These data are matched to regular weight records and subsequently used to calculate heritability of feed intake, and important derivatives of intake such as gross-feed conversion efficiency (intake/weight gain) and net (residual) feed intake (actual weight adjusted for liveweight and growth rate). Intake measurements may also be used to investigate effects of previous and current nutritional treatments on performance and efficiency.

The CRC recognises the industry needs to improve feed efficiency, through genetic and non-genetic means. The automatic 'Tullimba' monitors are an important tool to achieve this goal. There is an anticipated demand for these units from the seedstock industry, to measure net feed conversion efficiency in young bulls.

The 'Tullimba', automatic feed-intake monitors also provide information about cattle behaviour, such as meal size and frequency of eating. These data are important in assessing the effects of different rations and additives on cattle behaviour and performance. The 'Tullimba' monitors are now being manufactured and marketed by Ruddweigh Australasia.

Studies of immune competence and development of bovine respiratory disease vaccines

The CRC's studies of immune competence of cattle were based on assays to measure neutrophil chemotaxis, neutrophil myeloperoxidase activity, IgG1, IgA, lymphocyte proliferation, natural killer-cell activity, interferon γ and cell-surface markers by flow cytometry.

For those assays, the following 2 major items of equipment were acquired for CRC use: a Becton-Dickinson FACS vantage flow cytometer, for quantification of lymphocyte subpopulations and expression of leucocyte surface antigens in blood; and a Cell-Dyn 3500 haematology analyser, for rapid measurement of seven red-cell parameters and full differential white-cell counts.

Development of a vaccine against *Pasteurella hemolytica* was a major objective of the CRC's Health and Welfare subprogram. A Phase I, killed vaccine required only conventional laboratory facilities. For the Phase II, live vaccine against the mutant (genetically modified) *P. hemolytica* organism, the high-security facilities at the Australian Animal Health Laboratory (AAHL), Geelong, were required. At this site it was possible to evaluate the efficacy of the live vaccine against a challenge in which cattle were injected with extreme levels of virulent *P. hemolytica*. The experimental animals, in a maximum-security environment, were monitored and then

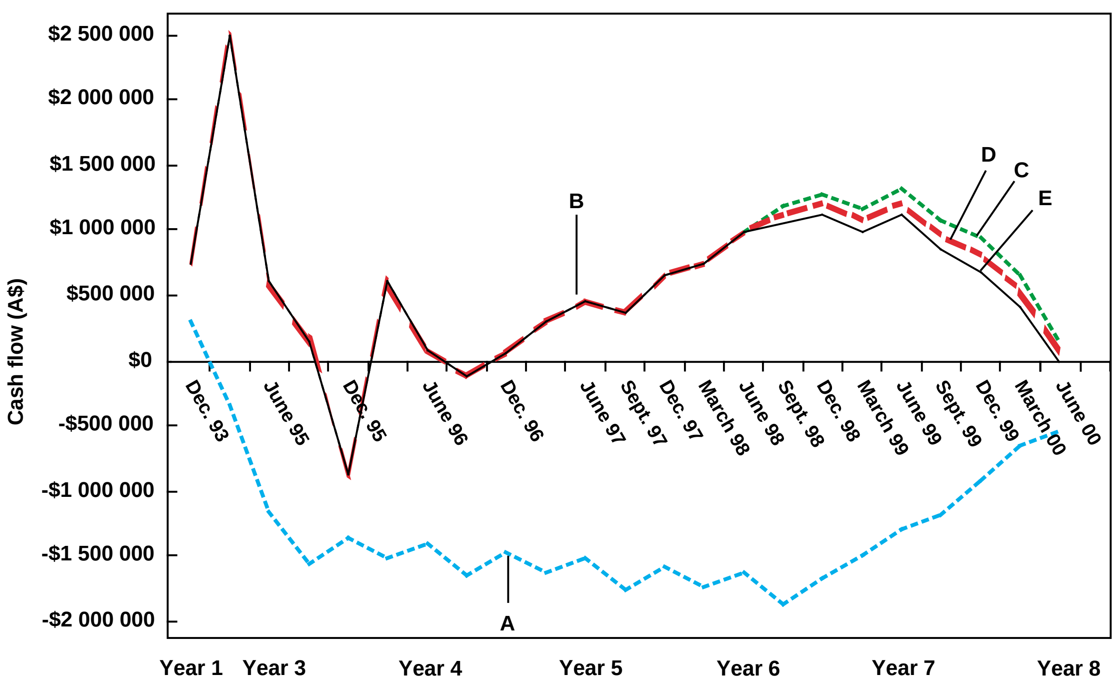

Figure 11. Cash-flow forecast as at June 1998. The original recurrent deficit cash-flow prediction (A) was replaced by the positive cash-flow (B), made possible by advancing year 7 funds with the help of the Secretariat. Cash-flows (C), (D) and (E) are outcomes dependent on cattle revenue scenarios in years 7 and 8.

euthanased 72 h. after the challenge. Non-vaccinated animals died of pneumonia within 72 h. of challenge. Vaccinated cattle showed minor lung lesions only.

Financial outcome — March 2000

When the CRC commenced in July 1993, it was not clear how the CRC's ambitious progeny-test (breeding) projects, aimed to identify the genetic and non-genetic determinants of meat quality in Australian beef cattle, could be financed. The plan was to breed, grow-out, transport, finish, slaughter and evaluate more than 12000 pedigreed cattle during the life of the CRC. The Board made it clear at the outset that no recurrent deficit would be permitted during the life of the project. There was to be no credit facility to finance cattle purchases or to underpin expenditure through to the point where cattle revenue would begin to accrue.

The CRC Secretariat in Canberra made it possible to develop a business plan to draw forward funds from Year 7 to enable these ambitious projects to proceed without deficit (see Fig. 11). In 1994 and 1995, the worst drought in recent memory coupled with extremely high grain-feeding costs was experienced, followed by extremely low cattle prices. Despite this, the final financial outcome for the CRC was a favourable surplus of $300000 after all cattle were slaughtered and the CRC database completed. Details of the CRC's comprehensive database and operation are contained in Upton *et al.* (2001).

The CRC Board has steered this process with the generous cooperation of the CRC's core partners and participating scientists. Sponsorship from the commercial sector and MRC has also helped.

Discussion

The special resources, including funds required for the CRC program, confirm the need for a coordinated program across institutions and states. The integrated nature of the research and the extended time frame for some projects made the program well-suited to the Cooperative Research Centre's Program. The scope of the breeding program, the number and diversity of cattle and huge costs and complexity of the meat-processing task, explains why no other beef-producing nation has attempted anything on this scale. Scientific and industry outcomes described in the papers that follow demonstrate that the CRC program was a timely initiative, placing Australia in a good position to remain the world's premier beef trader and to guarantee consistent eating quality of Australian beef for domestic and export consumers.

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