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Growth and meat quality of grain finished entire male *Bos indicus* cattle

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Abstract

Production parameters, carcass characteristics and eating quality of meat from young entire *Bos indicus* males sourced from northern breeding herds and grain finished was studied. Entire male calves were weighed and allocated to one of four treatment groups: 1) Early-castrate; 2) Late-castrate; 3) Short-scrotum; 4) Entire. Weaners were grown out on grass pasture to ≈330 kg liveweight, then grain fed for 75 days, prior to slaughter at 25 to 28 months of age. Data collected included liveweights and growth rates, carcass characteristics, MSA grade and eating quality. Three muscles from thirty animals in each treatment group were further evaluated for eating quality by consumer taste panels. Non-castrated animals that met AusMeat specifications for “male” had a ≈$52 higher gross value carcasses than those from castrated animals. Only striploins from early-castrated animals were rated as being of higher eating quality than other cuts evaluated from late-castrate, short-scrotum or entire animals. Production of young entire *Bos indicus* males has the potential for substantial returns for northern beef producers with little impact to meat quality. However, there is a need for further data to be generated to allow the MSA grading model to be further refined for high-grade *Bos indicus* cattle.

Executive summary

This project addressed several major concerns for northern beef producers – animal welfare, improved growth rates and possibly more efficient beef production. The hypothesis was that young entire *Bos indicus* males could deliver increased returns with minimal loss in meat quality, while readily meeting all animal welfare standards. In addition, the production of high quality beef from entire males may offer some niche marketing opportunities in countries where cultural values favour meat from uncastrated animals.

Entire male calves from northern breeding properties were weighed and allocated at random to one of four (4) treatment groups, as follows: 1) Early-castrate: surgically castrated at 1 to 4 months of age; 2) Late-castrate: castrated at weaning at ≈200 kg liveweight (≈9 to 12 months of age); 3) Short-scrotum: underwent a rubber banding procedure at 1 to 4 months of age to produce short-scrotum entire males (artificial cryptorchid); 4) Entire: remained intact for the duration of the experiment.

At ≈9 to 12 months of age (≈200 kg liveweight), all calves were weaned and relocated to the Cloncurry district where those calves in Group 2 (Late-castrate) were castrated. All the weaners were grown out on pasture to ≈330 kg liveweight, at which time they were sent to a feedlot in southern Queensland and grain fed for 75 days, to ≈420 kg liveweight. On exiting the feedlot (25 to 28 months of age), all animals were sent for slaughter at JBS Australia's Dinmore abattoir.

Vendor feedback sheets provided data on carcass, sex, dentition, subcutaneous fat depth, butt shape, bruise score, grade, hot carcass weight and gross value. For MSA grading purposes, all the project cattle were classed as being 100% *Bos indicus*, hung by the achilles tendon during the slaughter process and entered in the MSA grading model as steers. Three muscles, eye round, rump and striploin, aged either 7 days or 35 days, from each of thirty animals in each treatment group were selected for further meat quality and sensory testing following MSA carcass evaluation. Each sample was evaluated by consumers, using Meat Standards Australia standard protocols, for tenderness, juiciness, flavour and overall liking. Additionally, consumers assessed the star-rating (satisfaction) for each sample.

Grain finishing non-castrated male cattle offers producers the opportunity to achieve a higher gross value for their cattle due to their inherently superior weight-for-age, and enhanced feed conversion efficiency - provided the rate of carcass downgrade is minimal. While there was no difference in growth performance between castrated and non-castrated animals prior to their entering the feedlot, which coincided with the expected time of sexual maturity of the non-castrates, after 75 days of grain feeding, non-castrated animals were on average about 4% heavier and had 11% higher estimated average daily gain than castrated animals.

There were no observed behavioural differences between the treatment groups during the course of the project, and there were no differences in growth rates or liveweights between Early-castrate and Late-castrated animals or Short-scrotum and Entire animals. Carcasses from non-castrated animals that met the target AusMeat specification for "male" had a ≈$52 higher gross value than did those from castrated animals. Overall, there was a very low incidence of "dark cutters" in the project cattle, and grain finishing entire animals at a younger age to their castrated counterparts may help avoid downgrades due to the appearance of secondary sex characteristic and facilitate achieving a premium sale price target.

Castrated animals had a higher rate of allocation to MSA boning groups ≤10 (the "premium" boning groups), than non-castrated animals. However, boning groups do not appear to be a sensitive indicator of eating quality of meat from high-grade *Bos indicus* cattle.

While meat from castrated animals had higher PMQ scores than did meat from non-castrated animals, this difference was not generally reflected in taste panel sensory test scores. Although meat from castrated animals had higher MQ4 scores than meat from non-castrated animals, there were no differences between the boning groups for any of the sensory test outcomes, and of the three muscles that were sensory tested, only striploins from early-castrated animals were rated as being of higher eating quality than those from late-castrate, short-scrotum or entire animals.

Sensory testing of meat quality as measured by MQ4 did not differ between carcasses of non-castrated animals that were graded as either "steer" or "bull" (43.862 ± 0.990 *vs* 45.078 ± 1.807, respectively; mean ± SEM), indicating that taste panels did not detect differences in the eating quality of the three muscles from these animals. This suggests that grading of carcasses of young animals on secondary sex characteristics may not accurately reflect the eating quality of meat from those carcasses.

For the high-grade *Bos indicus* cattle in this study, at least, there was a disparity in the allocation of MSA star grades between boning groups, PMQ and MQ4 outcomes from sensory testing. This disparity appeared to be more than might be expected from a grading system designed to ensure that the consumer does not have an unacceptable eating experience from consumption of beef of MSA 3-star quality or better, and represents a potential financial loss for producers.

There is clearly scope to improve the quality and consistency of meat from *Bos indicus* genotypes in northern Australian, with a majority of carcasses from young cattle producing primals of the MSA 3-star grade being a realistic goal. However, if MSA grading is to be more relevant to the north Australian beef industry, there is a need for additional research to generate data relevant to the northern beef industry, to allow the MSA grading model to be further refined for *Bos indicus* cattle. In addition, further research is indicated to evaluate the feed conversion efficiency and the effects and interactions of castration status, nutrition and HGPs on meat quality of young entire male cattle.

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1 Introduction

This project is a good example of producer initiated research in the northern beef industry. It emerged originally as a Producer Demonstration Site (PDS) proposal by the North-west Queensland Regional Beef Research Committee (NWQRBRC), following some personal experience with producing beef from feedlot finished young entire-male cattle by the late Mr Zanda McDonald, who was Chair of the NWQBRC at the time. Meat and Livestock Australia (MLA) staff, who manage MLA's research and development program for the north Australian beef industry, recognised that the scope and scale of the proposal was beyond that of a PDS, and so approached James Cook University (JCU) to manage the project.

Professor Lee Fitzpatrick from the School of Veterinary and Biomedical Sciences at JCU was the Chief-Investigator. Co-investigators were Associate Professor Tony Parker from JCU and Professor Henry Zerby, an international renowned meat scientist from the Department of Animal Science at The Ohio State University in Columbus, Ohio, who has experience in the Australian meat industry and holds an adjunct academic appointment at JCU.

2 Background

Although young, entire male cattle are used for premium beef production in many parts of the world, e.g. Europe and South America, utilising entire male cattle for beef production is not widely practiced in Australia. Furthermore, the Meat Standards Australia (MSA) grading system does not currently accommodate entire male cattle in its model.

Each year some 8-10,000 young, entire male cattle are sent to slaughter from breeding properties in northern Australia (McDonald DA, 2008, *pers comm*.). Anecdotal evidence suggested that, if appropriately managed through the growing phase and finished on grain, the nett financial return from this class of cattle could be enhanced.

The use of entire males in Australian beef production systems

In Australian production systems, beef from entire males, "bull beef", has traditionally been a by-product of cow/calf breeding operations or the dairy industry, despite evidence suggesting that beef enterprises can benefit from the highly efficient fast growing characteristics of entire male cattle that achieve target weights earlier (Nichols *et al.* 1963, Bailey *et al.* 1966, Field 1971, Seideman *et al.* 1982).

In contrast to the potential production benefits, there is also evidence that suggests that meat from entire males has less marbling, is of coarser texture, is darker in colour and is less tender than meat from castrates (Arthuad *et al.* 1969). Furthermore, larger carcasses and difficulties in removing the hide have contributed to negative perceptions in the processing sector, while consumer acceptance of beef from entire males is also a major issue due to the negative association with a darker and less tender product. This perception may be attributed to the knowledge that the majority of beef produced from entire males in Australia is a product of cast for age bulls, rather than young animals. As a result, historical values of carcasses from entire males in the Australian domestic market have been heavily discounted. Although there has been little research undertaken focusing on the production of beef from entire males over the past 30 years, there was previously a large amount of literature published that discussed the advantages and disadvantages of using entire males with specific reference to growth, efficiency, behaviour and carcass characteristics (Field 1971, Seideman *et al.* 1982).

Average daily gain

The importance of growth and daily gain in a breeding, backgrounding or finishing operation is imperative to its success. Historically, male calves have been castrated at an early age in Australia to comply with market demand and to decrease management stress. This practice essentially reduces the potential liveweight gain of the animal and reduces the rate of carcass maturation (Arthuad *et al.* 1969). In 14 studies referenced in the review completed by Field (1971), it was found that entire males had a 17% higher average daily gain than did castrates. It was also concluded that entire males were 13% more efficient as measured by the conversion of feed consumed to liveweight gained. The period of growth prior to puberty has been reported to be similar in both entire and castrated males (Hinch and Thwaites 1984), while the period following puberty is that during which entire males exhibit superior growth traits (Bailey *et al.* 1966, Watson 1969, Kellaway 1971).

Behaviour and management of entire males

The aggressive and sexual behaviour that pubertal and post-pubertal entire male cattle can display is a major management issue limiting the acceptance of entire males at the property level and subsequent damage to pastures, feeders, fencing and handling equipment as a result of this behaviour can affect the profitability of an operation (Seideman *et al.* 1982). Producer apprehension to a production system using entire male cattle may also be attributed to the incidence of injury to both handler and animal. Poor economic returns associated with dark cutting and bruising as a result of poor pre-slaughter behaviour have also been reported (Price *et al.* 2003).

It is well recognised that cattle are gregarious animals and develop social rankings within groups. Aggressive behaviour in establishing these hierarchies is a common observation that can reduce intake, increase stress and ultimately downgrade carcass quality. Re-grouping cattle based on size and liveweight prior to finishing is a standard practice and can predispose animals to unwarranted stress. Mounier *et al.* (2006) suggested that reducing stress and aggressive behaviour in entire male cattle was achievable. This study compared mixing entire males at the beginning of the finishing period compared to mixing during the fattening phase reduced aggressive behaviour. Entire males that had already established a social hierarchy displayed less fear when separated and were less stressed prior to slaughter.

In an early survey of Australian beef producers conducted by Hinch and Thwaites (1979) it was found that management difficulties were a common reason for poor acceptance of producing entire male cattle. In listing the reasons for the difficulties, farmers nominated fence damage, early separation of sexes and difficulties in yard handling. The low adoption rate of producers who specialise in the production of entire male cattle in today's industry suggests that these inherent perceptions still exist.

Meat quality from entire males

Carcasses from entire males have historically been heavily discounted in the domestic market as the majority of entire males are cast for age bulls. This has given rise to the perception that meat from entire males is of lower quality, is less tender and has a darker appearance than meat from castrated animals (Seideman *et al.* 1982), however, there is contradictory evidence that suggests that on sensory evaluation using both trained and untrained panels, the difference in quality of meat from young bulls and steers is often undetectable (Morgan *et al.* 1993, Woodward *et al.* 2000).

A number of studies have indicated that while beef from entire males was slightly tougher than that of castrates, it was still of an acceptable eating standard. Rib cuts from entire male cattle slaughtered at chronological ages of 12, 15, 18 and 24 months were of a satisfactory

eating standard based on sensory assessment (Arthuad *et al.* 1969). Field *et al*. (1966) suggested that the chronological age of an entire male strongly influenced objective and sensory meat quality traits. The study found entire male cattle slaughtered between 300-399 days had lower Warner-Bratzler Shear Force (WBSF) (2.81 kg *vs* 3.12 kg) and a higher or more desirable sensory tenderness score compared to castrates. Entire males that were slaughtered from 500-699 days had higher WBSF values and less desirable sensory tenderness scores. These results support the theory that as animals age, the properties of connective tissue changes decreasing the solubility and increasing overall toughness of the meat (Aberle *et al.* 2001).

A perception of reduced quality of meat from entire male's may be a limiting factor to the adoption of bull beef in Australia. Carcasses from entire males tend to have a higher an ultimate pH (>5.8) than carcasses from castrates (Mach *et al.* 2009). Meat with a high pH is associated with reduced glycolysis, a subsequent darker colour and lower level of tenderness. Purchas *et al.* (2002) concluded that the difference in tenderness between entire males and castrates could be explained predominately by background toughness. These variables included; higher amounts of connective tissue, lower levels of intramuscular fat, and higher pH, however, the study also recognised the importance of proteolytic activity in meat tenderness.

Production of short-scrotum males

Artificial cryptorchidism, as a method of castration, is not a common practice in Australian beef production systems. The method involves pushing the testes up in the scrotum so that they are adjacent to the abdominal wall and placing a rubber band around the upper portion of the scrotum, resulting in aspermatogenesis due to the removal of the thermo-regulated environment needed to produce spermatozoa (Bass *et al.* 1976). Male cattle castrated by this process are referred to as short-scrotum bulls or cryptorchids. Short-scrotum bulls continue to produce male hormones resulting in similar secondary sex characteristics and mating behaviour as observed in entire male cattle. They are infertile while still attaining similar superior growth traits that have been observed in entire males compared to castrates. Albaugh *et al.* (1975) demonstrated that short-scrotum bulls had similar growth rates, carcass data and sensory scores to entire males. The lower sensory tenderness scores of short-scrotum and entire versus castrated males that were observed in that study were still considered of an acceptable eating standard.

There is an ever growing body of international evidence that supports the concept of producing lean efficient beef from entire males. Animal welfare benefits are also considered with the elimination of castration from a production system. The lack of data on the production of entire male cattle in Australia, notably in northern Australia, represents an opportunity for commercial based research to determine the viability and sustainability of such an operation and to exploit the increasing consumer preference for organic, hormone free, "natural" beef.

Previous MLA funded projects have demonstrated productivity gains in entire male cattle (Ridley and Schatz 2006). The results showed that in comparison to Brahman steers, when slaughtered at the same fatness, Brahman bulls had a 15% advantage in carcass weight. Some live export markets actually pay a premium for entire males but in the local domestic trade, entire male cattle historically receive a heavy discount because of perceptions of poorer meat quality.

The purpose of the current project was to evaluate carcass yield and quality and consumer eating quality characteristics along with growth and behaviour aspects of young short-scrotum and entire male cattle finished on grain for the domestic trade compared with early- and late-castrated males. There is potential for young, entire male cattle from northern breeding properties to be value-added through grain-finishing, however, meat eating quality

perceptions of entire young *Bos indicus* are largely unsubstantiated. In addition, there are animal welfare benefits to be gained if castration of these animals is avoided.

3 Project objectives

1. Test the hypothesis that entire male *Bos indicus* cattle from a north Queensland breeding herd, when grown out to ≈300 kg liveweight and finished at ≈460 kg liveweight by grain feeding for a minimum of 70 days in a feedlot, would produce a carcass of comparable characteristics and eating quality to that of early- and late-castrated males.

2. Evaluate the economic returns, production parameters, feedlot performance, carcass characteristics, eating quality and animal welfare and behavior issues associated with early and late-castrated, short-scrotum and entire male calves, that have been sourced from northern breeding herds and grain finished.

3. Produce a plan outlining future possible marketing and research strategies which will support the findings of this research.

4 Methodology

This project was conducted in collaboration with McDonald Holdings Pty Ltd (MDH) on a number of their properties. The project purchased MDH weaner steers which were bred on *Rutland Plains* (15^{o} 38.804'S 141^{o} 50.800'E) and *Dunbar* (16^{o} 2.852'S 142^{o} 23.644'E), adjoining properties in the eastern Gulf of Carpentaria/western Cape York region, grown out on pasture at *Devoncourt*, Cloncurry (21^{o} 12.937'S 140^{o} 13.958'E), and finished on grain to Domestic Trade Steer specifications at MDH's *Wallumba* feedlot (26^{o} 50.646'S 150^{o} 14.173'E) on the Darling Downs.

Experimental design

The project was conducted in an experimental design incorporating four (4) male treatments. In the second mustering round at *Rutland Plains* and *Dunbar* (late September/early October 2008), entire male calves were weighed and allocated at random to one of four (4) treatment groups, as follows:

1. Early-castrate: to be surgically castrated at 1 – 4 months of age
2. Late-castrate: to be castrated at weaning at ≈200 kg liveweight (≈9 - 12 months old)
3. Short-scrotum: to undergo a rubber banding procedure at 1 – 4 months of age to produce short-scrotum entire males (artificial cryptorchid)
4. Entire: to remain intact for the duration of the experiment

The number of animals selected as calves for each treatment group is presented in Table 1.

At ≈9-12 months of age (≈200 kg liveweight), from late May 2009, all calves were weaned and relocated to *Devoncourt*, where those calves in Group 2 (Late-castrate) were castrated. All the weaners were grown out on *Devoncourt* to ≈330 kg liveweight, at which time (mid-July 2010) they were sent to *Wallumbah* feedlot and grain fed for 75 days, to ≈420 kg liveweight. On exiting the feedlot at the end of September 2010 (25 – 28 months of age), all animals were sent for slaughter at JBS Australia's Dinmore abattoir (JBS).

Table 1 Planned and actual numbers of calves established in each of four treatment groups, either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatments	Numbers of calves	
	Planned	Actual
1) Early-castrate	170	169
2) Late-castrate	170	170
3) Short-scrotum	170	161
4) Entire	170	165
Total	680	665

Data collection

The following data were collected:

1. Liveweights on allocation to treatment groups, at weaning, ≈10 months after weaning, on trucking from *Devoncourt*, on entry to the feedlot, and at mid-feeding period.

2. Carcass quality and yield characteristics as per standard abattoir vendor feedback:

- Category (sex) of animal: B – Male, entire, with secondary sex characteristics
  M – Male, without secondary sex characteristics
  F – Female
- Dentition: Number of permanent erupted incisor teeth
- P8 fat depth: Manual measurement (mm) using 'cut and measure' at the P8 site.
- Butt profile: Based on a two dimensional view of the carcase as seen from the side, and scored from A (highly convex) to E (highly concave), where C is straight.
- Bruising: AUS-MEAT bruise score 1 to 9
- For each carcass side – hot side weight, $/kg
- Hot carcass weight: Hot weight of AUS-MEAT Standard Trim Carcase.
- Gross carcass value

4. MSA carcass evaluation:

- Ossification - measured on a 100 – 590 point scale, in 10 point increments
- Marbling - assessed from the 5th to 13th rib on the carcase, marbling score is divided into tenths for grading, creating a score range from 100 to 1,190 in increments of 10)
- Rib fat - subcutaneous fat measured in mm at the quartering site or P8 site
- Loin temperature and ultimate pH
- Fat colour – assessed against the AUS-MEAT meat colour reference standards
- Meat colour (assessed at M. *longissimus dorsi* against the AUS-MEAT meat colour reference standards)
- Eye muscle area - measured in square cm using an AUS-MEAT grid
- Pre/post-rigor pH/temp/time measurements

5. A subset of carcasses (30 from each treatment group) underwent meat quality evaluation including 'Warner-Bratzler' shear force test, measurement of sarcomere length and cooking loss, and consumer taste panel sensory evaluation of flavour, tenderness, juiciness and overall eating quality using MSA protocols.

6. Hair samples were collected from all animals at the feedlot to facilitate genetic testing for Molecular Value Predictors (MVP) of Marbling and Tenderness

7. Behavioural observations were made on the animals at weaning, at yarding for weighing ≈10 months after weaning, at yarding for trucking to the feedlot and at mid-feeding period, particularly in relation to aggression and sexual interactions.

Project staff

In addition to the Chief-investigator, Co-investigators and associated technical staff, the project employed a research officer and appointed a Masters by Research (MSc) graduate student, Mr Steven Wainewright, to assist with the conduct of the project.

Conduct of the project

In late-September/early-October 2008, the Chief Investigator accompanied by technical staff from JCU and the project research officer worked at *Rutland Plains* and *Dunbar* alongside MDH staff to weigh, identify and allocate at random, male calves to treatment groups such that groups were balanced across the range of calf weights and property of origin, as follows:

- All calves in the project were identified with MDH numbered ear tags, NILS ear tags and coloured button ear tags specific to their treatment groups.

- Calves in the early-castrate group were surgically castrated at the time of allocation, and calves allocated to the short-scrotum group were banded so that their testes were retained high in the scrotal sac using a Tri-bander™ medium latex ring applicator (Wadsworth Manufacturing, St. Ignatius, Montana, USA)

As a result of the big 2009 “wet” season, mustering of cattle on *Rutland Plains* and *Dunbar* was substantially delayed, however, all of the cattle that were available for the continuation of the project were mustered, weaned and relocated in groups as they became available, along with other weaners to *Devoncourt* by 30 October 2009. Those animals in the Late-castrate group were castrated immediately on arrival at *Devoncourt* using a Callicrate™ bander (Bainbridge Veterinary Instruments Pty Ltd, Murarrie, Australia).

As a consequence of the extensive nature of these breeding properties and the scale of the 2009 wet season, 137 calves that were allocated to treatment groups in 2008 were not recovered for weaning in the 2009 muster. However, the viability of the project was not affected by this wastage as some failure to recover animals between establishment of the treatment groups in 2008 and weaning in 2009 was anticipated, and provision was made for this loss when the numbers of animals to be allocated to the treatment groups was originally established.

In March 2010, all of the animals that had been relocated to *Devoncourt* were weighed and ranked on weaning weight, and a sample (25 head from each treatment group, allocated at random) had ultrasound scans for fat depth at the 12/13th rib, P8 fat depth, and eye muscle area.

Purchase of steers from MDH and custom feeding

The project cattle were purchased from MDH Pty Ltd by JCU with project funds, at the time of entry into the feedlot. MDH delivered the project cattle to *Wallumba* feedlot on 13 July 2010, where they were allocated at random to one of three adjoining pens (176 per pen). and they were inducted into the feedlot on 16 July 2010. The project funded the custom feeding of the trial cattle at commercial rates.

The cattle were weighed at induction and again on 23 August 2010, when hair samples were collected for GeneStar Molecular Value Prediction (MVP) testing for marbling and

tenderness (Pfizer™ Animal Health, West Ryde, Sydney, Australia). GeneSTAR MVPs are by definition a "molecular breeding value" based on the effects of the specific markers in the current panel. Thus, they represent a portion of the expected underlying genes affecting the traits. By definition, an MVP is similar to an expected progeny difference (EPD) from a genetic evaluation in how it is expressed. The difference is that an EPD is based on phenotypic records of the animal and its relatives, whereas an MVP is derived from an animal's genotype only. The GeneSTAR MVP for marbling is reported as USDA marbling score with a positive marbling MVP value being favourable (ie, higher marbling score). Tenderness is predicted on the basis of the peak force required to shear cooked steak after 14 days of postmortem aging. The GeneSTAR MVP for tenderness is reported in pounds of Warner-Bratzler shear force with a negative tenderness MVP value being favourable (ie, more tender).

There were two deaths during the feeding period, both from the Late-castrate group. The causes of the deaths were determined to be from non-eating in one case and respiratory disease in the other. As it was not possible to weigh the cattle on exit from the feedlot, an exit liveweight was estimated from the hot carcass weight using historical dressing percentage data for similar genotype and class of cattle (McDonald DA, *pers comm*; Fitzpatrick LA, *unpublished*), ie 54.5% and 56.0% for castrated and uncastrated animals, respectively.

Sale of trial cattle and reimbursement of MLA

On 26 September 2010, after 75 days on feed, 526 head were trucked to JBS's Dinmore plant, where they were slaughtered the following day. At the completion of the trial, proceeds from the sale of the cattle to JBS were returned to MLA.

Table 2 Number of cattle either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

	Early-castrate	Late-castrate	Short-scrotum	Entire	Total
Allocated to the project (Sept/Oct 2008)	169	170	161	165	665
Relocated to *Devoncourt* at weaning (July – Oct 2009)	≈147	≈151	≈133	≈140	≈571
Inducted into *Wallumba* feedlot (16 July 2010)	142	136	121	129	528
Slaughtered at JBS, Dinmore (23 Sept 2010)	140	136	121	129	526

Behavioural studies

It was not logistically possible to record formal behavioural data from paddock studies. However, the Chief Investigator interviewed a number of stockpersons who handled the trial cattle, both in the paddocks and yards at *Devoncourt* and at *Wallumba*.

On arrival at the *Wallumba* feedlot, cattle in the four treatment groups were allocated at random to one of three feedlot pen lots 1058A, 1058B, and 1058C, respectively, containing either 175 or 176 animals each. Five weeks after the cattle were inducted into the feedlot they were weighed and a formal behavioural study was conducted with animals from one pen. Animals from Pen 1058A were identified in their four treatment groups (Early-castrate = 44, Late-castrate = 46, Short-scrotum = 41, Entire = 45) with stock paint markings on either their poll, shoulder, mid-back or tail-head. A high definition video camera with a wide angle

lens was fixed to a pole over-looking the feed bunks of Pen 1058A, and ≈8 hours of video recording made of the behaviour of the cattle in the pen between the hours of 0800 and 1600. On subsequent examination of the video recordings, cattle were observed for riding, fighting and dominance behaviours, with individual behavioural interactions being counted and the treatment groups of the animals involved recorded. The period of observation included one feeding event.

Carcass grading data from vendor feedback sheets

The vendor feedback sheets supplied by JBS provided data on carcass Sex (M = male, B = bull), Dentition (number of permanent incisors), Hot Carcass Weight (kg) and Gross Value ($); and for each side – P8 Fat Depth (mm), Butt Shape (A to E, with A being most convex and E being most concave.), Hot Weight (kg), Bruise score (1-9 depending on the position of the score-able bruise), $/kg.

Secondary sex characteristics are defined by the following aspects being well developed (AusMeat 2006):

- muscles of the neck and shoulders
- inguinal canal and prominent erector muscle
- penis stub
- pubic tubercle
- exposed area of the M. *semimembranosus* muscle triangular, and relatively scarce
- scrotal fat and dark muscle colour

MSA carcass evaluation

The MSA grading model assigns one of four eating quality grades (2-star = unsatisfactory, 3-star = “good every day”, 4-star = “better than everyday”, or 5-star = “premium”) to 40 individual carcass muscles cooked by up to six alternative methods. The grade is assigned by an empirical prediction model which estimates a predicted meat quality (PMQ) score on a 0 – 100 scale for each muscle x cook outcome, based on inputs of % *Bos indicus*, sex, carcass weight, ossification, marbling, rib fat, carcass suspension method, ultimate pH, and meat colour (Watson *et al.* 2008). The current PMQ cut-offs for 3-star, 4-star and 5-star are 46.5-63.9, 64.0-76.9 and 77.0-100.0 points, respectively (Watson *et al. 2008*).

For MSA grading purposes, all the project cattle were a high grade Brahman genotype and so were classed as being 100% *Bos indicus*. All were hung by the achilles tendon during the slaughter process and entered in the MSA grading model as steers.

An MSA Index was calculated for each carcass. The index is a weighted average of the PMQ score for all the cuts for which an MSA value is calculated. The weighting is based on the physical weight of each cut (derived from earlier research work by Meat Standards Australia). The index assumes that each cut is cooked using the most common cooking method for that cut, and all values are calculated for AT hung carcass at 5 days ageing

Assessment of meat quality

Animals were ranked in ascending order of Tenderness MVP and then 40 animals from each treatment group were allocated at random for evaluation of meat quality, resulting in a spread of MVP values in each of the treatment groups. From the 40 animals from each treatment group that were initially allocated for evaluation of meat quality, 30 animals were selected for further meat quality and sensory testing following MSA carcass evaluation.

Three muscles, eye round (*M. semitendinosus*) (EYE), rump (*M. gluteus medius*) (RMP) and striploin (*M. longissimus dorsi lumborum)* (STR)*,* aged either 7 days or 35 days were used to evaluate meat quality. The cooking method was "grill" (Watson *et al.* 2008).

Shear force, sarcomere length, cooking loss and pH

Samples of three muscles (EYE, RMP and STR) were collected from 15 animals in each treatment group and aged for either 7 or 35 days, prior to being tested for shear force, sarcomere length, cooking loss and pH. Muscle samples (250 g blocks) were cooked using the following protocol: muscle samples were placed individually in vacuum bags and heated in a 100 ^{o}C water bath (Model: BTC9090) to an internal temperature of 70 ^{o}C. Core temperature of the sample was monitored using a thermometer (8 channel thermocouple, PICO TC-08 RS 232, PICO Technology Limited). The heating rate was about 2.4 ^{o}C /min. Thereafter, the samples were chilled under running tap water and stored overnight at 4 ^{o}C until sampling. Shear force and cooking loss were determined as described by Perry *et al.* (2001b). Sarcomere length was determined according to Cross *et al.* (1981) using phase contrast microscopy (filar micrometer method). The pH of the muscle samples used for the measurement of shear force, cooking loss and sarcomere length was measured using an insertion probe (WP-80 Waterproof pH-mV-Temperature meter, TPS Australia). The pH of the raw meat samples was measured by inserting the probe in three location of the sample, with the average reading being recorded.

Sensory testing

The sensory testing of muscle samples from a subset of cattle from each of the treatment groups was carried out by Meat Standards Australia using protocols as published in Meat Standards Australia Protocol Books:

- Book One – Model Design with CUD
- Book Two – Acquisition of Cuts
- Book Three – Cut Ups, Picks & Posts
- Book Four – Thawing, Preparation, Cooking & Serving
- Book Five – Venues, Staff, Consumers, Forms etc
- Book Six – Managing BLUE (The International Beef Database)

To briefly summarise the sensory testing protocol, a consumer testing protocol was generated through a series of trials. The number of responses required from a consumer about a particular meat sample was limited to four (tenderness, juiciness, flavour and overall liking), in addition to an assessment of the star-rating (satisfaction). In order to generate a more reliable measure, a trimmed mean is used (ie, a sample of 10 consumers is used, the smallest two and the largest two observations are deleted and the middle six averaged), to give a robust and reasonably reliable measure, MQ4. This measure forms the basis of the MSA consumer prediction model, which generates a predicted MQ4 (PMQ4) from available data which is considered to be a good assessment of the consumer assessment of meat eating quality (Watson *et al. 2008*).

5 Statistical methods

Growth data

The analysis method used to analyse liveweights was a REML model in Genstat (Genstat 2011) with animal ID as the random effect. Time was a within-animal fixed effect and group was a between-animal fixed effect. The two-way interaction between time and group was also considered. The outcome satisfied the assumptions of normality and homogeneity of variance for the model.

Carcass data

The analysis method used to analyse the carcass data of was one-way ANOVA models in Genstat, with treatment group as the factor. The outcomes satisfied the assumptions of normality and homogeneity of variance for the models.

Genetic data

The analysis methods used to analyse the impact of genetic factors, Marbling MVP and Tenderness MVP, on related outcomes were linear models and general linear models using Genstat, with treatment group as the factor and the interaction between treatment group and the genetic factors also considered. For outcomes measured at multiple cuts per animal, a random effect for animal was included and REML was used to fit the model, along with adjustments for type of cut and age. All outcomes satisfied the model assumptions.

Post-mortem pH decline data

A REML model (GenStat 2011) with animal ID as the random effect was used to analyse post-mortem pH declines. Time was a within-animal fixed effect and treatment Group was a between-animal fixed effect. All of the outcomes satisfied the assumptions of normality and homogeneity of variance for the model.

Predicted meat quality (PMQ) data

The analysis method used to analyse all outcomes was a REML model in Genstat with animal ID as the random effect. The categorical variables included in the models were treatment Group (Early-castrate, Late-castrate, Short-scrotum or Entire), Muscle (EYE, RMP or STR) and Aged (7 or 35 days), including all of their higher level interactions. There were also two numerical variables, Marbling MVP and Tenderness MVP, which were adjusted for in the model. All of the outcomes satisfied the assumptions of normality and homogeneity of variance for the model.

Objective and sensory test data

The analysis method used to analyse all outcomes was a REML model in GenStat with animal ID as the random effect. The categorical variables included in the models were treatment Group (Early-castrate, Late-castrate, Short-scrotum or Entire), Muscle (EYE, RMP or STR) and Aged (7 or 35 days), including all of their higher level interactions. There were also two numerical variables, Marbling MVP and Tenderness MVP, which were adjusted for in the model. All of the outcomes satisfied the assumptions of normality and homogeneity of variance for the model.

MSA star grade

For the animals that were selected for taste panel sensory testing of meat quality, MSA Star Grades were determined either from the boning group data derived from MSA carcass grading (MSA1-BG), the PMQ data generated by the MSA Model (MSA2-PMQ), or from the

MQ4 data derived from sensory testing (MSA3-MQ4). As there were multiple muscles per animal, these scores weren't independent and therefore this comparison was performed separately for each muscle. McNemar's test (GenStat 2011), was used to test whether one grading system was more likely to give a grade of 3-star or better, compared to the other. McNemar's test does this by assessing the distribution of the discordant pairs (ie muscles for which the two grades disagreed) and which fraction were in which direction (ie which grading system rates it higher). Gradings above 3-Star were collapsed into the 3-star grade to facilitate the analysis.

6 Ethics approval

Approval to conduct the project as outlined in the contract was obtained from the JCU Animal Ethics Committee on 15 September 2008 (Approval no. A1342 - see Appendix 1).

7 Results

Growth and feedlot data

Liveweights at allocation to treatment groups

Liveweights of the calves at branding are presented in Table 3. As might be expected, if animals were allocated to treatment groups at random, there were no differences in mean liveweights between the groups.

Liveweights at weaning

Liveweights of the cattle at weaning are also presented in Table 3. There were no differences in mean liveweights at weaning between animals in the four treatment groups.

Liveweights, carcass characteristics, and behavioural traits prior to feedlot entry

Liveweights and carcass characteristics prior to feedlot entry are presented in Table 3. There were no liveweight differences between the treatment groups on March 2010 when the cattle were yarded to facilitate a subset of animals (25 per group) undergoing ultrasonography to measure fat depth at the 12/13th rib, P8 fat depth, and eye muscle area. Cattle in the Late-castrate group had lower liveweight gains from branding to March 2010 than did Early-castrate, Short-scrotum or Entire animals ($P<0.05$), and castrated cattle had lower liveweight gains from weaning to March 2010 than did entire cattle ($P<0.05$). Rib fat, rump fat and eye muscle areas in March 2010, did not differ between the treatment groups. Liveweights at the time of trucking to Wallumbah feedlot did not differ. There were no observed behavioural differences between the treatment groups from branding to trucking to the feedlot.

Feedlot performance

Feedlot performance data is presented in Table 4, and an overall summary of the feedlot data is presented in Table 2a of Appendix 2. Weather conditions were not conducive to good liveweight gains, particularly through the later period of feeding, with a large amount of unseasonal rainfall. Rainfall in August and September 2008 was 94 mm and 82 mm *versus* mean rainfall of 36 mm and 28 mm, respectively. On entry to the feedlot, liveweights of the treatment groups differed ($P<0.01$), with Late-castrate, Short-scrotum and Entire animals being heavier than Early-castrates. After 38 days on feed, the non-castrated animals were

heavier than castrated animals (P<0.001). Overall, castrated animals had lower estimated average daily gains than did non-castrated animals; 1.12 ± 0.02 vs 1.24 ± 0.03 kg/day for castrated versus non-castrated animals, respectively (P<0.01). This is in contrast to an expected average daily gain of around 1.5 kg/day, for this class of animal in similar circumstances (McDonald DA, *pers comm*; Fitzpatrick LA, *unpublished*).

Animal Behaviour

Paddock - In all cases it was reported that behaviour, and in particular riding or fighting behaviour, of the trial cattle did not differ from that which might be seen among a similar size group of steers under similar conditions.

Feedlot – Riding and fighting behaviours were at a very low level among animals in all treatment groups across the duration of the recording and there were no differences in behaviours observed between the treatment groups.

Table 3 Liveweights and liveweight changes (mean ± SEM kg, with the numbers of animals in brackets) at allocation, weaning, in March 2010 and prior to trucking to Wallumbah feedlot, and carcass data (rib fat, rump fat and eye muscle area) of a subset of animals in March 2010, of cattle either castrated at allocation (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

	Treatment group			
	Early-castrate (n)	**Late-castrate (n)**	**Short-scrotum (n)**	**Entire (n)**
Wt. at allocation, Sept/Oct 2008 (kg)	87.26 ± 2.43 (169)	87.39 ± 2.60 (170)	86.45 ± 2.66 (161)	88.16 ± 2.67 (165)
Wt. at weaning, July – Oct 2009 (kg)	220.53 ± 3.31 (126)	223.83 ± 3.02 (131)	223.15±3.26 (115)	218.78±2.98 (114)
Wt. in Mar 2010 (kg)	328.88 ± 3.92 (112)	324.62±4.00 (113)	337.63±4.07 (95)	334.88±4.16 (98)
Wt. change, allocation - Mar 2010 (kg)	238.31 ± 3.33^{ab} (119)	232.78 ± 3.88^{b} (118)	246.62±3.59^{a} (104)	243.78±3.71^{a} (107)
Wt. change, weaning - Mar 2010 (kg)	107.57 ± 1.62^{b} (112)	101.88 ± 1.78^{c} (113)	113.75±2.25^{a} (95)	114.25±1.94^{a} (98)
Rib fat, Mar 2010 (mm)	3.30 ± 0.01 (24)	3.30 ± 0.02 (25)	3.70±0.02 (26)	3.10±0.01 (25)
Rump fat, Mar 2010 (mm)	1.55 ± 0.01 (24)	1.47 ± 0.01 (25)	1.56±0.01 (25)	1.60±0.01 (25)
Eye muscle area, Mar 2010 (cm2)	51.57 ± 0.97 (24)	51.19 ± 1.19 (25)	50.89±0.95 (25)	50.84±0.98 (25)
Wt. at trucking to feedlot, Jul 2010 (kg)	347.04 ± 3.82 (140)	345.05 ± 3.59 (136)	354.30±4.22 (121)	353.15±3.53 (125)
Wt. change, allocation – trucking (kg)	259.57 ± 3.56 (139)	253.75 ± 3.52 (137)	265.88±3.57 (121)	262.95±3.31 (125)
Wt. change, weaning – trucking (kg)	125.52 ± 1.83^{b} (108)	119.73 ± 1.78^{c} (109)	132.24±2.42^{a} (90)	131.17±2.29^{ab} (95)
Wt. change, Mar 2010 – trucking (kg)	18.29 ± 0.79 (116)	17.85 ± 1.45 (114)	20.22±1.56 (98)	18.03±1.19 (106)

a, b, c – row means with unlike superscripts differ, P ≤ 0.05

Carcass grading data from vendor feedback sheets

About 30% of the carcasses from non-castrated animals were graded as "bull" following slaughter, compared with less that 1% of carcasses from castrated animals (Table 5).

Sex effects

There was an association between Sex (M = male or B = bull, where "M" represented castrated or non-castrated animals not showing secondary sex characteristics, and "B" represented animals showing secondary sex characteristics) and Dentition (Pearson Chi-Square = 10.410, DF = 2, P-Value = 0.005). 87% of animals graded as bulls ("B") had permanent incisors compared with 70% of animals graded as males ("M"), while 15% of animals graded "B" had at least four permanent incisors, compared with only 9% of animals graded "M" (see Table 7). Animals graded as bulls ("B") (n = 79) had greater Hot Carcass Weights than did animals graded as males ("M ") (n = 447), ie 257.7 ± 2.7 kg *vs* 229.0 ± 1.3 kg, respectively (P<0.001).

Table 4 Liveweights (mean ± SEM kg, with ranges in square brackets) on entry to the feedlot, in the middle of the period on feed, estimated feedlot exit weight, estimated average daily gain, and and observed behavioural differences of cattle either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire), and fed a grain based ration for 75 days.

	Treatment group			
	Early-castrate [range] (n)	**Late-castrate** [range] (n)	**Short-scrotum** [range] (n)	**Entire** [range] (n)
Feedlot entry wt. (kg) (16 July 2010)	327.65 ± 4.08 [212.0 – 446.0] (140)	329.10 ± 3.74^{b} [176.0 – 408.0] (136)	340.48 ± 4.02^{a} [222.0 – 438.0] (121)	337.09 ± 3.47^{ab} [230.0 – 434.0] (129)
Feedlot wt. – mid feeding period (kg) (23 Aug 2010)	388.93 ± 4.63^{b} [248.00 - 500.00]	393.50 ± 4.00^{b} [276.00 – 534.00]	409.65 ± 4.25^{a} [278.00 – 534.00]	406.78 ± 3.48^{a} [302.00 – 490.00]
Est^{1}. feedlot exit wt. (kg) (22 Aug 2010)	417.55 ± 4.75^{b} [241.28 – 576.15]	409.14 ± 4.25^{b} [270.64 – 510.09]	430.96 ± 4.59^{a} [299.11 – 585.71]	431.97 ± 4.13^{a} [287.50 – 544.64]
Est^{1}. av daily gain (kg)	1.16 ± 0.03^{ab} [-0.30 - 2.27]	1.07 ± 0.03^{b} [-0.13 - 2.78]	1.22 ± 0.04^{a} [-0.13 - 2.75]	1.25 ± 0.04^{a} [0.18 - 2.48]
Observed differences in behaviour at feedlot (fighting, riding etc)	Nil	Nil	Nil	Nil

	Castrate (n=276)	**Entire (n=250)**
Est. av daily gain (kg)	1.12 ± 0.02^{b} [-0.30 – 2.78]	1.24 ± 0.03^{a} [-0.13 – 2.75]

a, b, c - row means with unlike superscripts differ, P ≤ 0.05
1 – based on an assumed dressing percentage

Table 5 Numbers of carcasses (with proportions in brackets) of the treatment groups that were classified as either male (M) or bull (B), based on the presence or absence of secondary sex characteristics, for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	Male	Bull
Early-castrate	140	139 (99.3)[a]	1 (0.7)
Late-castrate	136	135 (99.3)[a]	1 (0.7)
Short-scrotum	121	87 (72.1)[b]	34 (27.9)
Entire	129	87 (72.5)[b]	43 (27.5)

a, b – Column means with unlike superscripts differ, P<0.05

Hot Carcass Weights

Hot carcass weights differed between treatment groups (P<0.001). Castrated animals had lower hot carcass weights than did non-castrated animals. For Early-castrate *vs* Late-castrate and Short-scrotum *vs* Entire, hot carcass weights did not differ (see Table 6).

Gross value of the carcass

The gross value of the carcasses did not differ between the treatment groups (see Table 6).

Table 6 Hot carcass weights and gross carcass values for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	Hot carcass weight (kg)	Gross carcass value ($)
Early-castrate	140	226.24 ± 2.49[a]	737.88 ± 12.27
Late-castrate	136	224.09 ± 2.19[a]	725.03 ± 12.68
Short-scrotum	121	242.49 ± 2.66[b]	744.75 ± 12.70
Entire	129	242.09 ± 2.26[b]	737.65 ± 10.40

a, b – Column means with unlike superscripts differ, P<0.001

Table 7 Numbers (with proportions in parenthesis) of animals with permanent incisors (either 0, 2, 4 or 6), either classed as Male (no secondary sex characteristics) or Bull (secondary sex characteristics).

Sex	Dentition No. of permanent incisors (Proportions)				
	0	2	4	6	All
Bull	10 (0.13)	57 (0.72)	11 (0.14)	1 (0.010)	79
Male	133 (0.30)	275 (0.62)	39 (0.09)	0 (0.000	447
All	143 (0.28)	332 (0.63)	50 (0.10)	1 (0.002)	526

Hot Carcass Weights increased with the number of permanent incisors (P<0.01) (see Table 8).

Table 8 Hot carcass weights (mean ± SEM, with 95% confidence intervals in square brackets), for animals with either 0, 2 or 4 permanent incisors.

Dentition (No. of permanent incisors)	n	Hot Carcass Weight (kg)
0	143	227.90 ± 2.38[a] [223.19 - 232.61]
2	332	233.94 ± 1.56[b] [230.87 - 237.01]
4	50	244.40 ± 4.03[c] [236.31 - 252.49]

a, b, c – column means with unlike superscripts differ, P<0.01

Ignoring one "6 tooth" animal in the Entire treatment group as an outlier, there were no differences in dentition between the treatment groups at slaughter, with the median values of all treatment groups being two. Dental ages were uniformly distributed between the castrated and non-castrated treatment groups (see Table 9).

There was an association between Butt Shape and Hot Carcass Weight (P<0.001), with animals graded as butt shape "D" being lighter than those graded as butt shape "C" (see Table 10)**.** Ossification did not differ with butt shape.

Table 9 Distribution of dental ages between animals either castrated at branding or weaning (castrated), or banded to create an artificial cryptorchid or left intact (non-castrated).

Treatment group	Dentition (no. of permanent incisors)	n	%
Castrated	0	76	27.3
	2	172	62.5
	4	28	10.2
Non-castrated	0	68	27.2
	2	160	64.0
	4	22	8.8

Table 10 Hot carcass weight (mean ± SEM) for carcasses classed as having either butt shape C (straight) or butt shape D (concave).

Butt Shape	n	Hot Carcass Weight (kg)
C	481	235.3 ± 1.3[a]
D	45	212.3 ± 4.5[b]

a, b – column means with unlike superscripts differ, P<0.001

Bruising

There were no differences between the treatment groups for bruising of the carcasses, in fact, carcasses from only two animals in total were trimmed for bruising.

Gross returns

Hot carcass weights, P8 fat depth and gross value of the carcasses are presented in Table 11. Of 526 animals killed, 79 graded "bull" (447 graded "male") - one animal each from the

Early-castrate (0.7%) and Late-castrate (0.7%) groups, 34 Short-scrotum (28.1%) and 43 Entire (35.6%). Those animals graded "bull" were the heaviest carcasses with the lowest fat scores. Carcasses from uncastrated animals that graded "male" had a ≈$52 higher gross value than did those from castrated animals (P<0.05), while carcasses from uncastrated animals that graded "bull" had a ≈$83 lower gross value than those from castrated animals (P<0.05), and a ≈$137 lower gross value than those from uncastrated animals that graded "male" (P<0.05).

Chiller assessment and MSA grading

Genetic data

There was no effect of Marbling MVP or the treatment group and Marbling MVP interaction on USAMB or AUSMB (binary outcome).

There was an effect of Tenderness MVP on the sensory test measure, Tender - an effect which also differed across the treatment groups, as evidenced by the interaction between treatment group and Tenderness MPV. For Short-scrotum animals, there was no relationship between Tender and Tenderness MVP, however, for the other three treatment groups, there was a negative relationship which was particularly strong for Entire and Late Castrate treatments. There was no effect of Tenderness MVP on Shear Force test results.

Table 11 Hot carcass weights, P8 fat depth and gross values (mean ± SEM) of carcasses from animals graded as "male" or "bull", and either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Grade	Treatment group	n	Hot carcass weight kg	P8 fat depth mm	Gross value $
For carcasses graded "male"	Early-castrate	139	225.61±2.43[a]	11.99±0.35[a]	737.27±12.34[a]
	Late-castrate	135	223.97±2.20[a]	11.77±0.33[a]	726.16±12.73[a]
	Short-scrotum	87	236.61±3.05[b]	9.76±0.32[b]	**783.94±14.75[b]**
	Entire	87	234.80±2.66[b]	10.31±0.35[b]	**780.62±12.09[b]**
For carcasses graded "bull"	Early-castrate	1	314.00	6.00	822.68
	Late-castrate	1	240.50	8.00	573.72
	Short-scrotum	34	257.10±4.47[c]	8.63±0.36[c]	647.34±15.56[c]
	Entire	42	257.18±3.16[c]	8.36±0.48[c]	648.65±10.74[c]

a, b, c - column means with unlike superscripts differ, P<0.05

There was no effect of Marbling MVP, and no treatment group x Marbling MVP interaction on PMQ scores. There was small, but significant, effect of Tenderness MVP on PMQ scores (P<0.05), but no treatment group x Tenderness MVP interaction. There were no differences in Marbling MVP or Tenderness MVP between the MSA boning groups.

Ossification

Ossification scores differed between treatment groups (P<0.001). Castrated animals had lower ossification scores than did Short-scrotum or Entire animals (see Table 12). Dentition was positively correlated with Ossification (n = 526, r = 0.228, P<0.001) (see Table 13). Ossification scores for animals graded as "male" were lower (P<0.001) than for those animals graded as "bull" (144 ± 1 *vs* 165 ± 2, respectively) (see Table 14).

Table 12 Ossification scores (mean ± SEM) for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	Ossification score
Early-castrate	140	138.57 ± 0.932[a]
Late-castrate	136	138.89 ± 1.121[a]
Short-scrotum	121	156.97 ± 1.801[b]
Entire	129	155.43 ± 1.868[b]

a, b – Column means with unlike superscripts differ, P<0.05

Table 13 Ossification scores (mean ± SEM) for animals with dentition scores of either 0, 2, 4 or 6.

Dentition score	n	Ossification score
0	143	140.63 ± 1.12
2	332	148.67 ± 1.09
4	50	154.20 ± 2.82
6	(1)	(170.00)

Data for the one animal with a dentition score of 6 is shown in parenthesis, for completeness only.

Table 14 Ossification scores (mean ± SEM) for animals that we graded as either “male” or “bull”.

Grade	n	Ossification score
Male	447	144 ± 1
Bull	79	165 ± 2

AusMeat (AUSMB) and USDA (USMB) marbling scores

There were no differences between the treatment groups for AUSMB. Castrated animals had higher USMB scores than did non-castrated animals (see Table 15).

Meat colour and fat colour scores

There were no differences between the treatment groups for either meat colour (MC) or fat colour (FC) scores (see Table 16).

Rib fat score (RFT)

Castrated animals had higher rib fat (RFT) scores than did Short-scrotum or Entire animals (P<0.001). For Early-castrate *vs* Late-castrate and Short-scrotum *vs* Entire, fat scores did not differ (see Table 17).

Table 15 USDA marbling scores (mean ± SEM) for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire); and for animals that were either castrated at branding or weaning (castrated), or either banded to create an artificial cryptorchid or left intact (non-castrated).

Treatment group	n	USMB
Early-castrate	140	236.07 ± 5.41
Late-castrate	136	220.37 ± 5.66
Short-scrotum	121	208.44 ± 5.61
Entire	129	200.85 ± 5.51
Castrated	274	228.36 ± 3.94[a]
Non-castrated	252	204.54 ± 3.94[b]

a, b – Column means with unlike superscripts differ, P<0.05

Table 16 Meat colour and fat colour scores for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	Meat colour score (median, mode, range)	Fat colour score (mean ± SEM)
Early-castrate	140	1C, 1C, 1B-4	1.46 ± 0.04
Late-castrate	136	1C, 1C, 1B-3	1.47 ± 0.06
Short-scrotum	121	1C, 1C, 1B-3	1.35 ± 0.04
Entire	129	1C, 1C, 1B-6	1.35 ± 0.04

Table 17 Rib fat scores (mean ±SEM) for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	Rib fat score (mm)
Early-castrate	140	4.76 ± 0.180[a]
Late-castrate	136	4.61 ± 0.164[a]
Short-scrotum	121	3.54 ± 0.123[b]
Entire	129	3.56 ± 0.137[b]

a, b – Column means values with unlike superscripts differ, P<0.05

pH decline and ultimate pH

Muscle pH decline over time for each of the treatment groups are presented in Figure 1. Carcasses from Entire animals had slower pH declines (P<0.001) than did carcasses from castrated or Short-scrotum animals. There were no differences between the treatment groups for ultimate pH.

Hump height (Hump)

Hump heights differed between treatment groups (P<0.001). Castrated animals had lower hump heights than did non-castrated animals. For Early-castrate *vs* Late-castrate and Short-scrotum *vs* Entire, hump heights did not differ (see Table 18).

Table 18 Hump heights (mean ± SEM) for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	Hump height (mm)
Early-castrate	140	132.54 ± 2.480[a]
Late-castrate	136	131.74 ± 1.984[a]
Short-scrotum	121	153.16 ± 2.840[b]
Entire	129	152.52 ± 2.775[b]

a, b – Column means with unlike superscripts differ, P<0.05

Eye muscle area (EMA)

Eye muscle areas differed between treatment groups (P<0.001). Castrated animals had smaller eye muscle areas than did entire animals. For Early-castrate *vs* Late-castrate and Short-scrotum *vs* Entire, eye muscle area did not differ (see Table 19).

Boning groups and non-compliance with MSA standards

The numbers of animals in each of the treatment groups that graded MSA (MSA grade code = 0, ie allocated to MSA boning groups 6 – 14), or were ungraded for MSA (MSA grade code = 1, 4, 5, 13, 14, 15, 19, 45 or 139), are presented in Table 20. Overall, 82.3% of carcasses graded MSA, with 88.0% of carcasses from castrated animals and 76.2% of carcasses from uncastrated animals grading MSA.

No animals produced carcasses that graded MSA boning group ≤5. Allocation of carcasses to MSA boning groups differed between the treatment groups, with fewer non-castrated animals being allocated to boning groups ≤10 (Pearson Chi-Square = 48.981, DF = 6, P<0.001). The most common reason for non-compliance with MSA standard requirements was *"Subcutaneous fat depth out of specification"*, with 14% of castrated animals being ungraded for MSA versus 31% of non-castrated animals.

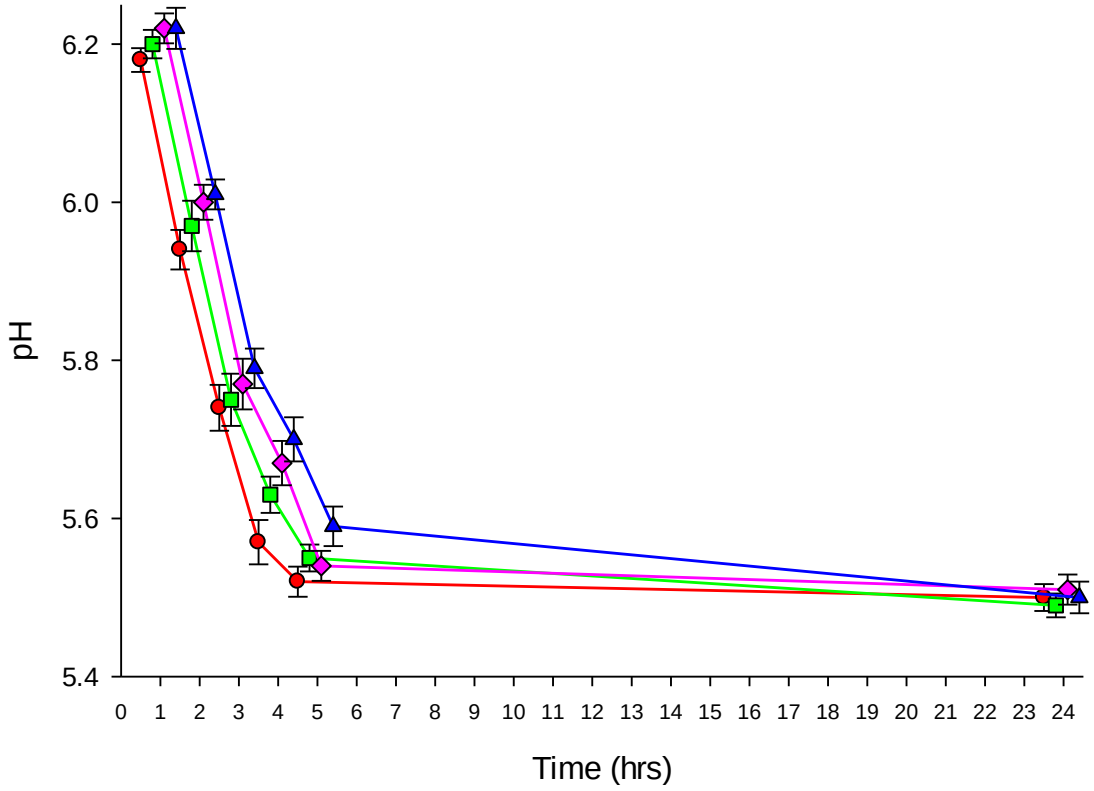

Fig 1 pH decline (mean ±SEM) and ultimate pH (≈24 hrs post-slaughter), for animals that were either castrated at branding (Early-castrate, ●), castrated at weaning (Late-castrate, ■), banded to create an artificial cryptorchid (Short-scrotum, ♦) or left intact (Entire, ▲).

Table 19 Eye muscle areas (mean ± SEM) for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	EMA (cm^2)
Early-castrate	140	65.15 ± 0.864[a]
Late-castrate	136	66.12 ± 0.862[a]
Short-scrotum	121	67.91 ± 0.787[b]
Entire	129	69.02 ± 0.842[b]

a, b – Column means with unlike superscripts differ, P<0.05

Eye Muscle Area (EMA) differed between the MSA boning groups (P<0.001), with animals allocated to boning groups >10 having larger EMA than animals either allocated to boning groups 6 to 10, or ungraded, which did not differ; ie 69.10 ± 0.71 cm^2, 65.64 ± 0.61 cm^2 and 66.45 ± 1.00 cm^2, respectively (see Table 21). US Marbling Score (USMB) differed between the MSA boning groups (P<0.001) (see Table 21).

Numbers of animals with AusMeat Marbling Scores (AUSMB) of either 0 or 1 differed between the MSA boning groups (P<0.001), with more animals from boning groups 6 to 10 having a AUSMB score of 1 (see Table 22).
Meat colour score differed between MSA boning groups, with animals allocated to boning groups 6 – 10 tending to have lighter muscle colour than animals allocated to boning groups >10 or ungraded for MSA (Pearson Chi-Square = 18.981, DF = 6, P<0.01) (see Table 23).

Fat colour scores for MSA boning groups 6 – 10, >10, or ungraded for MSA are presented in Table 24. Fat colour scores did not differ between the boning groups.

Table 20 Numbers of animals in each of the treatment groups that graded MSA grade code = 0 (ie allocated to MSA boning groups 6 – 14) or were ungraded for MSA (MSA grade code = 1, 4, 5, 13, 14, 15, 19, 45 or 139), for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

	Treatment group				
	Early-castrate	Late-castrate	Short-scrotum	Entire	All
MSA boning group					
6	1	-	-	-	1
7	2	3	-	-	5
8	29	20	2	4	55
9	28	18	12	9	67
10	33	37	25	27	122
11	6	17	10	11	44
12	20	25	43	43	131
13	-	-	-	-	-
14	1	1	3	3	8
Total	**120**	**121**	**95**	**97**	**433**
MSA grade code					
1	10	12	23	20	66
4	2	1	-	3	6
5	1	-	-	-	1
13	2	-	3	6	11
14	-	-	-	1	1
15	1	-	-	-	1
19	2	-	-	1	3
45	2	-	-	1	3
139	-	-	1	-	1
Total	**20**	**13**	**27**	**32**	**93**
TOTAL	**140**	**134**	**122**	**130**	**526**

1 – Subcutaneous fat depth out of specification (≥3 mm at the quartering site)
4 – pH greater than 5.70
5 – Meat colour 1A or > 3
13 – Subcutaneous fat depth & fat distribution out of specification
14 – Subcutaneous fat depth out of specification & pH greater than 5.70
15 – Subcutaneous fat depth out of specification & Meat colour 1A or > 3
19 – Subcutaneous fat depth out of specification & hide puller damage
45 – pH greater than 5.70 & Meat colour 1A or > 3
139 – Subcutaneous fat depth & Fat distribution out of specification & Hide puller damage

Table 21 Means (± SEM) for hump height, eye muscle area (EMA), US marbling score (USMB), rib fat depth (RFT), ultimate pH (pH), and hot carcass weight, for animals allocated to MSA boning 6-10, >10 or ungraded for MSA (U).

Carcass Parameters	MSA Boning Group		
	6 – 10 (n = 250)	**>10** (n = 183)	**U** (n = 93)
Hump height (mm)	134.68 ± 1.79[a]	144.57 ± 2.13[b]	150.74 ± 3.66[b]
EMA ($cm^{2)}$	65.64 ± 0.61[a]	69.10 ± 0.71[b]	66.45 ± 1.00[a]
USMB	260.00 ± 3.13[a]	168.31 ± 3.66[b]	197.20 ± 3.56[c]
RFT (mm)	4.92 ± 0.10[a]	4.16 ± 0.11[b]	2.01 ± 0.16[c]
pH	5.50 ± 0.01[a]	5.49 ± 0.01[a]	5.55 ± 0.01[b]
Hot carcass weight (kg)	232.17 ± 1.81[ab]	237.54 ± 2.12[a]	228.25 ± 2.97[b]

a, b, c – Row means with unlike superscripts differ, P<0.001

Table 22 Numbers of animals with AusMeat Marbling (AUSMB) scores of either 0 or 1, allocated to MSA boning 6-10, >10 or ungraded for MSA (U).

MSA Boning groups	AUSMB score		
	0	**1**	**All**
6 – 10	165	85	183
>10	183	0	250
U	81	12	93
All	429	97	526

Table 23 Numbers of animals with meat colour scores either 1B, 1C, 2, 3, 4, or 6 for carcasses allocated to MSA boning groups 6 – 10, >10, or ungraded for MSA.

MSA Boning Groups	Meat Colour Score						
	1B	**1C**	**2**	**3**	**4**	**6**	**All**
6 – 10	52	114	76	8	0	0	250
>10	31	64	84	4	0	0	183
Ungraded	15	35	30	8	4	1	93
All	98	213	190	20	4	1	526

Table 24 Numbers of animals with fat colour scores from 0 to 5 for carcasses allocated to MSA boning groups 6 – 10, >10, or ungraded for MSA.

MSA Boning Groups	Fat Colour Score					
	0	1	2	3	5	All
6 – 10	1	156	90	2	1	250
>10	2	105	76	0	0	183
Ungraded	0	50	41	2	0	93
All	3	311	207	4	1	526

MSA Index

Mean (± SEM) MSA Indexes for carcasses in each of the treatment groups are presented in Table 25. Castrated animals had higher MSA Indices than uncastrated animals (52.60 ± 0.11 *vs* 50.70 ± 0.10, respectively).

Table 25 MSA Index (mean ± SEM) for animals that were either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	n	MSA Index
Early-castrate	140	52.78 ± 0.14[a]
Late-castrate	136	52.40 ± 0.14[a]
Short-scrotum	121	50.74 ± 0.15[b]
Entire	129	50.66 ± 0.16[b]

a, b – Column means with unlike superscripts differ, P<0.05

Predicted meat quality scores

Predicted meat quality (PMQ) scores of three muscles (EYE, RMP and STR) aged for either 7 or 35 days, for the each of the four treatment groups are presented in Table 26 and Figure 2. Castrated animals had higher PMQ scores than did uncastrated animals (P<0.001).

There were no effects of Marbling MVP or Tenderness MVP, and no treatment group x Marbling MVP or treatment group x Tenderness MVP interactions on PMQ scores. Eye muscle area, fat colour, ultimate pH, and carcass weight did not influence PMQ score. Ossification had an effect on PMQ score (P<0.001) with carcasses with higher ossification scores having lower PMQ scores, and there was a treatment group x Ossification interaction (P<0.05). Ausmeat marbling score (AUSMB), USDA marbling score (USMB), and Rib Fat had an effect on PMQ score (P<0.001).

Boning Groups of animals selected for sensory testing

The numbers of animals, of those selected for sensory testing, in each of the treatment groups, that were allocated to MSA boning groups 8 to 14, or ungraded for MSA are presented in Table 27.

An analysis of whether the allocation to boning groups was unrelated to treatments could not be performed due to the small numbers in some treatment groups without some collapsing of the boning groups. Boning group 14 was excluded as it only had one animal and the Early-castrate and Late-castrate groups were combined (Castrated), along with the Short-scrotum and Entire groups (Non-castrated). There was an association between boning group and the two level group variable (Pearson χ^2 = 37.858, DF = 5, P<0.001). Castrated animals tended to be allocated to lower boning groups than did non-castrated animals (see Table 28).

Marbling MVP and Tendernes MVP

There were differences between the boning groups of animals selected for sensory testing for Marbling MVP (*P*=0.007). Marbling MVP tended to become increasingly negative as boning group increased (see Table 29). There were no differences between mean Tenderness MVP across the boning groups.

Percentage Bos indicus content versus hump height

As all of the cattle in this project were high-grade Brahmans, the MSA prediction model used 100% *Bos indicus*, as specified on the vendor declaration, as a factor in the model. In addition, hump height is measured at the time of MSA grading and related to carcase weight. Where the hump height is outside a specified range for the declared *Bos indicus* percentage, a higher *Bos indicus* adjustment is applied. To compare the outcomes of the MSA prediction

model using either % *Bos indicus* or hump height, the model was also run, for the animals selected for sensory testing, with either % *Bos indicus* or hump height as a factor in the model.

There were no overall differences in the outputs of the MSA prediction model, either for carcasses or muscles, when either % Bos indicus or hump height were used as a factor in the model (see Table 30).

Meat quality test results

Shear force test

The results from shear force testing are presented in Table 31 and Figure 3. For shear force, there was an interaction between treatment group and muscle (*P*<0.001), and an overall effect of Tenderness MVP (Coef. = -0.541, SE = 0.465, P=0.002), but no overall effect of Age (post-slaughter age of the muscle) or Marbling MVP. Striploins from castrated animals had lower shear force test results than did striploins from non-castrated animals (P<0.001). Shear force test results for eye rounds and rumps did not differ between the treatment groups. Only for striploins from entire animals did ageing from 7 days to 35 days reduce shear force test results (P<0.001).

Sarcomere length

There were no interactions for sarcomere length. There was an overall effect of Muscle (*P*<0.001) and treatment group (*P*<0.05) but no effect of Age, Marbling MVP or Tenderness MVP. Short-scrotum animals had longer sarcomeres than did Late-castrate or Entire animals (P<0.05), which did not differ. Eye rounds, rumps and striploins had sarcomere lengths that differed (P<0.001), with eye rounds having the longest and rumps having the shortest sarcomeres (see Table 32 and Figure 4).

Cooking loss

For cooking loss, there was an overall effect of treatment group (*P*=0.001). Meat from Early-castrate animals had lower cooking losses than did meat from Late-castrate, Short-scrotum or Entire animals (see Table 33 and Figure 5).

Table 26 Predicted meat quality (PMQ) (mean ± SEM) of three muscles (EYE, RMP and STR), aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	**Aged** (days)	PMQ
Early-castrate	EYE	7	43.70 ± 0.14
		35	46.19 ± 0.14
Late-castrate		7	43.47 ± 0.15
		35	45.96 ± 0.15
Short-scrotum		7	41.63 ± 0.17
		35	44.12 ± 0.17
Entire		7	41.62 ± 0.17
		35	44.11 ± 0.17
Early-castrate	RMP	7	48.84 ± 0.11
		35	53.62 ± 0.11
Late-castrate		7	48.70 ± 0.12
		35	53.48 ± 0.12
Short-scrotum		7	47.19 ± 0.14
		35	51.96 ± 0.14
Entire		7	47.19 ± 0.14
		35	51.96 ± 0.14
Early-castrate	STR	7	45.22 ± 0.18
		35	51.45 ± 0.18
Late-castrate		7	44.75 ± 0.18
		35	50.98 ± 0.18
Short-scrotum		7	43.61 ± 0.19
		35	49.84 ± 0.19
Entire		7	43.39 ± 0.18
		35	49.62 ± 0.18

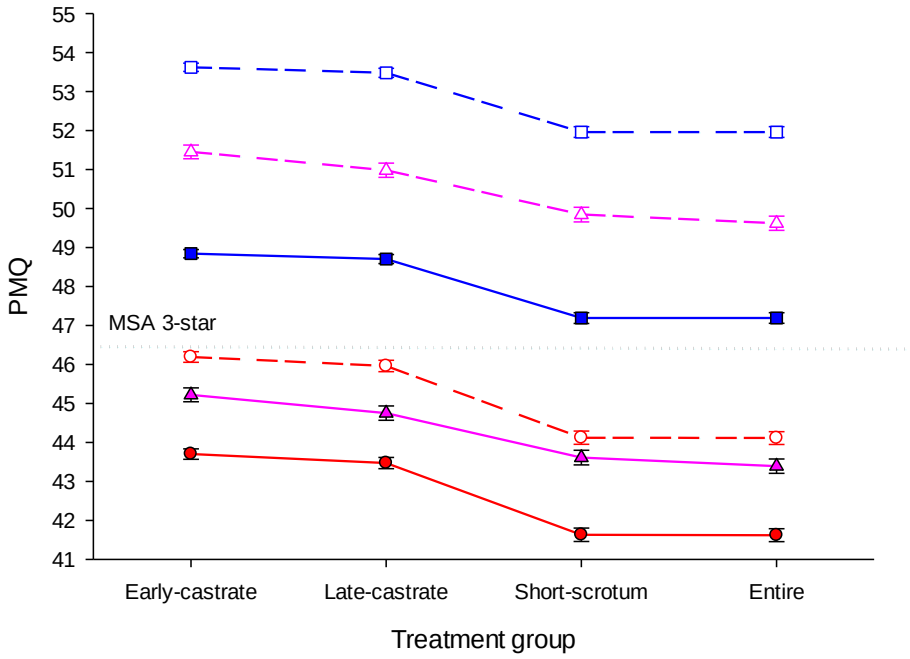

Fig 2 Predicted meat quality (PMQ) (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 27 Numbers of animals, of those selected for sensory testing, either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire), that were allocated to MSA boning groups 8 to 14, or ungraded for MSA.

Boning group	Treatment group				
	Early-castrate	Late-castrate	Short-scrotum	Entire	All
8	8	4	0	0	12
9	9	6	3	0	18
10	9	8	6	5	28
11	2	5	3	6	16
12	0	4	9	10	23
14	0	0	1	0	1
Ungraded	2	3	8	9	22
All	30	30	30	30	120

Table 28 Numbers of animals, of those selected for sensory testing, either castrated or non-castrated that were allocated to MSA boning groups 8, 9, 10, 11, 12 or were ungraded for MSA (U).

MSA Boning group	Treatment group		All
	Castrated	Non-castrated	
8	12	0	12
9	15	3	18
10	17	11	28
11	7	9	16
12	4	19	23
U	5	17	22
All	60	59	119

Table 29 Marbling MVP (means ± SEM) of animals selected for sensory testing and allocated to MSA boning 8, 9, 10, 11, 12, and 14, or ungraded for MSA (U).

MSA Boning group	n	Marbling MVP
8	12	-0.22 ± 0.03
9	18	-0.26 ± 0.03
10	27	-0.30 ±0.02
11	16	-0.27 ± 0.03
12	21	-0.37 ± 0.03
14	1	-0.19 ± 0.11
U	22	-0.26 ± 0.03

pH

For pH, there was a interaction between Marbling MVP and Tenderness MVP (Coef. = -0.362, SE = 0.127, *P*=0.005) and an overall effect of Muscle (*P*=0.004), but no effect of treatment group or Age. Increasing Marbling MVP (less negative Marbling MVP) was associated with a decrease in pH, which was strengthened with increasing Tenderness MVP. Increasing Tenderness MVP was associated with an increase in pH but this effect was weakened as Marbling MVP increased. Eye rounds had the highest pH and striploins had the lowest pH, with rumps being intermediate (see Table 34 and Figure 6).

Table 30 Indicators of meat quality for carcasses (boning group and MSA index) and predicted meat quality (PMQ) scores for three muscles (STR, RMP and EYE), aged for 7 days and 35 days, using either of two measures of *Bos indicus* content (% *Bos indicus* or hump height) in the MSA prediction model.

Meat quality indicators		Factor used in the MSA prediction model	
		% *Bos indicus*	Hump height
Carcasses	Boning group	10.2 ± 0.1	10.4 ± 0.1
	MSA Index	51.95 ±0.18	51.80 ± 0.17
Muscles			
STR	PMQ7	43.96 ± 0.24	43.58 ± 0.14
	PMQ35	50.22 ± 0.25	49.90 ± 0.23
RMP	PMQ7	47.24 ± 0.17	47.15 ± 0.17
	PMQ35	51.98 ± 0.17	51.90 ± 0.16
EYE	PMQ7	39.84 ± 0.21	39.72 ± 0.20
	PMQ35	42.30 ± 0.21	42.23 ± 0.20

Sensory testing

The MSA sensory testing protocols deliver outcomes for the evaluation of muscles as Tender, Juicy, Flavour, Overall like, MQ4 (meat quality, four variables) and Satisfaction.

Tenderness

The results for tenderness (Tender) are presented in Table 35 and Figure 7. There was an interaction between treatment group and Muscle (*P*=0.002) and Age and Muscle (P=0.032), and an overall effect of Tenderness MVP (Coef. = -12.73, SE = 4.82, P<0.01). Of the three muscles tested, only striploins from Early-castrate animals were rated as more tender than striploins from Late-castrate, Short-scrotum or Entire animals (P<0.01). Muscles aged for 35 days were more tender than those aged for only 7 days (P<0.05). Adjusted for Muscle and Age, there was a significant correlation between shear force test and tenderness (P<0.001). For a one unit increase in shear force test, decreases Tender score by 4.5. There was no relationship between Tender and sarcomere length.

Juiciness

The results for Juicy are presented in Table 36 and Figure 8. There were no treatment group x Muscle or Muscle x Aged interactions, and no overall effect of Tenderness MVP. Striploins from Early-castrate animals only, were rated as being being more juicy than those from late-castrate and entire animals (P<0.01). Juiciness of muscles from Early-castrate, Short-scrotum and Entire animals did not differ. There was no effect of aging on juiciness of muscles.

Flavour

Taste panels judged Striploins and Rumps to have more flavour than Eye rounds (P<0.001) and muscles aged for 35 days to have more flavour than those aged for only 7 days (P<0.001). The differences in flavour between the treatment groups were only in Striploins (see Table 37 and Figure 9).

Taste panels judged Striploins only from Early-castrate animals, to have more flavour than those from Late-castrate, Short-scrotum or Entire animals (P<0.05). Aging for 35 days improved the flavour of Eye rounds and Striploins, but not rumps (P<0.05). Tenderness MVP influenced flavour (Coef. = -7.50, SE = 3.88, P<0.05).

Overall Like

For striploins only, Early-castrate animals had higher Overall Like scores than Late-castrate, Short-scrotum or Entire animals (P<0.05), which did not differ. Muscles aged for 35 days had higher Overall Like scores than muscles aged for only 7 days (P<0.001). Tenderness MVP of animals influenced Overall Like scores (Coef. = -9.04, SE = 4.14, P<0.05) (see Table 38 and Figure 10).

MQ4

For Striploins only, Early-castrate animals had higher MQ4 scores than did Late-castrate, Short-scrotum or Entire animals, which did not differ (P<0.01). Muscles aged for 35 days had higher MQ4 scores than did muscles aged for 7 days only (P<0.001). Tenderness MVP of animals influenced MQ4 scores (Coef. = -8.92, SE = 4.06, P<0.05) (see Table 39 and Figure 11).

Satisfaction

For Striploins only, Early-castrate animals had higher Satisfaction scores than did Late-castrate, Short-scrotum or Entire animals, which did not differ (P<0.001). Muscles aged for 35 days had higher Satisfaction scores than did muscles aged for 7 days only (P<0.001). Tenderness MVP of animals influenced Satisfaction scores (Coef. = -3.33, SE = 0.13, P<0.05) (see Table 40 and Figure 12).

Boning groups

There were no differences between boning groups for any of the sensory outcomes.

Sensory test outcomes versus carcass grade

Sensory test, as measured by MQ4 did not differ between carcasses of non-castrated animals that were graded as either “steer” or “bull”, although carcasses from castrated animals had higher MQ4 scores (see Table 41).

Table 31 Shear force test (kg, mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Age (days)	Shear force (kg)
Early-castrate	EYE	7	5.459 ± 0.229
		35	5.110 ± 0.229
Late-castrate		7	5.152 ± 0.227
		35	5.330 ± 0.234
Short-scrotum		7	5.050 ± 0.256
		35	5.481 ± 0.230
Entire		7	4.893 ± 0.228
		35	4.863 ± 0.227
Early-castrate	RMP	7	4.397 ± 0.229
		35	4.256 ± 0.229
Late-castrate		7	4.450 ± 0.226
		35	4.493 ± 0.226
Short-scrotum		7	4.525 ± 0.230
		35	4.389 ± 0.256
Entire		7	4.738 ± 0.219
		35	4.575 ± 0.233
Early-castrate	STR	7	4.336 ± 0.229[a]
		35	4.302 ± 0.228[c]
Late-castrate		7	4.729 ± 0.227[a]
		35	4.299 ± 0.227[c]
Short-scrotum		7	5.110 ± 0.255[b]
		35	5.060 ± 0.229[d]
Entire		7	6.060 ± 0.227[b]
		35	5.012 ± 0.227[d]

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

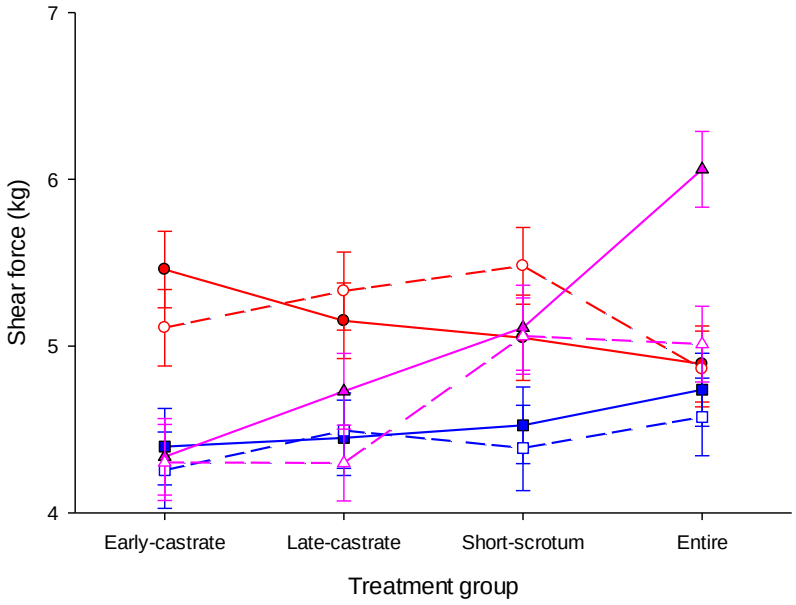

Fig 3 Shear force test (kg, mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 32 Sarcomere length (µm, mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Age (days)	Sarcomere length (µm)
Early-castrate	EYE	7	2.030 ± 0.052
		35	2.066 ± 0.054
Late-castrate		7	1.960 ± 0.050
		35	1.919 ± 0.051
Short-scrotum		7	2.069 ± 0.560
		35	1.990 ± 0.051
Entire		7	1.947 ± 0.051
		35	1.908 ± 0.050
Early-castrate	RMP	7	1.693 ± 0.050
		35	1.560 ± 0.050
Late-castrate		7	1.657 ± 0.052
		35	1.564 ± 0.050
Short-scrotum		7	1.637 ± 0.051
		35	1.627 ± 0.056
Entire		7	1.663 ± 0.049
		35	1.585 ± 0.054
Early-castrate	STR	7	1.612 ± 0.050
		35	1.726 ± 0.050
Late-castrate		7	1.643 ± 0.050
		35	1.657 ± 0.050
Short-scrotum		7	1.761 ± 0.056
		35	1.811 ± 0.050
Entire		7	1.720 ± 0.050
		35	1.698 ± 0.050

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

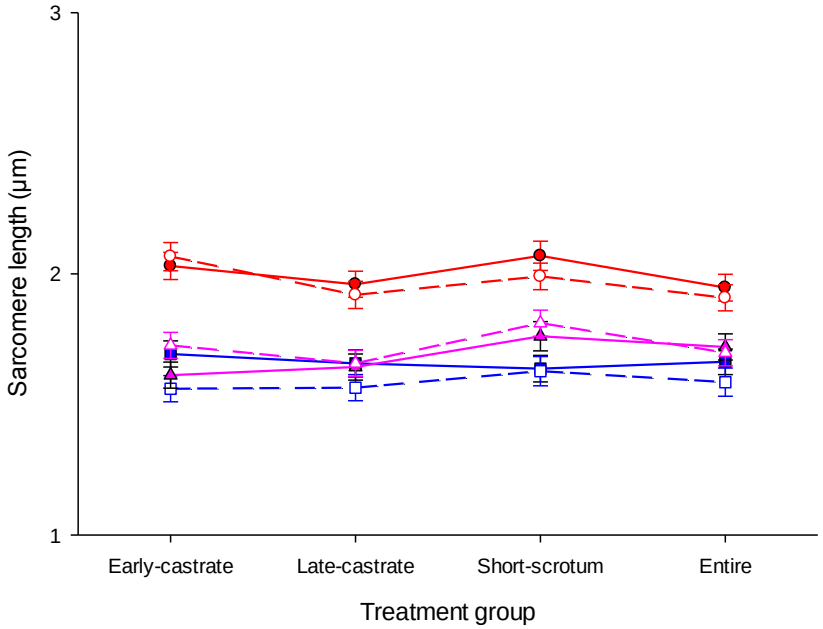

Fig 4 Sarcomere length (µm, mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 33 Cooking loss (%, mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Age (days)	Cooking loss (%)
Early-castrate	EYE	7	26.10 ± 0.66
		35	23.71 ± 0.66
Late-castrate		7	25.94 ± 0.65
		35	26.23 ± 0.68
Short-scrotum		7	26.65 ± 0.73
		35	26.26 ± 0.66
Entire		7	26.30 ± 0.65
		35	24.47 ± 0.65
Early-castrate	RMP	7	24.79 ± 0.66
		35	25.78 ± 0.70
Late-castrate		7	26.68 ± 0.65
		35	25.63 ± 0.65
Short-scrotum		7	27.72 ± 0.66
		35	26.62 ± 0.73
Entire		7	26.79 ± 0.63
		35	27.08 ± 0.68
Early-castrate	STR	7	25.29 ± 0.66
		35	24.93 ± 0.66
Late-castrate		7	26.20 ± 0.66
		35	26.74 ± 0.65
Short-scrotum		7	26.76 ± 0.65
		35	26.51 ± 0.73
Entire		7	26.41 ± 0.66
		35	27.08 ± 0.65

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

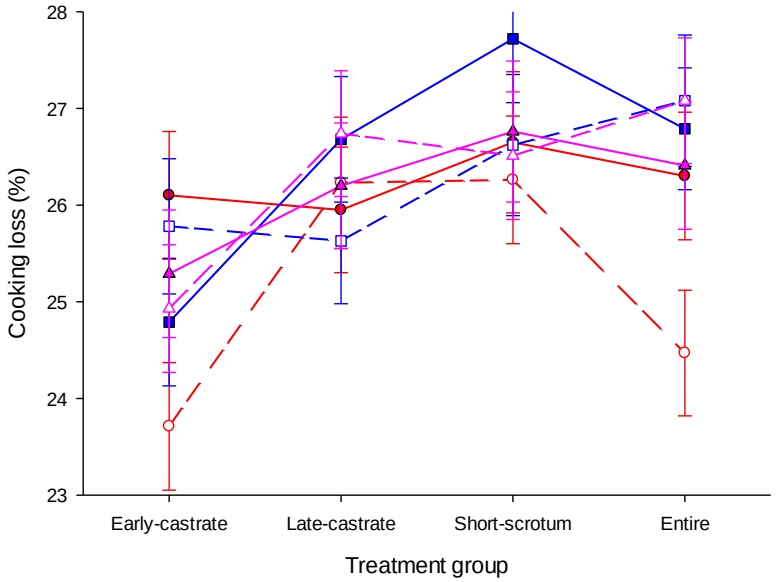

Fig 5 Cooking loss (%, mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 34 pH (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Aged (days)	pH
Early-castrate	EYE	7	5.534 ± 0.013
		35	5.522 ± 0.013
Late-castrate		7	5.557 ± 0.013
		35	5.538 ± 0.014
Short-scrotum		7	5.518 ± 0.015
		35	5.538 ± 0.013
Entire		7	5.516 ± 0.013
		35	5.502 ± 0.013
Early-castrate	RMP	7	5.512 ± 0.013
		35	5.510 ± 0.013
Late-castrate		7	5.535 ± 0.013
		35	5.520 ± 0.013
Short-scrotum		7	5.505 ± 0.013
		35	5.498 ± 0.015
Entire		7	5.530 ± 0.013
		35	5.505 ± 0.014
Early-castrate	STR	7	5.489 ± 0.013
		35	5.517 ± 0.013
Late-castrate		7	5.510 ± 0.013
		35	5.505 ± 0.013
Short-scrotum		7	5.519 ± 0.015
		35	5.507 ± 0.013
Entire		7	5.497 ± 0.013
		35	5.504 ± 0.013

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

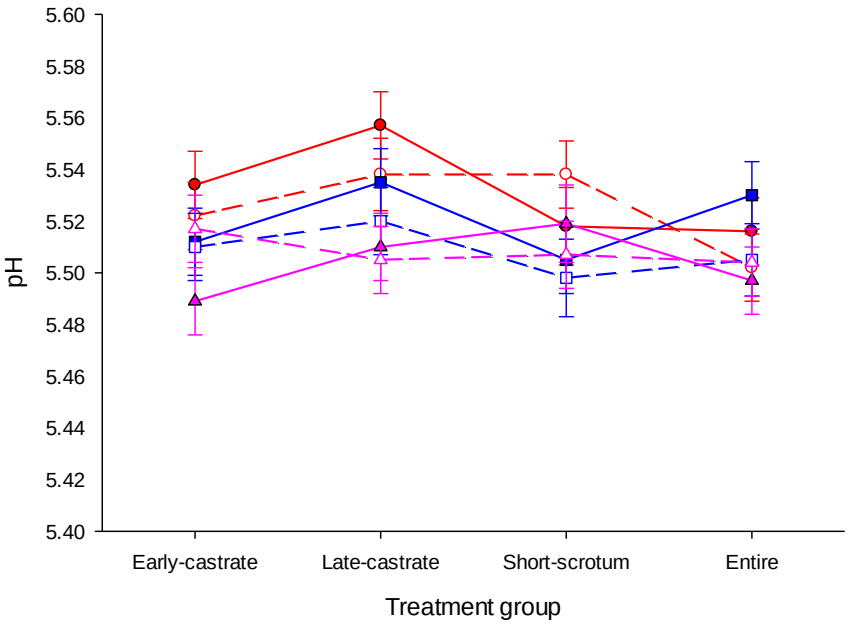

Fig 6 pH (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 35 Tender scores (mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Age (days)	Tender score
Early-castrate	EYE	7	27.96 ± 3.04
		35	35.20 ± 3.04
Late-castrate		7	35.61 ± 2.91
		35	36.75 ± 3.00
Short-scrotum		7	26.25 ± 3.38
		35	34.47 ± 3.06
Entire		7	26.03 ± 2.93
		35	37.12 ± 2.92
Early-castrate	RMP	7	43.94 ± 3.04
		35	48.44 ± 3.04
Late-castrate		7	40.10 ± 2.89
		35	50.25 ± 2.89
Short-scrotum		7	44.17 ± 3.06
		35	51.73 ± 3.38
Entire		7	43.52 ± 2.89
		35	44.94 ± 2.97
Early-castrate	STR	7	50.10 ± 3.03
		35	62.40 ± 3.02
Late-castrate		7	46.11 ± 2.91
		35	53.92 ± 2.91
Short-scrotum		7	40.17 ± 3.03
		35	55.02 ± 3.03
Entire		7	37.72 ± 2.93
		35	52.32 ± 2.92

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

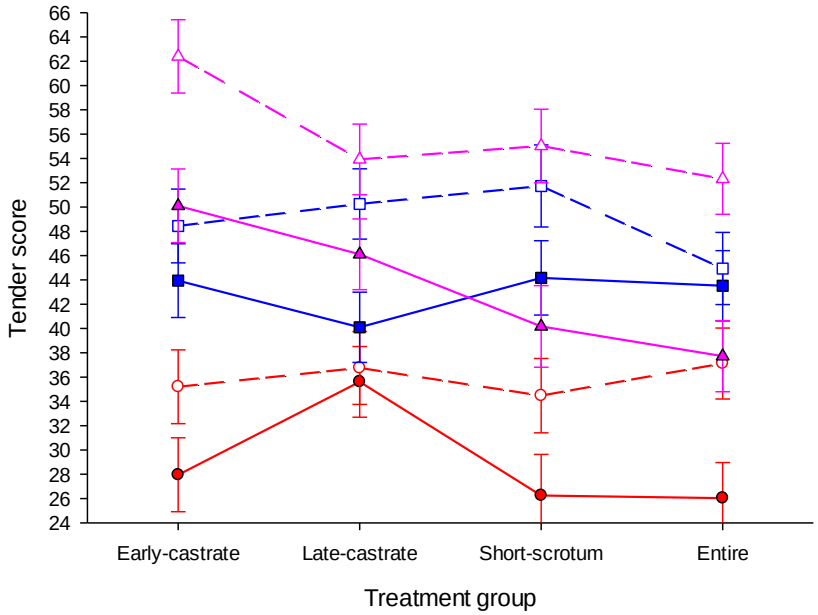

Fig 7 Tender scores (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 36 Juicy scores (mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Age (days)	Juicy score
Early-castrate	EYE	7	36.48 ± 2.90
		35	36.08 ± 2.90
Late-castrate		7	40.33 ± 2.84
		35	37.57 ± 2.94
Short-scrotum		7	34.45 ± 3.24
		35	36.16 ± 2.91
Entire		7	33.61 ± 2.86
		35	37.25 ± 2.85
Early-castrate	RMP	7	46.51 ± 2.90
		35	42.45 ± 2.90
Late-castrate		7	42.99 ± 2.83
		35	47.18 ± 2.83
Short-scrotum		7	43.06 ± 2.91
		35	48.65 ± 3.24
Entire		7	45.55 ± 2.83
		35	42.41 ± 2.92
Early-castrate	STR	7	50.93 ± 2.90
		35	54.46 ± 2.89
Late-castrate		7	48.56 ± 2.84
		35	44.19 ± 2.84
Short-scrotum		7	45.19 ± 3.22
		35	50.12 ± 2.90
Entire		7	42.43 ± 2.85
		35	51.27 ± 2.85

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

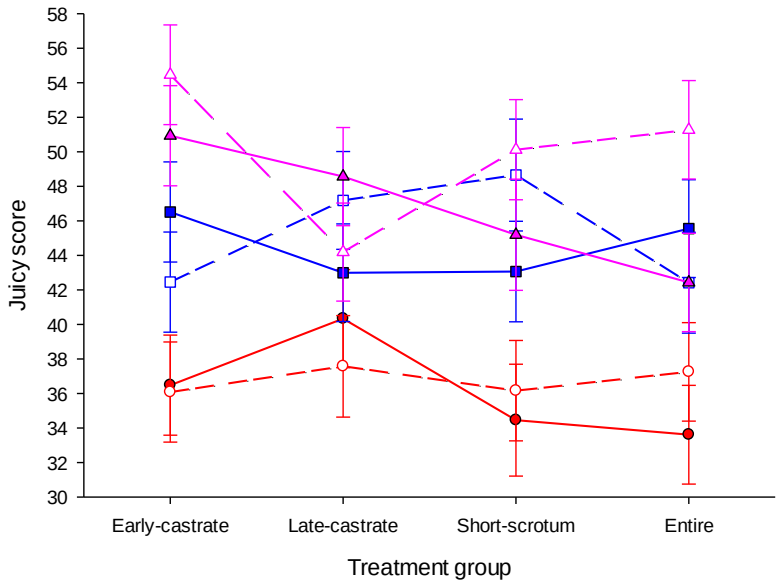

Fig 8 Juicy score (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 37 Flavour scores (mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Aged (days)	Flavour score
Early-castrate	EYE	7	40.93 ± 2.63
		35	45.18 ± 2.62
Late-castrate		7	44.82 ± 2.57
		35	47.32 ± 2.65
Short-scrotum		7	40.66 ± 2.93
		35	43.22 ± 2.64
Entire		7	37.91 ± 2.59
		35	46.29 ± 2.57
Early-castrate	RMP	7	52.48 ± 2.63
		35	53.37 ± 2.62
Late-castrate		7	48.77 ± 2.56
		35	55.07 ± 2.56
Short-scrotum		7	49.30 ± 2.64
		35	54.59 ± 2.93
Entire		7	49.19 ± 2.56
		35	49.93 ± 2.32
Early-castrate	STR	7	55.52 ± 2.62
		35	60.40 ± 2.61
Late-castrate		7	48.72 ± 2.57
		35	52.99 ± 2.57
Short-scrotum		7	48.93 ± 2.92
		35	56.46 ± 2.62
Entire		7	44.08 ± 2.58
		35	54.48 ± 2.57

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

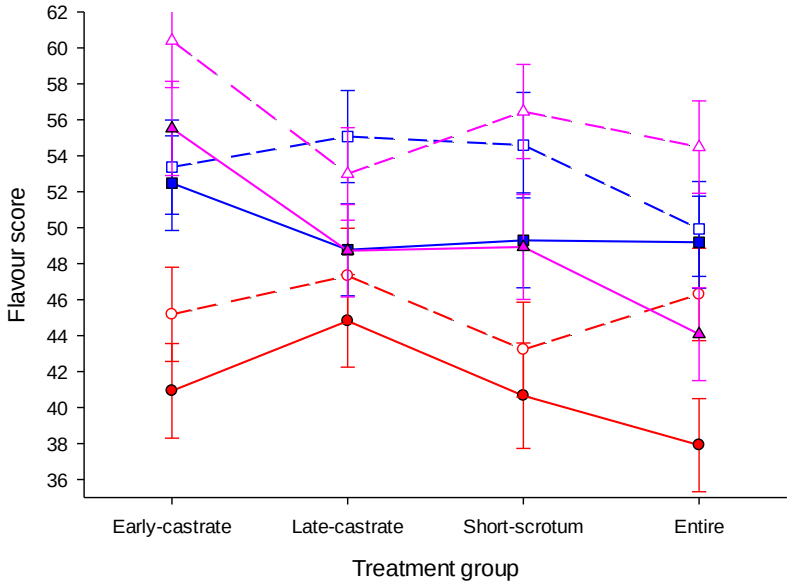

Fig 9 Flavour scores (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 38 Overall like scores (mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Aged (days)	Overall like score
Early-castrate	EYE	7	35.77 ± 2.74
		35	40.62 ± 2.73
Late-castrate		7	40.78 ± 2.66
		35	43.04 ± 2.75
Short-scrotum		7	33.61 ± 3.05
		35	39.57 ± 2.75
Entire		7	33.12 ± 2.68
		35	42.50 ± 2.67
Early-castrate	RMP	7	49.16 ± 2.74
		35	50.79 ± 2.73
Late-castrate		7	45.11 ± 2.65
		35	52.32 ± 2.64
Short-scrotum		7	48.01 ± 2.75
		35	53.76 ± 3.05
Entire		7	47.12 ± 2.65
		35	49.09 ± 2.73
Early-castrate	STR	7	54.00 ± 2.73
		35	59.19 ± 2.72
Late-castrate		7	48.09 ± 2.66
		35	52.78 ± 2.66
Short-scrotum		7	46.99 ± 3.04
		35	55.10 ± 2.73
Entire		7	42.84 ± 2.67
		35	54.45 ± 2.67

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

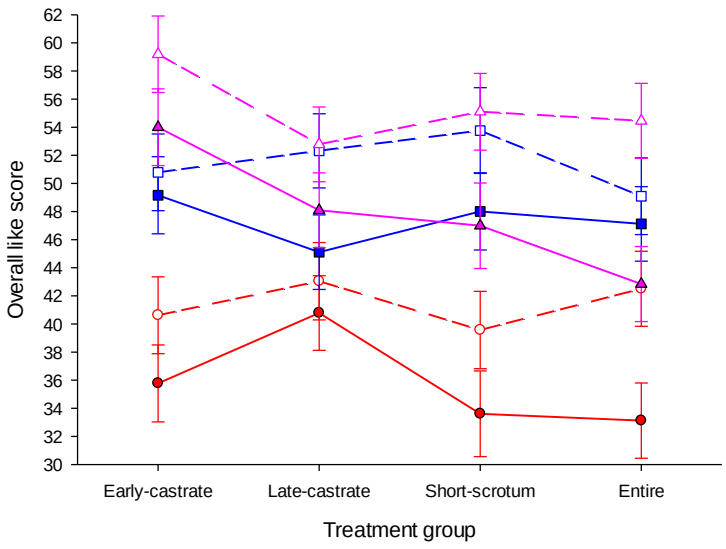

Fig 10 Overall like scores (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 39 MQ4 scores (mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Aged (days)	MQ4 score
Early-castrate	EYE	7	35.27 ± 2.61
		35	40.59 ± 2.61
Late-castrate		7	40.98 ± 2.52
		35	42.06 ± 2.60
Short-scrotum		7	33.80 ± 2.91
		35	39.15 ± 2.62
Entire		7	32.98 ± 2.54
		35	41.59 ± 2.53
Early-castrate	RMP	7	48.33 ± 2.61
		35	50.17 ± 2.61
Late-castrate		7	44.63 ± 2.50
		35	51.86 ± 2.50
Short-scrotum		7	46.90 ± 2.62
		35	52.86 ± 2.91
Entire		7	46.74 ± 2.50
		35	47.07 ± 2.58
Early-castrate	STR	7	53.11 ± 2.60
		35	60.00 ± 2.60
Late-castrate		7	47.73 ± 2.52
		35	51.98 ± 2.52
Short-scrotum		7	45.73 ± 2.89
		35	54.43 ± 2.61
Entire		7	41.50 ± 2.53
		35	53.29 ± 2.53

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

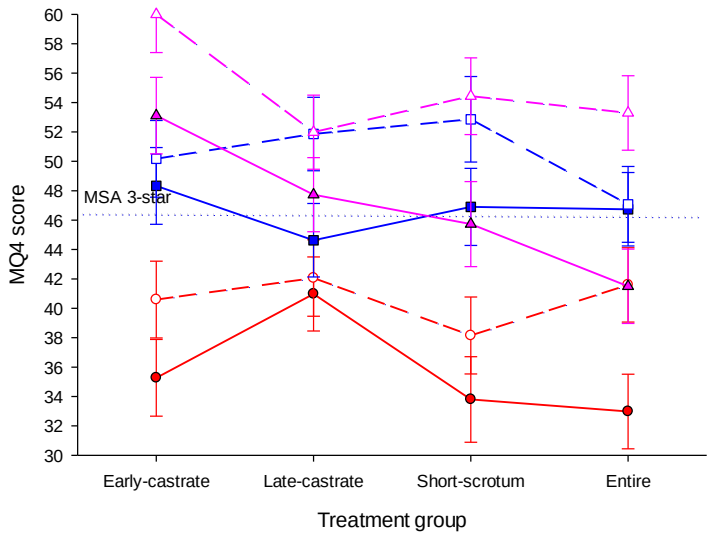

Fig 11 MQ4 scores (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 40 Satisfaction scores (mean ± SEM) of three muscles, EYE, RMP and STR, aged for either 7 or 35 days, from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Treatment group	Muscle	Aged (days)	Satisfaction score
Early-castrate	EYE	7	2.47 ± 0.09
		35	2.60 ± 0.09
Late-castrate		7	2.56 ± 0.08
		35	2.64 ± 0.09
Short-scrotum		7	2.42 ± 0.10
		35	2.61 ± 0.09
Entire		7	2.40 ± 0.08
		35	2.71 ± 0.08
Early-castrate	RMP	7	2.91 ± 0.09
		35	3.00 ± 0.09
Late-castrate		7	2.85 ± 0.08
		35	3.06 ± 0.08
Short-scrotum		7	2.82 ± 0.09
		35	3.05 ± 0.10
Entire		7	2.87 ± 0.08
		35	2.87 ± 0.09
Early-castrate	STR	7	3.20 ± 0.09
		35	3.27 ± 0.09
Late-castrate		7	2.89 ± 0.08
		35	3.04 ± 0.08
Short-scrotum		7	2.75 ± 0.09
		35	3.01 ± 0.09
Entire		7	2.73 ± 0.08
		35	2.99 ± 0.08

a, b, c, d – for any Muscle x Age, column means with unlike superscripts differ, P<0.05

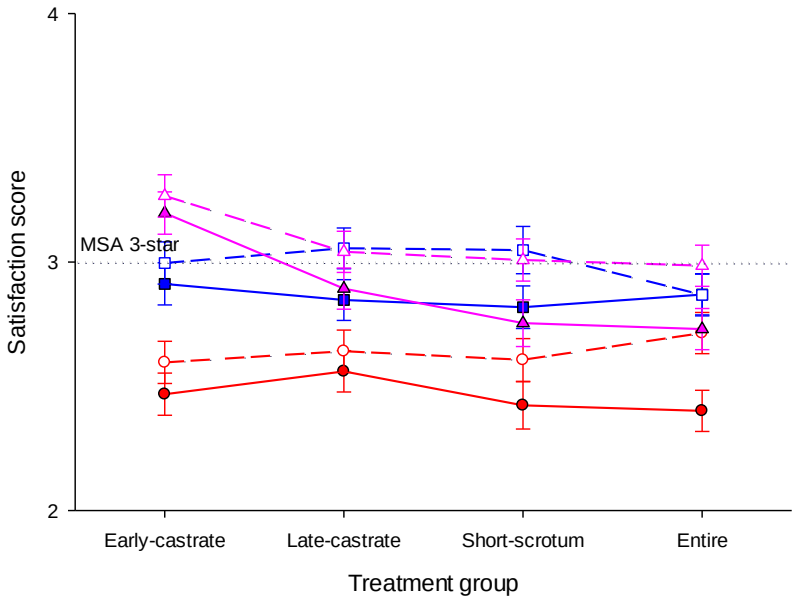

Fig 12 Satisfaction scores (mean ± SEM) of three muscles, EYE (● ○), RMP (■ □) and STR (▲ Δ), aged for either 7 (solid line) or 35 days (dashed line), from animals that had been either castrated at branding (Early-castrate, n = 140), castrated at weaning (Late-castrate, n = 135), banded to create an artificial cryptorchid (Short-scrotum, n = 122) or left intact (Entire, n = 129).

Table 41 MQ4 from sensory testing of 3 muscles x 2 ages, for animals either castrated (Early-castrate and Late-castrate), or entire (Short-scrotum and Entire), and graded as either "male" or "bull".

Treatment group	n	MQ4		
		Mean ± SEM	Median	95% CI
Castrated	179	47.32 ± 0.92[a]	48.48	45.50 – 49.14
Entire – graded as "male"	137	43.86 ± 0.99[b]	44.07	41.91 – 45.82
Entire - graded as "bull"	36	45.08 ± 1.801[b]	44.43	41.41 – 48.75

a, b – Column means with unlike superscripts differ, P<0.01

Predicted Meat Quality (PMQ)

For the animals selected for sensory testing, there was an overall effect of treatment group on PMQ (P<0.001) (see Table 42), but no effect of Tenderness MVP or Marbling MVP. Early-castrate and Late-castrate animals had higher mean PMQ values than did Short-scrotum or Entire animals.

Table 42 Predicted meat quality (PMQ) scores (mean ± SEM) for animals selected for sensory testing, that had been either castrated at branding (Early-castrate), castrated at weaning (Late-castrate), banded to create an artificial cryptorchid (Short-scrotum) or left intact (Entire).

Treatment group	PMQ
Early-castrate	48.46 ± 0.48[a]
Late-castrate	48.02 ± 0.48[a]
Short-scrotum	46.51 ± 0.50[b]
Entire	45.76 ± 0.48[b]

a, b – Column means with unlike superscripts differ, P<0.001

There was no interaction between MQ4, Muscle and Aged, nor any interactions between MQ4 and Muscle, or MQ4 and Aged, indicating that the relationship between PMQ and MQ4 was constant across the different levels of these factors. However, there was an overall positive relationship between these two measures (P<0.001), given by the equation:

MQ4=45.93+1.333*PMQ

Hump height

There was no interaction between hump height and treatment group, indicating that the relationship between PMQ and hump height was constant across the different levels of this factor. However, there was an overall negative relationship between these two measures (P=0.014).

For each muscle and various measures of meat quality, the correlation with hump height, along with a P-value for the test of whether the correlation is equal to zero, are presented in Table 43.

MSA Star grades

For eye rounds (EYE), MSA1-BG was not able to distinguish star grades, with all muscles being rated as star grade 2, whereas 21% were rated as star grade 3 by MSA2-PMQ, and 24% were rated 3 by MSA3-MQ4. While MSA2-PMQ and MSA3-MQ4 had similar numbers of star grades 2 and 3, there was still disagreement over which samples were given which star grade, disagreeing 29% of the time.

For rumps (RMP), MSA2-PMQ was not able to distinguish star grades, with almost all muscles being rated as grade 3, whereas 60% were rated as star grade 2 by MSA1-BG and 44% were rated as star grade 2 by MSA3-MQ4. There was also substantial disagreement between MSA1-BG and MSA3-MQ4, disagreeing 48% of the time, with MSA1-BG favouring a rating of star grade 2.

Table 43 Correlation coefficients (R) for hump height and various measures of meat quality for three muscles (STR, RMP and EYE) and overall.

	Muscle						**Overall**	
	STR		RMP		EYE			
	R		R		R		R	
Cooking loss	0.076		0.088		-0.113		0.016	
Shear force	0.395	***	0.142		-0.243	**	0.186	*
Sarcomere length	0.059		0.105		-0.085		0.042	
Tender	-0.263	**	-0.192	*	-0.268	**	-0.307	***
Juicy	-0.099		-0.124		-0.263	**	-0.225	*
Flavour	-0.235	**	-0.145		-0.232	*	-0.278	**
Overall like	-0.202	*	-0.126		-0.266	**	-0.262	**
MQ4	-0.241	**	-0.166		-0.276	**	-0.295	***
Satisfaction	-0.215	*	-0.154		-0.188	*	-0.244	**

Statistical significance of the correlation co-efficient (r) is indicated by * , ** and *** for P < 0.05, 0.01 and 0.001, respectively

For striploins (STR), MSA1-BG rated more muscles as star grade 2 than did either MSA2-PMQ or MSA3-MQ4, almost all of the disagreement being of this nature. While numbers of muscles rated as star grades 2 and 3 were similar between MSA2-PMQ and MSA3-QM4, there was still 33% disagreement overall.

Tabulated statistics of numbers of two muscles, RMP or STR, graded either 2-star (ungraded) or 3-star by MSA Star Grade protocol 1 (MSA1-BG), MSA Star Grade protocol 2 (MSA2-PMQ), or MSA Star Grade protocol 3 (MSA3-MQ4) are presented in Table 44, and summarised for RMP and STR in Table 45.

Economic modelling

An economic case study of entire-male grain fed beef from a north-west Queensland production system was undertaken by Steven Wainewright as part of his Masters by Research graduate student program associated with the project. An assessment of the differences in gross margins for the beef production system was undertaken using Breedcow herd budgeting software (Holmes 2009). The analysis reviewed the viability of producing

beef for the domestic market from either an entire male or castrated cattle production system, based on a hypothetical herd of 1200 breeders created for the case study evaluation. An integrated beef production system, from breeding to feedlot finishing, was found to be less profitable for entire male beef production compared to a beef production system from castrates at the current market prices. Although production of entire males was more profitable than the production of castrates during the feedlot phase, the production of entire male cattle in this phase failed to compensate for the earlier economic losses in the weaning phase of -$24.04/AE. During the feedlot phase the entire male production system had lower break even sale prices compared to the production of castrates. In reviewing two pricing scenarios for entire male cattle it was found that entire males marketed at the same price as castrated cattle was the most profitable production system. It was concluded that the production of beef from entire males in a north west Queensland production system can only be profitable if entire males can be sold without discount relative to castrates.

Graduate research student outcome

Mr Steven Wainewright successfully completed his research masters degree program at JCU and was awarded the Master of Tropical Animal Science degree in December 2012.

Table 44 Tabulated statistics of numbers of two muscles, rump (RMP) and striploin (STR), graded either MSA 2-star (ungraded) or MSA 3-star by protocol MSA1-BG, MSA2-PMQ or MSA3-MQ4. Disagreement is indicated in red.

RMP			**MSA2-PMQ**		
			2	3	Total
	MSA1-BG	2	5	**68**	73
		3	**1**	46	47
		Total	6	114	120
			MSA3-MQ4		
			2	3	Total
	MSA1-BG	2	33	**39**	72
		3	**19**	28	47
		Total	52	67	119
			MSA2-PMQ		
			2	3	Total
	MSA3-MQ4	2	3	**49**	52
		3	**3**	64	67
		Total	6	113	119
STR			**MSA2-PMQ**		
			2	3	Total
	MSA1-BG	2	48	**32**	80
		3	**0**	40	40
		Total	48	72	120
			MSA3-MQ4		
			2	3	Total
	MSA1-BG	2	34	**46**	80
		3	**5**	35	40
		Total	39	81	120
			MSA2-PMQ		
			2	3	Total
	MSA3-MQ4	2	24	**15**	39
		3	**24**	57	81
		Total	48	72	120

Table 45 Proportions of two muscles, rump (RMP) and striploin (STR), graded as MSA 3-star by protocol MSA1-BG, MSA2-PMQ or MSA3-MQ4.

Protocol	RMP (% MSA 3-star)	STR (% MSA 3-star)
MSA1-BG	39.2[a]	33.3[a]
MSA2-PMQ	95.0[b]	60.0[b]
MSA3-MQ4	56.3[c]	67.5[b]

a, b - Percentages within a column with unlike superscripts differ, P<0.05

8 Discussion

Liveweight and carcass composition

There were no differences in liveweights or weight gains between the treatment groups prior to their entry to the feedlot, although there were some minor differences in weight gains at various times from branding to trucking to the feedlot (see Table 3). This is to be expected in the environment of northern Australia where high grade *Bos indicus* cattle generally don't achieve puberty before 18 months of age due to delayed development of testicular tissue (Aponte *et al.* 2005).

Differences in liveweight were well established by the middle of the grain feeding period, with entire animals (Short-scrotum and Entire) being ≈4% heavier on exit from the feedlot than castrated animals (Early-castrate and Late-castrate) (see Table 4). That entire males have a better feed conversion efficiency than castrates is well documented (Field 1971).

It was decided to not weigh the cattle on exit from the feedlot because of the possibility of increased bruising, however, and exit weight was calculated from hot carcass weight using historic dressing percentage figures for that type of cattle. Animals in the non-castrated treatment groups had ≈11% higher estimated average daily gain (1.24 ± 0.03 kg *vs* 1.12 ± 0.02 kg, mean ± SEM). While this is comparable with other reported figures for entire versus castrated cattle, it is well below the expected average daily gain of around 1.5 kg/day for this class of animal in similar circumstances in the *Wallumbah* feedlot (McDonald DA, *pers comm*). Unfortunately, weather conditions were not conducive to good liveweight gains, particularly through the later period of feeding, with substantial unseasonal rainfall and cold conditions.

Behaviour

There were no detectable behaviour differences between the treatment groups at any time. Stockman who worked with the cattle in the yards and paddock observed that their behaviour was not dissimilar to that of uniform mobs of steers of similar ages. More intensive observation of the cattle in the feedlot did not reveal any differences in fighting, riding or other behaviour between the treatment groups. This is most likely because (a) the non-castrated cattle were only achieving puberty around the time of their entry into the feedlot, and (b) because they had been run together as a single mob from weaning. Social hierarchies would have been well established within the group and only disrupted in a minor way by being penned in three groups in the feedlot.

Carcass grading data from vendor feedback sheets

Only one animal from each of the Early-castrate and Late-castrate treatment groups (0.7%) were graded as "bull", compared to 34 animals from the Short-scrotum (28%) and 43 animals from Entire (36%) treatment groups (see Table 5). The proportion of intact animals graded as "bull" in the present study was higher than has been observed in similar production systems and studies (Fitzpatrick LA, unpublished; McDonald DA, *pers comm*.). It can't be ruled out that the rate of downgrading of non-castrated animals was influenced by the fact that the personnel responsible for grading the carcasses were aware that there was a mixture of castrated and non-castrated animals on the chain. As animals graded "bull" tended to have more permanent incisors and higher ossification scores than those graded "male", and hot carcass weights increased with the number of permanent incisors (see Tables 7 and 8), the rate of downgrade to "bull" may be reduced by finishing entire animals at a younger age.

Animals with lighter hot carcass weights tended to have a less desirable butt shape, emphasising the need to target the ideal liveweight/degree of finish for a specific point on the sale grid (see Table 10).

"Dark cutters" are generally mentioned in any discussion of the utilisation of young entire male cattle for beef production. However, in the present study, Early-castrate, Late-castrate, Short-scrotum and Entire treatment groups had 4, 1, 0 and 5 carcasses classified as dark-cutters, suggesting that there was no difference in the incidence of dark-cutters between castrates and non-castrates.

There were no differences in ultimate pH, demonstrating that proper nutritional management and minimised sorting or mixing throughout the growing and finishing stages can help to minimise the incidence of dark-cutters. Similarly, there was no difference in the rate of bruising between carcasses of castrated and uncastrated animals, confirming the lack of behavioural differences between the treatment groups.

Gross returns

Interestingly, the mean gross value of the carcasses did not differ between the treatment groups. The lower returns from non-castrated animals that were down-graded as "bull" were countered by the greater carcass weights and premiums achieved for the non-castrated animals that graded "steer" (see Table 6).

Table 11 clearly illustrates the premium that can be achieved by marketing young entire male cattle that achieve a specific target of beef cattle AusMeat grade on a meatworks grid. The project cattle were sold as AusMeat Grain Fed Young Beef (GFYG), where the specification is for a minimum of 70 days on feed, 0 to 2 permanent incisor teeth, 5 mm minimum P8 fat depth, 1 a-b-c – 3 meat colour score and 0 – 3 fat colour score. Animals may be female, castrate or entire males that show no secondary sex characteristics.

Carcasses from uncastrated animals that met the GFYG specification had a ≈$52 higher gross value that did those from castrated animals, while carcasses from uncastrated animals that were graded "bull" because of secondary sex characteristics had a ≈$83 lower gross value than those from castrated animals, and a ≈$137 lower gross value than those from uncastrated animals that graded GFYG.

Chiller assessment and MSA grading

Genetic data

The lack of relationships between Marbling MVP or Tenderness MVP for individual animals and PMQ scores or the MSA boning group to which their carcass was allocated is difficult to explain, given the role that marbling and tenderness play in the MSA grading model. Furthermore, the lack of relationships between Marbling MVP and either AusMeat marbling score (AUSMB) or US marbling score (USMB) suggests that Marbling MVP is of limited value in selecting animals for increased meat quality.

Ossification and dentition

Ossification was positively correlated with dentition, and while there were no differences in dentition between the treatment groups, castrated animals had lower ossification scores than did non-castrated animals, indicating that although the treatment groups were of similar mean calendar age, non-castrated animals were physiologically older than castrated animals (see Table 12). Although significant ($P<0.001$), the difference was not great.

In the MSA model, for 100% *Bos indicus* cattle, a 10 point increase in ossification score leads to a 1 point decrease in PMQ4 score, for grilled striploin aged for 7 days (Geesink G, *pers comm.*). This supports the conclusion that entire animals should be finished at a younger age than their castrated equivalents, in order to minimise the chance of downgrades.

Fat score

Although entire animals had lower fat scores than did castrated animals (see Table 17), the difference was generally not sufficient to result in the downgrade of the carcass to a lower value point on the sale price grid.

Hump height

That castrated animals had lower hump heights than did non-castrated animals (see Table 18) suggests that in this case, given that all of the project cattle were high grade Brahmans, hump height may be more a reflection of testosterone levels than percentage of *Bos indicus* in the cattle.

Hot carcass weight and eye muscle area

Hot carcass weight was mirrored in eye muscle area. Non-castrated animals had greater hot carcass weights and eye muscle areas than did castrated animals, reflecting the anabolic effects of testosterone levels in the non-castrated animals (see Tables 19)

Boning groups

The boning group of a carcass is determined from PMQ data, and is used by processors to group carcasses for boning room efficiency. As such, boning groups tend to reflect the cuts with the lowest eating quality, and as a result can misrepresent many cattle (Hart 2012).

For cattle from northern Australia, boning groups 9 or 10 are generally considered to be cut-off for carcasses to attract a premium from MSA grading (Loxton M, JBS Australia, *pers comm.*). More castrated than non-castrated animals were allocated to boning groups ≤10, reflecting in the treatment groups many of the parameters than contribute to the MSA grading model (see Tables 20 – 24). In general, leaner carcasses were allocated to boning groups >10 or were ungraded for MSA.

MSA Index

The newly introduced MSA meat quality index is a weighted average of the PMQ score for all the cuts for which an MSA value is calculated. It is a more valid and effective indicator of "whole of carcass" quality than are boning groups. Carcasses from castrated animals had higher MSA Indexes than uncastrated animals, ie ≈2.0 units on a 100 point scale (see Table 25). This compares, for example, with a change of 3 to 4 index units between carcasses that have been hung by the Achilles tendon (AT) and tenderstretch (TS) carcasses that have been suspended by the pelvis (Ball A, 2013, *pers comm*.).

Predicted Meat Quality score

Although the current MSA model is not validated for non-castrated animals, inputs into the model other than castration status (ossification, marbling score and rib fat) resulted in castrated animals having higher PMQ scores than uncastrated animals (see Table 26 and Figure 2).

Boning groups of animals selected for sensory testing

Like the larger dataset of animals, for the subset of the animals selected for sensory testing, castrated animals tended to be allocated to lower boning groups than did non-castrated animals (see Table 27).

Percentage Bos indicus content versus hump height

That there were no overall differences in the outputs of the MSA model when either % *Bos indicus* or hump height were used as a factor in the model (see Table 30) suggests that hump height, being a readily measured quantitative parameter, would be the more reliable and repeatable estimator of *Bos indicus* content.

Meat quality test results

Shear force, sarcomere length, cooking loss, pH

For striploins only, there was a difference in shear force for castrated versus non-castrated animals, with the latter having higher shear force test. This result is broadly reflected in the sensory test outcome, Tender (see Tables 31 and 35, and Figures 3 and 7), with lower shear force scores being indicative of more tender meat, and is consistent with the status of striploin as being of superior eating quality to the other two muscles tested (Watson *etal.* 2008).

Cooking loss is associated with improved juiciness as judged by a sensory panel (Perry *et al*. 2001b). Only Early-castrate animals had lower scores than the other treatment groups (see Table 33 and Figure 5), although this result was not reflected in the sensory test scores for juiciness (see Table 36 and Figure 8). In contrast, there were no differences between the three muscles for cooking loss, however, sensory test scores for juiciness ranked the muscles as striploin, rump and eye round, in decreasing order of juiciness.

The results for pH of the three muscles tested (see Table 34 and Figure 6) further support the view that intact males, managed correctly, won't result in an increased incidence of 'dark cutters'.

Sensory testing

The results for sensory testing are best reflected in the MQ4 results, where only striploins from Early-castrate animals had higher MQ4 scores than did striploins from Late-castrate, Short-scrotum or Entire animals (see Table 39 and Figure 11). Of the three muscles used for sensory testing, grilled striploins would be expected to be of the highest meat quality score (Watson *et al.* 2008), and therefore are likely to be the most sensitive indicator of treatment effects. The increased eating quality due to ageing from 7 days to 35 days is well documented (Watson *et al.* 2008).

MSA boning groups from 8 to 12 were well represented among the animals that were selected for sensory testing (see Table 28). That there were no differences between the boning groups for any of the sensory test outcomes, for rumps and striploins in particular, is surprising and indicates that for high-grade *Bos indicus* cattle at least, taste panels were not able to detect differences in eating quality of some muscles. This finding supports the view that there is a need for further data to be generated to allow the MSA grading model to be further refined for *Bos indicus* cattle.

Sensory testing versus AusMeat carcass grade

Sensory test of meat quality as measured by MQ4 did not differ between carcasses of non-castrated animals that were graded as either “steer” or “bull” (43.86 ± 0.99 *vs* 45.08 ± 1.81 respectively; mean ± SEM), indicating that taste panels did not detect differences in the eating quality of the three muscles from these animals (see Table 41). This suggests that grading of carcasses of young animals on secondary sex characteristics may not accurately reflect the eating quality of meat from those carcasses. Muscles from castrated animals had a higher mean MQ4 score (47.32 ± 0.92; mean ± SEM), indicating that, on average, taste panels judged those muscles to be of slightly higher eating quality.

Relationships between hump height and meat quality

Overall, hump height was negatively correlated with most indicators of meat quality, although this varied with muscle, being strongest for eye round and weakest for rump. Given that all of the project cattle would be classed as having 100% *Bos indicus* content, there appear to be factors other than genotype influencing the relationship between hump height and meat quality. The fact that non-castrated animals had greater hump heights than castrated animals (~153 mm *vs* ~132 mm, respectively), suggests that testosterone levels during growth and development may play a role.

Predicted meat quality (PMQ)

In general, meat from castrated animals had higher PMQ scores than did meat from non-castrated animals (see Table 42). However, with the exception of striploins from the early-castrate group, this was not reflected in the taste panel sensory test scores. The lack of effects of Tenderness MVP and Marbling MVP on PMQ scores again brings into question the value of these genetic markers in selection of animals for improved meat quality - at least for *Bos indicus* cattle.

MSA Star grades

For the muscles that were sensory tested, there were disparities in the allocation of MSA star grades based on either boning groups (MSA1-BG), predicted meat quality scores (MSA2-PMQ) or taste panel sensory test results (MSA3-MQ4) (see Table 45). For striploins and rumps, in particular, this disparity appears to be more than you might expect from a grading system designed to ensure that the consumer does not have an unacceptable eating experience from consumption of beef of 3-star quality or better, and represents a potential financial loss for producers targeting the premium available for MSA graded carcasses, as animals that would have provided an MSA 3-star “good every day” eating experience, at least for those muscles, are being incorrectly “ungraded” for MSA.

Economic modelling

The economic modelling study showed that in the current marketplace, a beef cattle production system utilizing entire-male cattle from breeding through to feedlot finishing will only be more profitable than a traditional production system based on steers, if the turn-off in the entire-male cattle can be sold without discount relative to steers. A producer targeting the premium $/hd available in the marketplace for this type of cattle would need to be confident that their production pathway through to sale is sufficiently robust to allow them to hit the desired price-point on the meatworks sale grid, with a high level of probability.

None-the-less, in production systems where the castration of some animals either very young or older than desirable may result in a substantial delay (ie an additional year) in their

progress down a production pathway, leaving those animals entire and grain finishing them at a young age may be a more profitable alternative.

9 Conclusions

- There was no difference in growth performance between castrated and non-castrated animals prior to their entering the feedlot, which coincided with the expected time of sexual maturity of the non-castrates. After 75 days of grain feeding, non-castrated animals were on average about 4% heavier and had 11% higher estimated average daily gain than castrated animals. There were no differences in growth rates or liveweights between Early-castrate and Late-castrated animals or Short-scrotum and Entire animals.

- There were no observed behavioural differences between the treatment groups during the course of the project.

- Grain finishing entire animals at a younger age to their castrated counterparts may help avoid downgrades due to the appearance of secondary sex characteristic and facilitate achieving a premium sale price target.

- Grain finishing entire male cattle offers producers the opportunity to achieve a higher gross value for their cattle due to their inherently superior weight-for-age, and enhanced feed conversion efficiency - provided the rate of carcass downgrade due to secondary sexual characteristics is minimal.

- Marbling MVP may be of limited value in selecting animals for increased meat quality.

- In high grade *Bos indicus* cattle, hump height may be more a reflection of testosterone levels than the percentage of *Bos indicus* content.

- Castrated animals had a higher rate of allocation to MSA boning groups ≤10 (the "premium" boning groups), than non-castrated animals.

- MSA boning groups do not appear to be a sensitive indicator of eating quality of meat from high-grade *Bos indicus* cattle.

- While meat from castrated animals had higher PMQ scores that did meat from non-castrated animals, this difference was not generally reflected in taste panel sensory test scores.

- For high-grade *Bos* indicus cattle, there was a disparity in the allocation of MSA star grades between boning groups, PMQ and MQ4 outcomes from sensory testing. This disparity appeared to be more than might be expected from a grading system designed to ensure that the consumer does not have an unacceptable eating experience from consumption of beef of MSA 3-star quality or better, and represents a potential financial loss for producers.

- The utilisation of young, intact male cattle for beef production should not result in an increased incidence of "dark cutters".

- The production of high quality beef from entire males may offer some niche marketing opportunities in countries where cultural values favour meat from uncastrated animals.
- There is clearly scope to improve the quality and consistency of meat from *Bos indicus* genotypes in northern Australian, with a majority of carcasses from young cattle producing primals of the MSA 3-star grade being a realistic goal.

- If MSA grading is to be relevant to the north Australian beef industry, there is a clear need for additional research to generate data relevant to the northern beef industry, to allow the MSA grading model to be further refined for *Bos indicus* cattle.

Publications and extension to the beef industry

The outcomes of the project were presented to the industry at Beef 2012 at Rockhampton in the MLA scientific program on Wednesday 9th May 2012, and at the Northern Beef Research Update Conference held in Cairns on 13th - 15th August 2013. In addition, the Chief Investigators have attended meetings of the Regional Beef Research Committees in northern Australia to further promulgate the outcomes. A number of media articles will be developed to highlight the key aspects of the project for publication in the rural press and the MLA publications Feedback and Frontier. Finally a series of papers is being prepared for publication in the international peer reviewed scientific literature.

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The collection of data and samples for a project like this is a substantial imposition on the normal commercial operation of an abattoir. We acknowledge and are grateful for the outstanding co-operation and support of the management and staff of JBS Australia Pty Ltd, Dinmore, without which we could not have completed the project.

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Appendix 1

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ETHICS REVIEW COMMITTEE **Animal Ethics Committee** *APPROVAL FOR ANIMAL BASED RESEARCH OR TEACHING*						
PRINCIPAL INVESTIGATOR	**Professor Lee Fitzpatrick**					
SCHOOL	Veterinary & Biomedical Sciences					
PROJECT TITLE	**Growth and meat quality of grain finished entire male Bos indicus cattle**					
APPROVAL DATE	15 Sep 08	**EXPIRY DATE**	30 Apr 11		**CATEGORY**	**3**

This project has been allocated Ethics Approval Number with the following conditions:	**A**	**1342**

1. All subsequent records and correspondence relating to this project must refer to this number.
2. That there is NO departure from the approved protocols unless prior approval has been sought from the Animal Ethics Committee.
3. The Principal Investigator is to advise the responsible Ethics Monitor appointed by the Ethics Review Committee:
   - periodically of the progress of the project;
   - when the project is completed, suspended or prematurely terminated for any reason.
4. In compliance with the *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes*, and the *Queensland Animal Care and Protection Act 2001*, it is **MANDATORY** that you provide an annual report on the progress of your project. This report must also detail animal usage, and any unexpected event or serious adverse effect that may have occurred during the study.

NAME OF RESPONSIBLE MONITOR	Summers, Prof Phillip
EMAIL ADDRESS	phillip.summers@jcu.edu.au
ASSESSED AT MEETING **APPROVED** **Professor Phillip Summers** **Chair, Animal Ethics Committee**	**Date:** 2 Sep 08 **Date:** 15 Sep 08
Tina Langford Ethics Officer **Research Office** Tina.Langford@jcu.edu.au	Date: 15 Sep 2008

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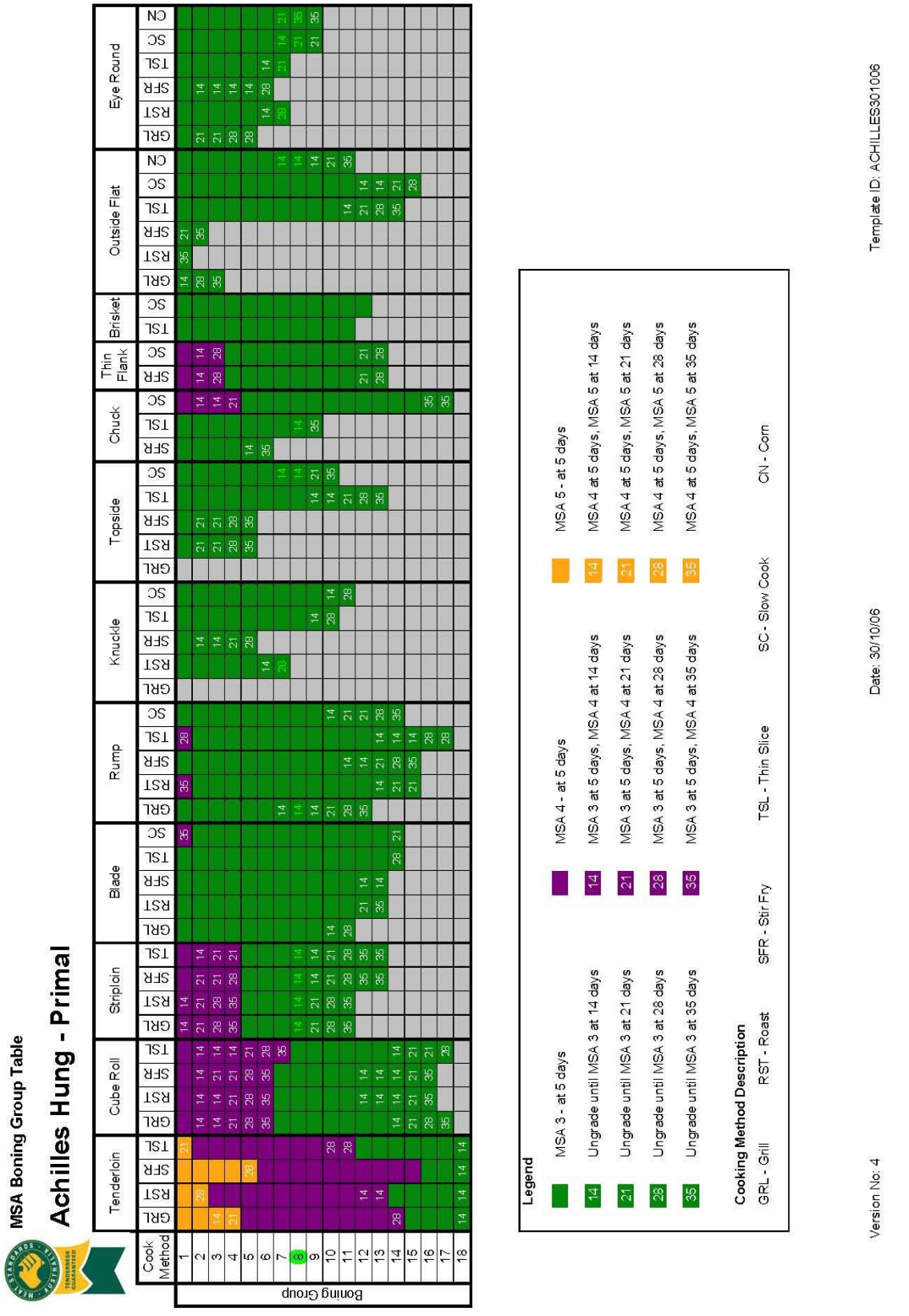
Appendix 2: Feedlot summary data

Table 2a Feedlot data for 528 head of cattle fed at Wallumbah feedlot for the period 13 July 2010 to 26 September 2010.

Lot No.		1058
Date started		13/07/2010
Cattle class		OX100
Average weight In (kg)		324
No. head In		528
Deaths		2
No. Head out		526
Average days on feed (days)		75
Av cost per hd per dy ($)		2.85
Feedlot charges ($)		112469.11
Headdays (days)		39506
Units feed fed		425.222
Consumption (as fed) (kg)		10.76
Consumption (dry) (kg)		8.03
Units feed dry (year)		317.173
Ration 1 Av price ($/tonne)		260.55
Ration 1 units		23.78
Ration 1 Amount (kg)		6194.8
Ration 2 Av price ($/tonne)		243.42
Ration 2 units		19.618
Ration 2 Amount (kg)		4777.2
Ration 3 Av price ($/tonne)		227.39
Ration 3 units		67.925
Ration 3 Amount (kg)		15445.46
Ration 4 Av price ($/tonne)		215.89
Ration 4 units		13.684
Ration 4 Amount (kg)		2954.23
Ration 5 Av price ($/tonne)		225.59
Ration 5 units		300.215
Ration 5 Amount (kg)		67614.62
MDH Induction charge (units)		528
MDH Induction charge ($)		2904.00
0.80c yardage/hd/dy (units)		12436
0.80c yardage/hd/dy ($)		9948.80
Weighing costs (526 hd) ($)		2630.00

Appendix 3: MSA Boning group table – Achilles hung – Primals



Appendix 4: JBS grid under which the project cattle were sold

Grade	Fat	Teeth	Shape	Price															
100 Day Jap Ox				**440+**	**420+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**150+**	**130+**	**110+**	**-110**
GD	7-22	0-2	A-C	2.85	3.20	3.55	3.55	3.55	3.50	3.45	3.40	3.35	3.30	3.12	2.05				
GE	23-32	0-2	A-C	2.80	3.15	3.50	3.50	3.50	3.45	3.40	3.35	3.30	3.27	3.07	2.00				
G0	7-22	0-4	A-C	2.80	3.15	3.50	3.50	3.50	3.45										
G9	23-32	04	A-C	2.75	3.10	3.45	3.45	3.45	3.40										
GG	7-22	0-6	A-C	2.75	3.10	3.45	3.45	3.45	3.40										
GV	23-32	0-6	A-C	2.70	3.05	3.40	3.40	3.40	3.35										
GR	7-32	0-8	A-D	2.40	2.75	3.35	3.35	3.27	3.22										
GZ	+32	0-7	A-C	2.40	2.75	3.35	3.35	3.27	3.22										
100 Day Jap Heifer				**440+**	**420+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**150+**	**130+**	**110+**	**-110**
GF	7-22	0-2	A-C	2.80	3.15	3.50	3.50	3.50	3.45	3.40	3.35	3.30	3.25	3.07	2.00				
GH	23-32	0-2	A-C	2.75	3.10	3.45	3.45	3.45	3.40	3.35	3.30	3.25	3.20	3.02	1.95				
G1	7-22	0-4	A-C	2.75	3.10	3.45	3.45	3.45	3.40										
G8	23-32	0-4	A-C	2.70	3.05	3.40	3.40	3.40	3.35										
G2	7-22	0-6	A-C	2.70	3.05	3.40	3.40	3.40	3.35										
G3	23-32	0-6	A-C	2.65	3.00	3.35	3.35	3.35	3.30										
GZ-	+32	0-7	A-C	2.30	2.70	3.30	3.30	3.22	3.17										
70 Day Trade Steer				**440+**	**420+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**150+**	**130+**	**110+**	**-110**
WA	5-12	0-2	A-C					3.55	3.50	3.45	3.40	3.35	3.30	3.12	2.05				
WB	13-17	0-2	A-C					3.55	3.50	3.45	3.40	3.35	3.30	3.12	2.05				
WC	18-22	0-2	A-C					3.55	3.50	3.45	3.40	3.35	3.30	3.12	2.05				
WD	23-32	0-2	A-C					3.50	3.45	3.40	3.35	3.30	3.25	3.07	2.00				
WE	5-32	0-4	A-D					3.45	3.40	3.35	3.30	3.27	3.20	3.02	1.95				
60 Day Trade Heifer				**440+**	**420+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**150+**	**130+**	**110+**	**-110**
W1	5-12	0-2	A-C					3.50	3.45	3.40	3.35	3.30	3.25	3.07	2.00				
W2	13-17	0-2	A-C					3.50	3.45	3.40	3.35	3.30	3.25	3.07	2.00				
W3	18-22	0-2	A-C					3.50	3.45	3.40	3.35	3.30	3.25	3.07	2.00				
W4	23-32	0-2	A-C					3.45	3.40	3.35	3.30	3.25	3.20	3.02	1.95				
W5	5-32	0-4	A-D					3.40	3.35	3.30	3.25	3.20	3.15	2.97	1.90				

Grade	Fat	Teeth	Shape	Price															
Grass Trade Yearling Steer				**440+**	**420+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**150+**	**130+**	**110+**	**-110**
YO	5-22	0-2	A-C			3.35	3.35	3.35	3.30	3.25	3.20	3.15	3.05	2.90					
Y1	23-32	0-2	A-C			3.30	3.30	3.30	3.25	3.20	3.15	3.10	3.00	2.85					
Y2	5-22	0-2	A-D			3.25	3.25	3.25	3.20	3.15	3.10	3.05	2.95	2.80					
Y3	23-32	0-2	A-D			3.20	3.20	3.20	3.15	3.10	3.05	3.00	2.95	2.75					
Ox				**440+**	**420+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**150+**	**130+**	**110+**	**-110**
I	7-22	0-4	A-C	2.75	3.00	3.30	3.30	3.30	3.25	3.20	3.15	3.10	3.00	2.85					
I9	23-32	0-4	A-C	2.70	3.00	3.25	3.25	3.25	3.20	3.15	3.10	3.05	2.95	2.80					
J	7-22	0-6	A-C	2.70	3.00	3.25	3.25	3.25	3.20	3.15	3.10								
J9	23-32	0-6	A-C	2.65	2.95	3.20	3.20	3.20	3.15	3.10	3.05								
A	7-22	7-8	A-C	2.65	2.95	3.20	3.20	3.20											
A9	23-32	7-8	A-C	2.60	2.90	3.15	3.15	3.15											
D	3-22	0-7	A-D	2.65	2.95	3.20	3.20	3.20	3.15	3.05	3.00	3.00	2.95	2.85	1.35	0.50	0.30	0.20	0.10
D9	23-32	0-7	A-D	2.60	2.90	3.15	3.15	3.15	3.10	3.00	2.95	2.95	2.90	2.80	1.30	0.45	0.30	0.20	0.10
E	3-22	8	A-D	2.65	2.95	3.15	3.15	3.15	3.10	3.00	2.95	2.95	2.80	2.65	1.20	0.45	0.30	0.20	0.10
E9	23-32	8	A-D	2.65	2.95	3.10	3.10	3.10	3.05	2.95	2.90	2.85	2.75	2.60	1.15	0.40	0.30	0.20	0.10
F	0-32	0-8	A-E	2.65	2.95	2.90	2.90	2.90	2.85	2.80	2.75	2.65	2.55	2.25	0.85	0.30	0.30	0.20	0.10
ZS	33-42	0-8	A-E	2.25	2.60	2.75	2.75	2.75	2.70	2.65	2.65	2.60	2.40	2.25	0.75	0.30	0.30	0.20	0.10
ZT	43+	0-8	A-E	2.05	2.40	2.55	2.55	2.55	2.50	2.45	2.45	2.40	2.20	2.05	0.55	0.30	0.30	0.20	0.10
Bull				**700+**	**650+**	**600+**	**500+**	**440+**	**340+**	**320+**	**300+**	**280+**	**260+**	**240+**	**220+**	**200+**	**180+**	**160+**	**-160**
Q	0-32	0-8	A-D	1.62	2.17	2.42	2.62	2.72	2.72	2.72	2.62	2.62	2.57	2.52	2.40	2.25	2.10	1.35	0.50
R	0-32	0-8	A-E	1.52	2.12	2.37	2.57	2.67	2.67	2.67	2.57	2.57	2.52	2.47	2.30	2.15	2.00	1.25	0.40

Fig 13.0 One of the yards on Dunbar during branding of calves for the project

Fig 14.0 Project cattle at Wallumbah feedlot

Fig 15.0 Carcasses from project cattle undergoing MSA grading.

Fig 16.0 Carcasses from project cattle prior to boning.