Final report

Creating a dairy beef supply chain to increase the value and volume of beef and veal products

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Abstract

While often a major component of beef supply in many countries, dairy beef is less commonly utilised in Australia. Reasons have included a processor belief that dairy carcases were of below premium quality compared to beef breed carcases whereas dairy farmers believed that the prices offered for dairy steers of similar weight to beef were non-viable. Consequently, many male calves have been euthanised at birth with others sold within 5 days of age as “bobby calves”. These options raise social license and animal welfare concerns, but also reflect the loss of considerable potential beef supply.

The project evaluated two growth rate pathways (target 0.7 kg/day and 1.2 kg/day) from birth to veal (Hot Standard Carcase Weight (HSCW) <150 kg with 0 teeth) and mature beef (300 kg HSCW) end points. Holstein, Holstein x Jersey and Jersey dairy breeds were evaluated together with lesser numbers of British and European beef breeds. Holstein sub-groups were also evaluated under grass and feedlot finishing together with a further accelerated growth pathway utilising a “Spanish” high carbohydrate ration program (SDT) and a control Australian formulation (ADT).

All pathways produced beef of MSA acceptable quality, at least equal to the beef breed cohorts. However serious non-compliance issues were encountered with the veal that requires further work to enable a successful MSA pathway.

Executive summary

Background

Male dairy calves have traditionally been an unwanted by-product of the Australian dairy industry and received scant consideration relative to the milking herd and replacement heifers. Many were euthanised at or soon after birth or sold as bobby calves although this practice is increasingly uncommon with producers with a recent report identifying that 1% of calves were euthanised on-farm. Both personal and financial reasons were indicated as reasons for reduction in this practice with producers looking for viable value chain options for their male non-replacement calves. Further, calves that were processed were generally within veal specification (maximum 150kg HSCW with zero teeth) and fewer yet grown out to heavier weights (300kg HSCW). Those that were grown on often these took several years to reach market specifications due to poor quality nutrition resulting in growth rates well below potential. The resulting carcases were frequently considered of low meat value by meat processors and downgraded accordingly. In contrast dairy breed cattle and 'beef on dairy' crosses provide a high proportion of beef supply in many countries, with some achieving high quality carcase grade outcomes.

The status quo represents a waste of potential meat supply, estimated at up to $550M per annum (550,000 head at $1,000/head), and is associated with animal welfare and industry social license concerns. This project evaluated several dairy beef supply chain pathways to evaluate and establish alternative production strategies and, critically, to evaluate consumer response to the final beef article through MSA consumer evaluation.

Production of a high value dairy beef product has been considered a challenge to the Australian beef industry, creating a "chicken and egg" conundrum where processors believed that dairy beef was of low quality and priced accordingly which in turn discouraged production. The research provides controlled production and sensory data that can inform both dairy producers and meat processors in relation to alternative dairy beef production approaches including expected breed and growth rate/ration interactions. The research results provide valuable insights and guidance for Australian commercial dairy beef production.

Objectives

To confirm that dairy breeds could generate a valuable carcase with high eating quality, a number of parallel trials were undertaken utilising different growth pathways, including an intensive high-carbohydrate lifetime ration, with growth characteristics, carcase quality and eating quality assessed. This was achieved under diverse seasonal and regional conditions, adding cost and complexity to the study, but providing a valuable "real life" extreme scenario.

A further objective was to develop data to establish the degree of challenge relating to creation of a consumer grading model for cuts from veal calves.

The research study also aimed to provide simple budget models, utilising the physical production data from the alternative pathways, suitable for linking to current pricing for livestock, feed and meat. Economics of alternative dairy beef production systems will vary extensively over time making solid physical performance data for alternative pathway combinations a valuable resource for extrapolating economic outcomes.

Methodology

A multi-site, multi-region randomised controlled trial compared growth rates of dairy steers to beef steers and the resulting carcase qualities at a veal, feedlot, and pasture finish. We planned to; i) establish a pathway for veal calves up to 150kg carcase weight to be graded for Meat Standards Australia (MSA); and ii) evaluate differences in meat quality between steers of traditional dairy breeds, Jersey, Holstein-Jersey Cross, and Holstein steers, to beef breeds of British origin and European Cross grown through backgrounding and feedlot together and finished at a carcase weight of ~300kg.

Consumer sensory evaluation was conducted utilising MSA protocols and included multiple cooking methods.

Results/key findings

The key finding was that dairy steer cuts had equal to higher eating quality to those from beef breeds within both growth treatments, at veal and heavier carcase weights and from feedlot or supplemented pasture-based systems. Between dairy breeds the Holstein steers were heavier at each production stage, with Holstein x Jersey crossbreds slightly lower and Jersey significantly so. The low weight and growth rate of Jersey steers in this study made them less desirable for feedlotting and beef processing despite some indication of a possible eating quality advantage.

At equivalent HSCW the dairy steers typically had similar marbling and ossification, lower P8 and rib fat but smaller EMA than the beef steers. The lower EMA may be offset by greater *M.longissimus* dorsi (LD) muscle length (Schaefer, 2005). Potentially a similar cut yield trade-off may apply to the observed lower external fat cover on dairy breeds carcases and their lower dressing percentage relative to beef.

A novel diet (Spanish Diet Treatment; SDT) and an Australian control formulation (ADT), fed from cow-calf separation, both produced high quality 300kg HSCW MSA-graded carcases at 14 months although a higher rate of liver abscess was observed in the SDT group. Higher rates of liver abscess were also noted in the older dairy breed feedlot groups relative to the beef steers which were raised on the cow. Further study is warranted to evaluate potential early feeding or dairy genetic relationships to liver condition at slaughter.

The highest eating quality and MSA compliance was produced through the accelerated growth high carbohydrate rations and the majority of feedlot groups.

While the dairy veal calves achieved acceptable eating quality, they were non-compliant with existing MSA screening criteria for rib fat and ultimate pH, and potentially compromised by cold shortening reducing their eating quality potential. The results indicate that a satisfactory MSA veal prediction model could be built upon a similar framework to the MSA V2.0 beef model. However, to create a commercially viable MSA veal model novel screening criterion in association with alternative chilling regimes may be required.

New schnitzel and Texas BBQ cooking methods, not currently in the MSA prediction model, produced superior consumer outcomes than existing grill and slow cook methods.

A small scoping evaluation utilising some dairy beef cuts also indicated that ageing may be conducted after thawing product frozen prior to 5 days post slaughter and currently excluded from MSA grading, though requires further research. Whilst this provides opportunity for export, frozen product commercial practicalities and controls would be considerations, around controlled conditions particularly internationally, it provides some challenges.

Benefits to industry

The research results provide valuable insights and guidance for Australian commercial dairy beef production. At 300kg HSCW, the project establishes a strong rationale for expanded utilisation of dairy steers for beef production within MSA graded programs. Issues relating to optimum veal outcomes have also arisen from the project together with confirmation that some basic biological mechanisms require further evaluation. Adoption of growth pathways utilising grass, a combination of grass and feedlot and very high carbohydrate rations are each confirmed as producing high eating quality outcomes and superior carcase value to the previous below premium market expectation. These results provide potential solutions to the social license challenges related to male dairy calves, particularly those from pure dairy breeds.

Ancillary results for schnitzel and Texas BBQ cooking methods and for post thaw ageing could respectively provide superior consumer outcomes and expanded MSA supply to export markets where many cuts are frozen after boning due to restricted chiller capacity.

This report indicates that the current MSA prediction model, developed from beef data, can be utilised for heavier dairy beef carcases but requires further evaluation regarding screening and processing criteria for effective application on veal carcases.

Future research and recommendations

Despite rating acceptably on eating quality, many dairy breeds, and in particular veal, carcases did not meet grid requirements for MSA grading. This conflicting situation reinforces the need for more detailed study of individual muscle pH, temperature and time relationships in order to specify more precise processing criteria. While the relationship of ultimate pH and meat colour was consistent some days post slaughter, pHu recorded during grading was often not at a genuine ultimate reading. This suggests that the value of pH in determining carcase grading must be re-considered as previous findings have indicated (Tarr et al., 2020). While there are conflicting demands of retail meat colour, Tarr et al., (2020) found that these were not associated with eating quality. Findings from this study reinforce the suggestion of a curvilinear pattern of muscle becoming tougher as pH increases until reaching a peak around pH 6 – 6.1 and then becoming more tender, but with very dark colour, however the study did not investigate any other potential negative factors, which may influence poorer eating experiences such as microbial activity at higher pH. The relationship between high pH, muscle toughness, cooking characteristics, meat colour, flavour precursors and shelf life need to be critically evaluated across principal cuts to understand further opportunities for high pH meat, which could differ across muscles. It is possible that high pH muscle may be utilised in value adding processes.

A structured study of pH, temperature, electrical inputs and flavour chemistry is recommended across major muscles as a base for effective commercial application. This reinforces MSA Pathways discussion to better understand the biological relationships with the outcomes expected to have relevance to predicting and modifying cooked flavour and in muscle selection and processing combinations including profitable utilisation of high pH cuts in value adding products. More fundamental metabolic measures may also relate to pH decline rates and meat colour development if these are found to have a dairy genetic influence.

For the lighter veal carcases, it is recommended that a step chilling regime be evaluated to potentially mitigate the risk of cold shortening and two toning meat colour associated with rapid chilling and low fat cover. A concurrent evaluation of the impact of electrical inputs including electrical versus percussion stunning or captive bolt and of electrical stimulation is also recommended to optimise processing and chilling practice in relation to eating quality, hygiene and shelf life.

Of the dairy breeds studied the Jerseys were associated with several commercial challenges. Despite high eating quality, Jersey animals graded poorly under the current MSA screening criteria due to higher than specified pH and low rib fat measures. They also grew slower than the Holstein and Holstein cross cattle and were lighter at each production stage making them unattractive for fattening and for efficient processing. There are some commercial programs designed to cross Jersey cows with carefully selected higher muscle beef sires. It is recommended that these be evaluated for both animal performance and consumer eating quality outcomes to assess their commercial potential. In the USA many dairy beef feeding programs utilise both hormonal implants and pre-slaughter beta-agonist feeding to increase growth rate, muscling and EMA. While beta-agonists are not licensed for use in cattle in Australia, and HGP implants reduce MSA outcomes, utilisation of HGP on lightly muscled early maturing dairy steers deserves evaluation in further projects.

Further data should also be gathered to better define relationships between liveweight, dressed weight and lean meat or retail cut yield for dairy breed relative to beef cattle including the impact of age and growth path. An examination of EMA relative to shape, mass, length and fat cover of the cube roll and striploin cuts is recommended to enable more accurate pricing of dairy cattle and dairy derived cuts. This may benefit from extension to internal fats and offals.

Liver abscess proved common across all dairy breeds in the study. Further research is needed in rearing methods that may reduce the incidence in early separated dairy beef animals. There is a need to increase understanding of early weaning on rumen development on differing rearing diets either utilising metagenomic or metabolomic methods and its potential impact on liver disease in dairy beef cohorts.

Data from this study also support that the Texas BBQ cooking method be added to the MSA prediction model and that schnitzel also be added subject to further consistent test results. Given sufficient industry interest, further research of the freeze and thaw impact on ageing is also recommended, as well as investigating supply chain and integrity issues relating to this pathway.

Effective industry extension relating to managing dairy beef production to achieve higher value MSA related outcomes can utilise many of the project findings. These include critical management to facilitate calf survival and health with minimal antibiotic use, the selection of breeds and crosses, alternative feeding strategies, and interaction of early growth and later finishing outcomes.

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Abbreviations

ADG: Average Daily Gain

ADT: Australian Dietary Treatment

A-MC: AUS-MEAT meat colour

A-FC: AUS-MEAT fat colour

A-MB: AUS-MEAT marbling

ARRIVE: Animal Research: Reporting of *In Vivo* Experiments

BIN: Beef Improvement Nucleus

EFinWt: Estimated Final Weight

EMA: Eye Muscle Area

EMM: Estimated Marginal Means

DFOF: Feedlot Days on Feed (actual)

DOF: Days on Feed

FEntWt: Feedlot Entry weight

FGAIN: Finishing Gain Kg

FinalWt: Final Weight

GADG: Grower / backgrounder ADG

GDays: Days of backgrounding

GEntWT: Entry weight to backgrounding

GGain: Grower / backgrounder gain (Kg)

GSV: Grill Sous-vide

HAM: Handbook of Australian Meat

Hd: Head

HG: High Growth

HH: Holstein

HSCW: Hot Standard Carcase Weight

HxJ: Jersey cross Holstein

IBR: Infectious Bovine Rhinotracheitis

JJ: Jersey

LADG: Lifetime ADG

LG: Lower Growth

LW: Live Weight

MFV: Milk Fed Veal

MH: *Mannheimia haemolytica*

MSA: Meat Standards Australia

NIR: Near Infrared

NSW: New South Wales

NY: New York

pHu: pH ultimate

SDT: Spanish Dietary Treatment

SNZ: Schnitzel

TBQ: Texas BBQ

U-MB: MSA marbling

USDA: United States Department of Agriculture

VIC: Victoria

EQSRef : Eating Quality System Reference

1. Background

The number of male dairy calves born annually in Australia is between 500,000-600,000, from a 1.6 million head dairy cow herd (Dairy Australia 2018). Traditionally, these 'non-replacement' male calves have been an unwanted by-product of the dairy industry representing an unnecessary and unwanted cost to the dairy producer to raise them to point of sale or slaughter. The dairy industry has identified that calf wastage, through the euthanasia of day-old male calves or early sale due to unprofitable performance in rearing systems, is perceived as a major animal welfare issue both in Australia and internationally. While some calves are sold within a few days of birth for "bobby veal" production, a limited numbers of calves are grown on a milk diet and sold as veal or sold later as steers. These animals are generally discounted in the market compared to beef animals due to a perceived lower yield and unknown eating quality generating a perception of low value for this product by the industry and consumer

Currently, the opportunity cost for loss of potential red meat yield through failure of a viable, evidenced and profitable production pathway for these non-replacement calves represents $550M per annum in lost profits and potential impacts related to animal welfare and industry social license concerns. Recent studies have shown that a minority of producers utilise euthanasia as part of their production system but that concerns regarding profitability of value chain pathways is a key concern (Vicic, Saliba et al. 2021, Vicic, Saliba et al. 2022). Currently less than 20% of all non-replacement calves enter a profitable production pathway.

In contrast, in Europe, the USA, and New Zealand, dairy beef contributes to a substantial percentage of finished beef production. In the USA, the estimated 8–8.5% contribution to finished steers suggests that Holstein genetics may be the largest recognisable single-breed source of beef (Schaefer 2005). Holstein steers represented 15–20% of lot-fed steers in the USA (Rust, Abney et al. 2005). In New Zealand, dairy breeds dominate beef production, providing approximately 50% of the weight of beef produced and slightly less than 50% of the value of beef produced (Charteris, Morris et al. 1999). The potential to reduce greenhouse gas production by 29% per kg of carcase by replacing suckler beef with dairy beef was investigated by van Selm, de Boer et al. (2021). Descriptors for 'Dairy Beef' in Australia are very broad and acknowledge the likely discounting of the steers (Mulley, Lean et al. 2014).

Global production systems vary widely for dairy beef with some utilising dairy bulls to produce a lean manufacturing beef product, typical in New Zealand, and often associated with fast food restaurant chain contracts. In other countries (Ireland, UK) young dairy bulls are utilised in, mostly price competitive, retail table beef markets whereas they are regarded as a premium product in different countries (Italy, Spain and Portugal) where light weight very lean carcases are preferred. In Japan the predominant domestic beef supply chain is an F1 Wagyu x Dairy cross of high eating quality whereas the USA market straddles both manufacturing and USDA Choice quality markets through their predominant feedlot systems that produce high carcase weights at young age.

However, Holstein and dairy influenced steers have equivalent or higher meat quality than beef breeds (Mulley, Lean et al. 2014). Rust, Abney et al. (2005) presented commercial feedlot data suggesting better grading performances and lower dry matter intake differences for Holsteins than beef breeds raised under similar conditions. Holstein steers generally have a lower yield and different muscle shape to traditional beef breeds. These carcase and meat quality descriptors require further investigation using a rigorous system of evaluation such as Meat Standards Australia (MSA). The MSA quality grading system allows a value to be placed on a carcase that reflects the quality of the meat and not just on weight or arbitrary perceptions of value. The MSA system of eating quality is peer reviewed (Polkinghorne, Thompson et al. 2008, Watson, Gee et al. 2008, Watson, Polkinghorne et al. 2008) and widely adopted. A further issue, as yet not effectively evaluated, is a comparison of boning yield between beef and dairy carcases which may offset the expected lower dressing percentage of dairy breed cattle.

More limited and less quantitative systems used in the USA may not fully describe the key carcase attributes regarding eating quality. Further, the same methods should be applied to other dominant dairy cross breeds including the Jersey and Jersey cross Holstein (HxJ). These breeds are prevalent in southern Australia, but there are limited data on the eating values of Jersey and HxJ, although these have been noted to have a more yellow fat cover possibly associated with carotenoids in pasture (Dunne, Keane et al. 2004).

This report presents a multi-site, multi-region study comparing the growth rates of dairy animals to beef animals and the resulting carcase qualities at a veal, feedlot and pasture finish. The overall objectives of the study were:

i) to establish a pathway for veal calves up to 150kg carcase weight to be graded for Meat Standards Australia;

ii) to evaluate differences in meat quality between steers of traditional dairy breeds, specifically Jersey, HxJ, and Holstein steers, to beef breeds of British origin and European cross steers (Beef) grown through backgrounding and feedlot together when finished at a carcase weight of approximately 300kg.

There is a strong emphasis on external validity of the study findings for industry, while maintaining an intent to retain a rigorous study structure. The effect of a high (HG) or lower growth (LG) path from weaning through to harvest on growth and meat quality attributes was evaluated. Growth and carcase attributes of dairy breed and euro breed steers that were finished in the feedlot are compared, but not statistically evaluated against Holstein steers that were fed only with pasture and supplement. These comparisons were conducted over two cohorts across three southern regions. Seasonal conditions differed markedly and included an extreme drought period during the rearing and finishing period for Cohort 1 which impacted some outcomes. Cohort 2 were maintained until slaughter in defined pods or groups allowing robust statistical comparison, including financial return.

A further study component, based on the SDT system, evaluated an extreme concentrate ration program from birth designed to produce an equivalent weight carcase at a younger age, providing potentially higher feed efficiency and superior MSA consumer outcomes.

Finally, eating quality of dairy beef product was considered, including the development of novel MSA cooking methods (Texas BBQ and schnitzel).

2. Objectives

The Australian dairy industry has identified that the management of “bobby calves” (non-replacement male calves, (~aged 5-30 days) is a major animal welfare issue. Currently most non-replacement male calves are sold into very low value markets or are euthanized on farm. Calves grown to steers (those with a carcase weight of approximately 300kg) that are sold into the beef market have generally been considered to be of poor quality in comparison to traditional beef breeds and have received a financial discount at slaughter. This in part reflects a typical leaner and older animal at slaughter resulting from moderate nutrition and growth rates substantially below genetic potential and highlights the need for the generation of a value proposition for non-replacement dairy steers that produces a carcase considered to be of good to high quality to create a viable value chain for these calves to market. The key aim of this project was to increase the value proposition of dairy (Holstein and Jersey) beef production as well as to investigate the viability of veal as part of the MSA pathway.

To address this issue, the project aimed to investigate several dairy genetics and nutritional/ management pathways on growth, carcase quality and eating performance of beef from dairy breeds. The project engaged with all sectors of the current dairy beef supply chain to generate whole of lifetime performance data from dairy, and dairy cross beef as a consumer product with results able to be directly implemented through the MSA model development process.

Our primary hypotheses were that:

i) Steers of dairy and beef breed backgrounded together would have similar veal and beef eating qualities; and,
ii) That a higher rate of growth using accelerated feed pathways would improve meat quality.

Secondary hypotheses were:

a) That steers of dairy and Beef breed backgrounded together would have different growth performance in backgrounding and the feedlot, but have similar carcase quality;
b) That differences in the backgrounding growth rate would result in differences in performance in the feedlot, in carcase characteristics and eating quality;
c) That based on observation of commercial systems in Europe, an extreme high concentrate nutritional regime from birth could produce a premium eating quality from dairy calves due to reaching slaughter weight at 12 to 13 months of age.

Lastly, the comparison to the performance of Holstein steers not finished in the feedlot, but primarily finished on pasture was of interest.

Key objectives for this project were:

- To provide evidence that the eating quality of dairy cattle, specifically Jerseys, Holstein and Jersey x Holstein steers, could be comparable to beef cattle cohorts.
- To develop a risk mitigation model for production of veal calves, with a carcase weight of approximately 150kg, that could be used to generate an MSA model adoption for veal product.
- To determine the genetic merit, by phenotype, of dairy steers that would perform well, or otherwise, in a beef production system.

- To undertake a multi-site, multi-region study design for dairy beef growth pathways with both grass-fed and grain-fed endpoints, to demonstrate evidence of consistent weight gain to producers.
- To test high carbohydrate accelerated growth pathways (SDT and ADT) as a comparison to pasture fed pathways for accelerated production of a high-specification carcase utilising Holstein steers.

3. Methodology

3.1 Overview of methodology

To achieve the outcomes of the project, six treatment groups were established:

1. Pasture Low Growth – Holstein, Jersey x Holstein and beef calves to be grown at 0.7kg average daily gain (ADG) with the use of supplements, for harvesting as veal with a carcase weight below 150kg or transfer to a feedlot at a target entry weight of 400kg live weight (LW).
2. Accelerated Pasture – Holstein, Holstein x Jersey, Jersey and beef calves, to be grown on pasture with a high-quality supplement, with a target of 1.2kg ADG until either harvest as veal with a target carcase weight below 150kg, transfer to a feedlot at a target entry weight of 400kg LW, or to remain on pasture and supplement until slaughter at a target 300kg carcase weight.
3. Veal Calves – calves randomly assigned from all breed groups and backgrounders within the low and accelerated pathways fed from birth until slaughter with a target carcase weight of close to 150kg (the AUS-MEAT specified maximum carcase weight for veal) to generate a dairy veal product.
4. Feedlot finishing after high and low growth pasture backgrounding - calves randomly assigned from all breed groups and backgrounders within the low and accelerated pathways to be transferred to a feedlot at a target entry weight of 400kg liveweight. These steers were to be fed a typical high concentrate commercial feedlot ration until harvested at a target 300kg carcase weight.
5. Pasture and supplement finishing to a targeted 300kg carcase weight – calves randomly assigned from the accelerated pasture Holstein pods and maintained on the same nutritional regime.
6. High-carbohydrate growth treatment (SDT and ADT) – Holstein calves to be intensively fed from birth with a novel formulation for accelerated growth. Feeding phases were a) Pre-Starter A (milk supplement plus colostrum); Pre-Starter B – Milk supplement plus pre-starter diet; Starter diet and Finishing diet. Cattle were housed in an intensive system and grown to a target carcase weight of 300kg. These were compared with a group of calves fed a ration (ADT) based on high quality feeds readily available in Australia and utilising rumen modifiers used commercially in Australia and the USA but not legal for use in the European Union.

To enrol sufficient cattle for comparison, two cohorts were considered – Cohort 1 which included calves born in a drop (February – May), and Cohort 2, which included spring drop calves (July – September). Growth characteristics, carcase characteristics and eating quality were assessed from primal cuts selected from all animals post slaughter from all pathways with consumer preferences compared utilising MSA consumer sensory protocols.

3.2. Growth pathways for grass-fed and grain-fed dairy beef high and low growth cohorts

3.2.1. Animals

This study was conducted in compliance with the Australian Code for the Care and Use of Animals for Scientific Purposes (2013) and was approved by Charles Sturt University Animal Care and Ethics Committee (Protocols A18051 and A21191). Informed consent for use of animals included in this study was obtained from the owner/manager of the cattle, in writing, at each location prior to sampling. The study was designed and reported using the ARRIVE (Animal Research: Reporting of *In Vivo* Experiments) guidelines (Percie du Sert, Hurst et al. 2020) for experiments involving live animals.

3.2.2. Study Design

The design is a randomised, controlled, multi-site study with the unit of interest being 'pod' of steers and the unit of measurement is the steer or carcase (Fig. 1).

3.2.3. Region and Timing

This study was conducted in Southern Australia with an autumn-born and spring-born cohorts of dairy cattle. The calves in Cohort 1 were born in February to mid-May 2018 and those in Cohort 2 primarily between July and September 2019. Calves were sourced from farms located in Gippsland, western Victoria, northern Victoria, and the southern Riverina. Farms in these areas were chosen to represent a diverse range of dairying areas. Steers were finished in feedlots at Yeungroon East Victoria (36° 21' S and 143° 24' E), Tullimba New South Wales (30.48' S and 151.19' E), and the New South Wales Riverina (35.84' S, 144.84' E). Beef breed calves were sourced after weaning and were older at entry than the dairy stock, particularly in the first cohort. Fig. 1 displays the study design.

3.2.4. Recruitment of farms and calves

Holstein, Jersey, and HxJ breeders and calf rearers (n = 5) were selected based on a history of good calf rearing performance as determined by appraisal of facilities, records, and review of practices. Bull calves of the dairy breeds were obtained from their farm of birth and either raised to weaning on that farm or were aggregated on calf-rearing facilities for rearing to weaning. All calves were castrated to allow only steers in the study. Beef steers were purchased either from farm or from the saleyards and sent to the backgrounding properties. Dates of birth were not available for these, but calves were specified to be of similar estimated age to the dairy calves; however, we cannot determine the similarity in age that was achieved. It was evident that the beef steers in cohort 2 were purchased at a younger age than those in cohort 1 which were approximately 6 months of age when purchased.

Figure 1. Study design and pathway exit points for all calves entering the trial: veal and cohorts 1 and 2. High growth steers are in grey and the low growth steers and in black. A low growth pathway was not applied to Jersey breed calves. Only Holstein calves had a ‘finished on pasture’ group.

In order to reduce the risks of early mortality and poor performance, good industry practice level protocols were established for colostrum management and rearing. In brief, calves were removed from mothers at the next milking after birth, at which time calves were given 3L of colostrum, which was repeated at the next milking; at the first milking after birth, calf birth date, weight, and sex were recorded, and calves were ear tagged. Calves continued to be fed 2.5-3L of colostrum or diluted colostrum or milk twice per day until 7 days of age. From 1 week until weaning (6-8 weeks), calves were fed 3L of milk or milk replacer twice per day and offered *ad libitum* calf pellets or mash and lucerne chaff or hay; after weaning, milk was removed from the diet, and pellet and hay feeding was increased. At approximately 6 weeks of age all calves were castrated by rubber ring and disbudded in conjunction with pain relief and sedation. Calves were vaccinated and parasite treatments were applied as per industry standard protocols.

In cohort 1, there were 3 properties used for backgrounding and 1 additional property used for extended rearing of grass finished Holsteins. After backgrounder rearing, calves were i) sent for slaughter as veal at an estimated 130kg carcase weight (dressing % estimated at 60% equivalent to approximately 220kg LW), or ii) sent to the feedlot, or iii) were finished at pasture. Table 1 provides the numbers and outcomes for steers in cohort 1.

Table 1. Cohort 1 - Number of calves and pods enrolled from each backgrounder (1-3).

Outcome	Backgrounder					
	1	2	3	Beef	Dairy	Total
Backgrounding target (including Beef)	210	160	230	160	440	600
Removed for veal production	72 (6 pods)	65 (4 pods)	104 (6 pods)	50	191	241
Entered feedlot	67 (6 pods)	70 (4 pods)	112 (6 pods)	55	194	249
Finished on pasture (Property 4)	18 (2 pods)	9 (1 pod)	9 (1 pod)	0	36	36
Finished in feedlot	65	67	112	54	190	244

In cohort 2, there were 4 properties used for backgrounding, 2 of which had integrated feedlots, and 1 additional property used for extended rearing of grass finished Holsteins. After backgrounder rearing, calves were i) sent to the feedlot, ii) remained in the feedlot if they were already backgrounded at the feedlot (integrated system), or iii) were finished at pasture. Table 2 provides the numbers and outcomes for steers in cohort 2.

Table 2. Cohort 2 - Number of calves and pods enrolled from each backgrounder **(1-5).**

Outcome	Backgrounder					**Totals**		
	1	2	3[1]	4	5	Beef	Dairy	Overall
Backgrounding	82[2]	81[3]	87	88[4]	69	100	307	407
Entered feedlot	69 (3 pods)	69[5] (3 pods)	76[6] (3 pods)	74 (3 pods)	69[7] (3 pods)	98	259	357
Finished on pasture	8 (1 pods)	10 (1 pod)	10[8] (1 pod)	10 (1 pod)	0	0	38	38
Feedlot carcase	69	62	74	74	68	93	254	347
Pasture carcase	8	10	8	10	0	0	36	36

[1] Pasture fed were finished elsewhere
[2] 5 died
[3] 2 died
[4] 4 died
[5] 2 slaughtered early in error, 5 culled, died or euthanised
[6] 2 died or were culled
[7] 1 died
[8] 2 died

3.2.5. Sample size and assignment to groups

Sample size estimates were made using rdpower (StataCorp 15.0 LLC, College Station, Texas). An effect size of 0.75 based on a difference of 4 in meat quality score (MQ4) or approximately 0.5 effect size, was used with an $\alpha = 0.05$, intraclass correlation of 0.1, and 8 replicates with 8 steers per replicate. Two additional steers were included in each group to allow for loss of steers between weaning and slaughter. One side of the study was designed to evaluate Jersey steers; the other to evaluate Holstein steers. Further, there was a veal cohort, a cohort for pasture finishing, and two feedlot cohorts. The study power was estimated to exceed 0.8 to determine the difference in MQ4.

3.2.6. Randomisation and group allocation

Calves were randomly assigned to 'pods' and replicates within pods according to breed, breeder origin, and weight via a stratified block randomisation procedure using a random numbers generator in Excel by Charles Sturt University staff upon arrival and weighing at the previously designated backgrounder location at approximately 12 weeks of age. Calves/weaners were inducted into the study at this point and experimental feeding began. For cohort 1, beef steers were obtained at approximately 6 months of age and allocated to the backgrounding 'pods'. Randomisation of the Beef steers to pods was not logistically possible due to the geographical spread of the study and Beef calves were purchased for a region. For cohort 2, the beef steers were randomised and allocated to pods at 12 weeks of age.

3.2.7 Growth strategy

Once calves were allocated to farms, growth and nutritional strategies were emplaced to target different growth paths; high growth (HG) for all breed types, based on 1.2kg per day gain, and low growth (LG) with 0.7kg per day gain for Holstein, Holstein x Jersey and beef steers. The strategies involved allocation of better pastures and increased allocation of pastures to the HG group and provision of commercial pellets based on wheat by-products (Manildra Group, Ridley Agriproducts) and loose mixes based on grain by-products (Rex James Pty Ltd) to support growth when growth targets were not being met or pasture quality or quantity was anticipated to fall below the requirements for the desired growth.

Vaccination and anthelmintic treatments were applied according to Standard Operating Protocols to minimise confounding of responses to nutrition and reduce the risks of disease.

3.2.8 Statistical analysis of high and low growth pathway steers

There was an initial evaluation of the data using graphical evaluation and summary statistics using the statistical package Stata.15™ (StataCorp LLC, College Station, Texas) to evaluate the normality of variables and to evaluate distributions. Mixed models were used to evaluate the fixed effects of treatment with the random effect of steer within pod within farm. Separate models were used to evaluate the effects of breed within growth path; however, the effects of growth path and breed were evaluated for the HxJ, Holstein, and combined beef breeds. For the veal data, days at backgrounder was used as a covariable. For feedlot finished cohorts, the effect of backgrounder days was included for the backgrounding phase and the effect of days on feed in the feedlot, slaughter date and feedlot entry weight, were evaluated and included in models for the feedlot phase where significant ($P<0.05$). For the evaluation of treatment and breed for example;

$$Y_{ijkm} = \mu + \alpha_i + \gamma_j + \beta X_{ijkl} + \omega\alpha\gamma_{ijk} + \varepsilon_{ijkl}$$

Y_{ijklm} = μ is the overall mean, α_i is the fixed effect of treatment (i = HG or LG), γ_j is the fixed effect of breed (j = HxJ, Holstein, or Beef), for steer number k (k = 179 for veal data or 175 for feedlot data), βX_{ijkl} is the covariable adjustment for days at backgrounder (l = 1 to 3) at the start of the study or in the feedlot (similarly for slaughter day or entry weight), and $\omega\alpha\gamma_{ijk}$ are the fixed effects of interaction terms for treatment and breed, and ε_{ijkl} is the random error term for steer within backgrounder and pod .

Further analysis was performed to determine whether the growth pathways were representative of the initial trial design. Using R-Studio (2020), linear mixed models were used to evaluate whether the growth pathways and breed types were significant predictors of average daily gain at the backgrounder. Estimated marginal means plots were created to visualise these results.

For the grass finished pods only the descriptive statistics are provided, and these are for comparison, not statistical evaluation to other pods. Cohort 1 and 2 were evaluated together.

3.2.9 Statistical Analysis of MSA eating quality analysis

An initial evaluation of the sensory data was performed using the R suite statistical package (2020). Linear mixed models were used to evaluate the fixed effects of breed and growth path allocation, and carcase characteristic covariates with the random effect of steer within pod for each of the sensory variables (MQ4, tenderness, juiciness, flavour and overall liking). This analysis was applied across both cohort 1 and 2, with an additional random effect of group included for the cohort 2 analysis. The group covariate explains the variation across the different groups and within that covers different kill dates, feedlots and processing facilities. This was done using R-Studio's lmer mixed models package and summarised using the sjPlots package.

Pearson's Chi-squared test were also used to determine whether any breed or growth path affected both pH or rib fat compliance.

Where insufficient samples sizes existed, simple summary statistics of such groups or cook types were presented.

3.3. Intensive high carbohydrate comparison feeding trial: 'Spanish' versus 'Australian' diet treatments for high growth and performance of Holstein-Friesian steers

3.3.1. Animals

This trial was approved by Charles Sturt Animal Care and Ethics Committee (protocol A20206). Informed consent for use of animals included in this study was obtained from the owner/manager of the cattle, in writing, at each location. The study was designed and reported using the ARRIVE (Animal Research: Reporting of *In Vivo* Experiments) guidelines (Percie du Sert, Hurst et al. 2020) for experiments involving live animals.

Seventy-five Holstein bull calves were sourced from seven dairy enterprises around the Camden, Southern Highlands and Bega areas based on a selection criterion including: date of birth, age of enrolment of less than seven days old, appeared to be clinically healthy, known date of birth, known sire and dam, had received four litres of full-strength colostrum (ideally BRIX measurement >22) at birth. The enterprise selection criteria also had to have a protocol that fed calves twice a day, had no recent history of mycoplasma infections and were willing to comply with the trial's protocols.

Calves were sourced from each of the dairy enterprises respectively; Enterprise A, n=24, Enterprise B, n=13, Enterprise C, n=11, Enterprise D, n=11, Enterprise E, n=10, Enterprise F, n=5, Enterprise G, n=1. Once the calves were sourced from each of the seven enterprises, they were then transported at three to seven days old and enrolled into one of two rearing facilities located at Bega (n=24) and Camden Park (n=48) in NSW.

3.3.2. Experimental allocation and housing

3.3.2.1. Experimental allocation

The whole of life growth rate for the Spanish diet was expected to be a minimum of 1.4kg/day, therefore, it was anticipated that calves within this groups would reach the 550kg target carcase weight at 12 months of age. If the calves on the Australian High Growth Diet achieved 1.3kg/day, the expected liveweight would be 514.5kg at 365 days of age based on an induction weight of approximately 40kg LW. Based on these values and an estimated standard deviation of 20kg, a significance level of 0.05 and a power of 0.8; a group size of 3 animals was required per pen to identify a significant difference in final weight using an ANOVA based analysis. To allow for animal deaths and/or removal of steers from the trial for other reasons, a target of 6 animals was included per pen for all groups. Increasing the group size to six animals also allowed for a much smaller difference in growth rates to be detected, whilst still detecting a difference between treatments. Additionally, larger sample sizes provided an increased likelihood of detecting changes in carcase and eating quality parameters by consumer sensory testing post slaughter.

3.3.2.2. Phase 1 – milk rearing and weaning

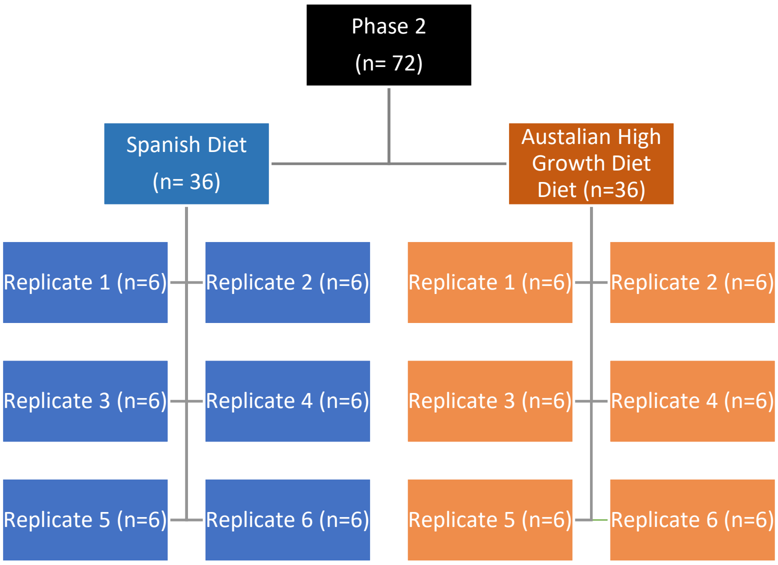
All calves at the Bega and Camden rearing facilities were housed in indoor dirt floored pens containing wood shavings for bedding and had continual access to clean drinking water. Wood shavings were replaced periodically to maintain clean housing environments. The Camden Park rearing facility had additional access to outdoor runs (total pen area 48m^2). The Bega farms provided a similar stocking density. Four litres of full-strength colostrum were provided to all calves within the first eight hours of life, and again at the second post-calving feeding. Calves were provided 2.5-3L diluted colostrum (Kwick Start, Dasco Pty, Ltd, Heidelberg Heights, VIC) twice per day until they were transported to one of the study calf rearing facilities. Table 3 details the chemical composition of the dry feed diets utilised within the SDT and ADT programs.

Calves were randomly allocated to pen one to eight at Camden (six calves per pen), and nine to twelve calves per pen at Bega. There was an intended target of n=72 in the experimental trial but three calves died before enrolment was complete and were replaced with new calves in their respective pens equating to n=75. The duration of the enrolment period was 26 days, from when the first calf entered the experimental trial until the final calf entered the experimental trial and all pens (n=6) were full. Two calves were replaced at the Camden rearing facility and one was replaced at Bega rearing facility during the 26-day enrolment period. Once the enrolment period was complete no further calves were replaced. All calves (n=75) were included in the survival analysis. Each pen was allocated one of two dietary groups Spanish dietary treatment (SDT) (INZAR Nutrición Animal, Zaragoza, Spain) or Australian dietary treatment (ADT). The calves that were reared at the Bega rearing facility were transported to the Camden Park rearing facility at approximately 70 days of age.

3.3.2.3. Phase 2 – finishing

Each treatment group consisted of 36 calves per treatment with 6 calves per pen. At approximately 7 months of age the steers were relocated from Camden to the ruminant research complex at Charles Sturt University and housed in the same treatment groups across 12 pens (50 m x 8 m) (Phase 2, Fig. 2).). All pens contained a cement bunker for feeding, shade over the feeding bunker and extra shade cloth was provided across the rear of all pens. The flooring of the feeding pens was dirt except for a concrete apron on which the feed bunkers were located. All animals had continuous access to water troughs (0.5 m x 1.2 m). Adjacent to the feeding pens were cattle yards which were used for drenching and vaccination, monthly weighing, and any health treatments.

Figure 2. Experimental design for Phase 2 of 'Spanish' (SDT) versus "Australian' (ADT) high carbohydrate diet trial.



Calves in the SDT group were managed according to protocols set out for the Spanish Diet feeding regimen as per the guidelines provided by INZAR (INZAR Nutrición Animal, Zaragoza, Spain); calves in the ADT group were managed according to standard Australian calf rearing protocols.

The calves in the Spanish Diet Treatment (SDT) continued to be fed according to the required protocols; the calves in the Australian Diet treatment (ADT) also continued to be fed by the same protocols with the exception of the presentation of the feed changing from a crumble to a pellet for a period of time (95 days) due to a change in the manufacturing process.

Table 3. Chemical composition of feed formulas offered to calves during pre-starter, starter and finisher stages.

ADT = Australian dietary treatment; SDT = Spanish dietary treatment.

Item (% of DM unless otherwise stated)	**Pre-starter**		**Starter**		**Finisher**		**Wheaten straw**
	SDT (Quick-Start)	**ADT**	**SDT (Papinbeef)**	**ADT**	**SDT (Econbeef)**	**ADT**	
DM	89.7	92.6	90.5	92.9	90.5	91	88.5
CP	18.0	24.9	19.8	22.7	18.2	21.3	4.9
Adjusted Protein	18.0	24.9	19.8	22.7	18.2	21.3	-
Soluble Protein	3.6	9.4	5.4	7.9	4.7	7.8	1.8
ADF Protein (ADICP)	0.77	0.65	0.52	0.66	0.77	0.76	1.16
NDF Protein (NDICP)	1.20	1.27	0.90	1.24	1.08	1.13	-
NDR Protein (NDRCP)	-	-	-	-	-	-	1.52
Rumen Degradable Protein	-	-	-	-	-	-	3.4
ADF	5.4	9.9	5.9	8.7	6.5	9.6	46.6
aNDF	13.8	16.1	14.0	15.0	14.1	17.1	-
Lignin	1.36	3.02	1.26	2.29	1.30	2.51	63.8
Ethanol Soluble CHO (ESC-Sugar)	10.2	10.7	10.1	9.6	5.0	7.6	4.6
Starch	47.9	29.4	43.5	35.9	47.5	38.0	1.5
Crude Fat	3.21	6.60	3.66	7.24	5.86	4.79	1.49
Ash	6.05	6.00	6.06	6.81	5.72	7.41	9.79
Calcium	1.02	0.86	0.87	1.03	0.78	1.62	0.25
Phosphorus	0.41	0.43	0.44	0.43	0.39	0.59	0.06
Magnesium	0.23	0.28	0.22	0.31	0.26	0.28	0.16
Potassium	0.85	0.93	0.95	0.86	0.78	0.81	0.78
Sulfur	0.20	0.29	0.23	0.36	0.22	0.23	0.11
Sodium	0.27	0.31	0.26	0.52	0.34	0.18	0.03
Chloride	0.33	0.46	0.35	0.52	0.36	0.33	0.37
Iron (PPM)	174	177	211	209	148	367	674
Manganese (PPM)	56	43	48	67	27	68	56
Zinc (PPM)	123	54	58	150	45	70	1
Copper (PPM)	34	20	18	73	15	40	3

Calves were weighed at approximately 14 and 35 days of age and monthly thereafter. Once the average liveweight of all steers reached 550kg, (approximately 14 months of age) all animals were transported to Teys, Wagga Wagga, for slaughter.

Carcases were graded through the MSA system and samples taken to test shelf-life (lipid oxidisation, colour and consumer preference) and eating quality.

From arrival at the study calf rearing facilities until weaning at approx. 42 days, SDT groups were provided 2L ProfeLAC GOLD (Premium Australian Dairy Powders including Bio-Active Proteins plus BioPAK GOLD Premix containing Vitamins (A, D3, E, C, K3, B1, B2, B3, B5, B6, B9, B12, Biotin, Choline), Organic Minerals (Zinc, Iron, Manganese, Copper, Cobalt, Iodine, Selenium), Acidifiers, Amino-V8, Betaine, Host Specific, Live Yeast, Prebiotics (Celmanax, Inulin, MOS & β-glucans, Free Flow Agent, Antioxidant, Aromatic Flavour and medicated with Bovatec (Lasalocid 120mg/kg) (Provico Rural, VIC, Australia) milk replacer twice per day at a rate of 125g milk powder/L.

The ProfeLAC GOLD milk was selected as a high-quality Australian made milk replacer for both SDT and ADT treatments. This differed substantially from the INZAR milk formulation utilised by INZAR in Europe which could not be imported due to quarantine regulations. Similar ingredient issues also made local manufacture of the INZAR milk formula impractical. The twice daily 2 litre feeding rate was that recommended for INZAR milk and less than the twice daily 3 litre feeds recommended for the ProfeLAC GOLD.

In the same timeframe, ADT (Australian Treatment Diet) groups were provided 3L ProfeLAC GOLD (Provico Rural, VIC, Australia) milk replacer twice per day at the same rate of 125g milk powder/L. In line with the SDT feeding guidelines (INZAR Nutrición Animal, Zaragoza, Spain) calf management system. Pre-starter concentrates (Table 3) were supplied to both groups in troughs within each pen from day 0 to 24, in addition to milk feeding. Ad libitum wheaten straw was provided to all calves throughout the study.

All feed for this study was manufactured at Ambos Stockfeeds (Young, NSW, Australia) in 20kg bags. Each new batch of feed was feed tested at Cumberland Valley Analytical Services (Pennsylvania, United States), a laboratory used extensively by Scibus in other research due to the high analytical standards, by wet chemistry analysis, and the wheaten straw by NIR. The NIR equations were developed by Cumberland Valley Analytical Service's in-house chemistry data. The wet chemistry methodology was as follows: DM of forages (Goering and Van Soest 1970), DM of grains, mixed feeds, concentrates, and by-products (Method 930.15; AOAC, 2000), NDF with the addition of amylase and sodium sulfite (Van Soest, Robertson et al. 1991), acid detergent fiber (ADF; Method 973.18; AOAC, 2000), ash (Method 942.05; AOAC, 2000), lignin (Goering and Van Soest 1970) with modifications described at https://www.foragelab.com/Resources/Lab-Procedures (Cumberland Valley Analytical Services 2021), crude fat (Method 2003.05; AOAC International, 2006), crude protein (CP; Method 990.03; AOAC, 2000) using a Leco FP-528 Nitrogen Combustion Analyzer (Leco Corporation, St. Joseph, MO), soluble CP (Krishnamoorthy, Muscato et al. 1982), starch (Hall 2009), sugar (DuBois, Gilles et al. 1956), a complete mineral panel (Method 985.01; AOAC, 2000; using a Perkin Elmer 5300 DV ICP, Perkin Elmer, Shelton, CT), sulfur was analysed by a Leco S632 Sulfur Combustion Analyzer (Leco Corporation) using Leco Organic Application Note "Sulfur and Carbon in Plant, Feed, Grain, and Flour" Form 203-821-321, 5/08-REV1, and chloride was analysed by sample extraction with 0.5% nitric acid followed by potentiometric titration with silver nitrate using a Brinkman Metrohm 848 Titrino Plus (Brinkmann Instruments Inc., Westbury, NY).

Table 4. Percentage inclusion of bulk ingredients for each feed ration for Spanish (SDT) and Australian (ADT) diet treatments.

	SDT				ADT				
	Milk Pre-Starter	Pre-Starter A	Starter	Finisher	Milk Pre-Starter	Pre-Starter B	Starter	Finisher A	Finisher B
Days	**<D7**	**<D24**	**<95**	**>95**	**<D7**	**<D24**	**<95**	**95 - 310**	**>310**
Constituent	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
KwikStart Bovine Colostrum	95.0				95.0				
Whey Powder sweetened	3.0	3.5	3.5		3.0		9.3		
Calcium carbonate	1.5	1.5	1.5	1.2	1.5				
NaCl	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.4	0.4
ProFeLAC Gold milk replacement (125g / L)		twice daily				twice daily			
Maize		38.0	38.0	28					
Wheat Grain		16.0	16.0			15.0	22.3	14.8	40.2
SoybeanML47.5Solv		14.0	14.0	9.4		15.0	9.3	4.9	4
Barley grain		13.0	13.0	48.7		29.9	32.6	49.6	30
PAPINBEEF COMPLEX-S EXCEL (INZAR)		6.0	6.0						
D.D.G. Wheat		5.0	5.0						
Oat hulls		2.5	2.5						
ECONOBEEF (INZAR)				2					
Lupins						10.0	9	12.4	11
Whey						3.0			
MagSulf7H2O						0.2	0.2	0.2	0.2
Sugar Sucrose						3.0	2.8	1.2	1.2
Fat Coconut						2.0	1.9		
Canola Meal Expeller				8		18.0	13	10	6
Limestone						1.5	1.4	2.4	2.5
Veg Oil (tallow spec)						2.0		1.5	1.5
Megalac				1.3				0.8	0.7
Canola Oil				1					
Fermenten							2.3		
CRU RT Premix							0.2	0.07	0.07
Flaveco 5							0.2		
Celmanax							0.4	1.2	1.2
Calcium Phosphate							1.5		1.5

Starter diet (Table 3) was provided to calves in troughs twice per day – once in the morning and evening, or as required from days 25-94, ensuring that troughs were not empty at any point. The finisher diets (Table 3) were introduced to the calves at day 95 and continued until the end of the study. Once calves were fed the starter feed, feed residuals were minimal. Feed offered per pen was recorded at each feeding session. Feed residuals per pen were weighed and recorded when troughs were cleaned periodically as needed.

The SDT diets were designed to have an attractive aroma to promote high intake of feed from introduction to the calves. The pre-starter diet (Quick-start) was formulated for high digestibility and palatability, with an attractive flaked consistency to maximise interest and intake. The pre-starter/starter diet was similarly designed to aid in palatability and digestibility. Additionally, it is intended to aid in the adaptation of high intakes of carbohydrate-rich feed, as would be provided by the finisher diet which is intended for use in a feedlot setting, allowing steers to reach average daily gains (ADG) of 1.45kg/day (INZAR Nutrición Animal, 2020, personal communication). Each of these formulations were designed to contain a higher concentration of starch and lower protein (Table 3) than the ADT diets, the exact formulation of the SDT concentrate components is commercial in confidence.

As the SDT diets were formulated for use in Europe, select ingredients could not be sourced and were replaced in the starter and finisher diets for this study. This included the substitution of oat hulls and palmitic acid for soybean and canola oil in both diets, and the exclusion of maize, molasses and urea in the finisher diet to meet the overall balance of the original diet formulation. Additional rumen modifiers including Celmanax (Arm and Hammer, New Jersey, USA), Flavomycin (International Animal Health Products, NSW Australia) and Fermenten (Arm and Hammer, New Jersey, USA) were used in ADT formulations, whereas the SDT formulations contained no antibiotic rumen modifiers. The final formulations were discussed and approved by INZAR Nutrición Animal, Spain.

The SDT diet ingredients were processed through a hammermilling process producing a somewhat finer particle size distribution than specified by INZAR. The ADT starter diets were offered in a crumble or pelleted form, with the crumble found to be preferred by the study animals.

Percentage inclusions for bulk ingredients in each diet are shown in Table 4.

3.3.3. Animal management and disease monitoring

All management protocols were in accordance with INZAR management guidelines and in compliance with NSW Animal Care and Ethics requirements. The calves were castrated by elastic castration rings and disbudded by an electric hot iron with analgesia (Lignocaine 2%; Meloxicam) and sedation (Xylazine) between 28 and 35 days of age. They were vaccinated against clostridial diseases and leptospirosis with Ultravac 7 in 1 (Zoetis, Australia) at approximately 35 days old and received a booster shot 40 days after the initial vaccination. The calves also received Pestigard (Zoetis, Australia) at approximately 100 days of age against Bovine Pestivirus and Bovilis MH + IBR (MSD Animal Health, Australia) at approximately 45 and 65 days respectively for the first and second dose, to guard against *Mannheimia haemolytica* (MH) and Infectious Bovine Rhinotracheitis (IBR). Animals were treated with an anthelmintic drench (Maximus® Boehringer Ingelheim, North Ryde, Sydney) prior to entering feedlot pens at the CSU Ruminant Research Facility.

Throughout the trial period, calves were monitored at least twice daily. Any physical ailments or behavioural abnormalities were noted by staff, and a veterinarian was called if required. Staff treated diseases according to study protocols and as summarised in Table 5. Rectal temperatures were taken when clinical disease was suspected and prior to administration of any treatment. All interventions were recorded.

The incidence and severity of scouring was of particular interest during the Pre-Starter and Starter diet phases as it can be associated with the onset of acidosis. The severity of scouring was recorded based on an adaptation of the scoring system on a scale of 1 to 5. In this study, a score of one was indicative of extremely liquid faeces, with bubbles and some grain content. A score of five represented stool samples with formed mounds. Data was collected on all calves during phase 1 and 2 of the trial.

Table 5. Diseases presenting throughout experimental trial, associated disease descriptions and treatments.

Disorder	Description	Treatment(s)
Bloat	Visible swelling of rumen	Neosulcin Flunixil
Infection	Inclusive of systematic or targeted infection on a particular body area including eyes, throat, navel and horns	Conjunctivitis: Ampiclox application Retropharyngeal abscess: Propercillin Omphalitis: Trisoprim and Meloxicam Horns: Ampiclox purple spray Other infection: Tolfejec, Alamycin, Metacam, Engemycin
Inflammation and/or pain	Avoidant of sensory pressure on a particular area of the body	Trisoprim Propercillin Flunixin
Lameness and other leg related injuries	Visible signs of pain that affect movement or open wound injuries sustained on legs	Propercillin Meloxicam Trisoprim Alamycin LA
Respiratory	Rapid exhalation of air from the lungs, causing wheezing or coughing.	Draxxin Tolfejec Micotil
Salmonellosis	Combination of bloody scours, fever and dehydration.	Trisoprim
Scours	Lose or water faecal matter. Scour score less than 3	Scourban Neo-Sulcin Scour Tablets Trisoprim-480 Amoxyclav 500 in conjunction with electrolytes (1-2L)

3.3.4. Statistical analysis – Spanish trial

The statistical analysis was performed using Stata.15™ (StataCorp LLC, College Station, Texas). A linear mixed model using the lmer package was used to determine the effect of each treatment group on final performance measures (BW, ADG, DMI, FCR). The model included random intercepts for calf ID and pen number to account for the clustering of observations within calves and within pens. Age in days was also considered as a covariable. Fixed effects of the treatment diets (SDT, ADT) and day of weight sampling were analysed. Welch's t-test was performed to determine the significance of scour scoring events to test the hypothesis that treatment group would influence disease occurrence. Significance was declared at $P < 0.05$.

Statistical analysis of consumer sensory results was performed in alignment with earlier cohorts as outlined in 3.5, with the only exception being that only the animal ID was used as a random effect.

3.4. Carcase grading

For all cattle for all growth pathway trials and high carbohydrate diet comparison, post slaughter HSCW was measured in kilograms at the end of the processing chain for each animal. All animals were dressed to AUS-MEAT standards and placed in the chiller within 1 hour 20 minutes of slaughter. At this point, plant staff took pH and temperature declines on all carcases. Declines were measured by a combined pH/temperature meter (TPS Ionode, Brisbane Australia) taking sequential pH and temperature readings at hourly intervals for 5 hours from chiller entry. A final pH was taken during MSA grading prior to boning. A further pH reading was taken during sample fabrication at CSU to establish whether the grading pH represented an ultimate value. Grading of the veal carcases was carried out by qualified MSA graders the following day, 18 to 24 hours post-mortem, with ribbing at the plant's normal veal site, that is the 5th/6th rib interface.

For beef carcase groups (target 300kg HSCW) ribbing followed individual processor procedures ranging from 10/11 rib (Greenham Gippsland, Moe, VIC) to 12/13 rib (Teys Cargill, Wagga Wagga, NSW and Bindaree Food Group, Bindaree, NSW).

The following carcase characteristics were measured for all veal and beef carcases: sex, dentition (the number of permanent incisor teeth), hump height of the *rhomboideus* muscle measured in millimetres at the point of greatest hump width (AUS-MEAT, 2005), eye muscle area (EMA) of the *longissimus thorasis et lumborum* measured at the carcase quartering site using a standardised AUS-MEAT grid in square centimetres (AUS-MEAT, 2005), P8 Fat depth, (AUS-MEAT score), subcutaneous rib fat measured in millimetres at the quartering site (AUS-MEAT, 2005) as utilised in MSA grading, marbling scores in AUS-MEAT (0 to 6 scale in units of 1) and MSA (100 to 1200 scale in units of 10) in the *longissimus thorasis et lumborum* muscle (AUS-MEAT, 2005) at the ribbing site, fat colour score (0-9) (AUS-MEAT, 2005), ossification score measured on a scale between 100 and 590 in increments of 10 based on the degree of calcification in the spinous processes as well as the shape and colour of the ribs (AUS-MEAT, 2005) (MLA, 2007), ultimate pH of the *longissimus thorasis et lumborum* using a pH meter (AUS-MEAT, 2005), and fat and meat colour measured using AUS-MEAT standard colour chips.

3.5. MSA consumer sensory testing protocols

3.5.1. Principles applicable to all cooking methods

Detail of the development of the MSA untrained consumer protocol development are reported by Watson et.al (Watson, Gee et al. 2008) with detailed protocol application for fabrication of consumer samples and individual cooking methods described in the accessory publication (Meyer, Todt et al. 2010)(2008c) and subsequent protocols. More recent MSA cooking protocols for grill sous-vide (GSV) and Texas BBQ (TBQ) were utilised, and an additional schnitzel (SNZ) protocol developed during the project in recognition that veal schnitzel is a common commercial marketing form of cooking for veal cuts.

In line with previous studies, the protocols to collect, describe and record cuts from carcases with related abattoir processes, to segregate individual muscle portions, to fabricate consumer samples from portions, to pack and age samples and subsequent cooking and serving were described, and applied, in detail as described further in the accessory publication "MSA sensory testing protocols (2008)" and the later protocols for GSV, TBQ and SNZ.

The MQ4 score are the primary data used to compare sensory results within the dairy beef study and to relate these to existing beef breed data. The current (2022) weightings of 0.3 Tenderness, 0.1 Juiciness, 0.3 Flavour and 0.3 Overall Satisfaction were applied for all dairy beef samples as were the standard MSA cut-offs of 45.5 for unsatisfactory, 63.5 for 3*, and 76.5 for the boundary between 4* and 5*. Both the raw (unclipped) and clipped means are stored in the AUSBlue database and linked to all recorded animal, slaughter, grading and objective measurement data that relates to each individual sample. The individual 10 consumer scores are stored separately and utilised in consumer evaluation studies.

The protocol details are incorporated in software to enable efficient high-volume testing and to reduce error potential. Important features are the automated allocation of a unique 4 digit alpha numeric "EQSRef" code to every consumer sample, these being allocated during the trial design process and automated linkage from animal to carcase, to carcase side, to cut, to muscle, to muscle position.

For all cook methods, a standard "Pick" arrangement in which 60 consumers are utilised to evaluate 42 samples, 6 Link and 36 test samples being 6 within each of 6 products, was adopted with each pick producing 420 sensory results, 10 per sample evaluated and 7 per consumer participant. To further reduce potential confounding the 10 consumers testing each sample (5 pairs of 2) are different for every sample. Further, the 5 portions (halved during serving) of each test sample are served in 5 of the possible 6 serving orders (2 to 7 with Link only served first) and served within 5 blocks of 12 consumers to ensure they are widely dispersed.

3.5.2. Project sensory 'pick' design

As summarised in 3.5.1, execution of each pick is controlled by software which ensures each non-link sample is dispersed evenly across 5 subsets of 12 consumers within the 60 utilised in a pick and served in 5 presentational orders between 2 and 7. Each product, which contain 6 samples each, are fully balanced across the 6 presentational order positions and via a 6x6 Latin square to ensure all products are served equally before and after each other product.

The selection and allocation of product however requires manual selection of samples and allocation into products utilising software routines, in essence a matrix as depicted in Fig. 3.

Figure 3. Example of sample allocation within a Pick (Pick 1564)

	LINK	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
1	CSU Striploin	Outside Flat	Chuck	Rump 131	Rump 231	Oyster Blade	Tenderloin
2	CSU Striploin	Outside Flat	Knuckle Cover	Rump 131	Rump 231	Oyster Blade	Tenderloin
3	CSU Striploin	Topside	Knuckle Cover	Blade	Rump Cap	Striploin	Spinalis
4	CSU Striploin	Topside	Chuck Tender	Blade	Rump Cap	Striploin	Spinalis
5	CSU Striploin	Eye Round	Chuck Tender	Knuckle Eye	Rump 131	Striploin	Cube Roll
6	CSU Striploin	Eye Round	Chuck Tender	Knuckle Eye	Rump 131	Striploin	Cube Roll

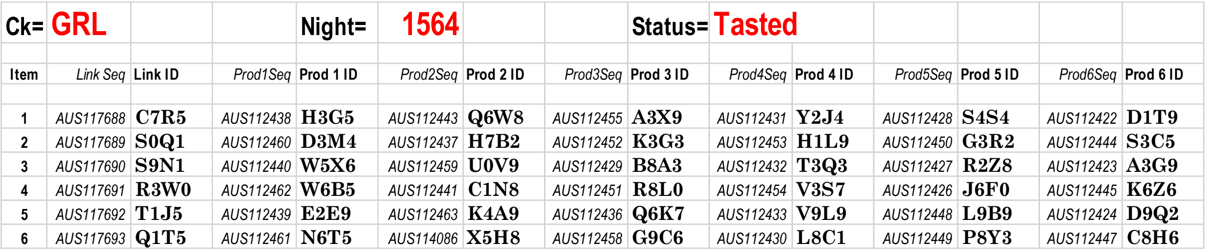
In the Pick 1564 example (Fig. 3), the six link products selected are all striploin from CSU collections and expected to be of mid eating quality, ideally around 50 MQ4 and therefore likely to have consumers start their scoring midway across the sensory scales. This ensures that there is the opportunity to score far lower or higher for subsequent samples served. All other Pick 1564 products are derived from dairy trial veal samples. In this Pick the expected range of eating quality is established by assigning different cuts with Product 1 expected to score lowest and Product 6 highest.

Every consumer is served a link sample first, Link 1 served to consumers 1 to 10, Link 2 to consumer 11 to 20 and so on to Link 6 served to consumers 51 to 60.

Each consumer is then served one sample from each product with these served in a different order as designated by the five 6x6 Latin squares within the pick.

The actual allocation is made within the software by selecting a sample line within the database with the unique sequence and EQSRef sample identifiers transferred by the software to the pick creation table as shown in Fig. 4 for pick 1564.

Figure 4. Example of actual allocation within AUSBlue software.



Ck=	GRL			Night=	1564			Status=	Tasted					
Item	*Link Seq*	Link ID	*Prod1Seq*	Prod 1 ID	*Prod2Seq*	Prod 2 ID	*Prod3Seq*	Prod 3 ID	*Prod4Seq*	Prod 4 ID	*Prod5Seq*	Prod 5 ID	*Prod6Seq*	Prod 6 ID
1	*AUS117688*	**C7R5**	*AUS112438*	**H3G5**	*AUS112443*	**Q6W8**	*AUS112455*	**A3X9**	*AUS112431*	**Y2J4**	*AUS112428*	**S4S4**	*AUS112422*	**D1T9**
2	*AUS117689*	**S0Q1**	*AUS112460*	**D3M4**	*AUS112437*	**H7B2**	*AUS112452*	**K3G3**	*AUS112453*	**H1L9**	*AUS112450*	**G3R2**	*AUS112444*	**S3C5**
3	*AUS117690*	**S9N1**	*AUS112440*	**W5X6**	*AUS112459*	**U0V9**	*AUS112429*	**B8A3**	*AUS112432*	**T3Q3**	*AUS112427*	**R2Z8**	*AUS112423*	**A3G9**
4	*AUS117691*	**R3W0**	*AUS112462*	**W6B5**	*AUS112441*	**C1N8**	*AUS112451*	**R8L0**	*AUS112454*	**V3S7**	*AUS112426*	**J6F0**	*AUS112445*	**K6Z6**
5	*AUS117692*	**T1J5**	*AUS112439*	**E2E9**	*AUS112463*	**K4A9**	*AUS112436*	**Q6K7**	*AUS112433*	**V9L9**	*AUS112448*	**L9B9**	*AUS112424*	**D9Q2**
6	*AUS117693*	**Q1T5**	*AUS112461*	**N6T5**	*AUS114086*	**X5H8**	*AUS112458*	**G9C6**	*AUS112430*	**L8C1**	*AUS112449*	**P8Y3**	*AUS112447*	**C8H6**

The transition from the selection of each sample based on all available data (animal, grading, muscle, ageing period etc.) to unique codes ensures that all subsequent sample management through the picking, posting, cooking and serving process is "blind". The unique alphanumeric EQSRef sample ID is assigned by software during sample fabrication and carried through to the consumer plate and questionnaire labels, also printed from software generated files. After double entry, the sensory scores are then processed through the software and added to the animal and grading data to produce the final data for analysis.

3.5.3. Allocation of samples to picks

To fully meet the experimental objectives and to ensure that these data were able to be reliably and robustly linked to current samples and further additions in the AUSBlue database for development or adjustment of prediction models several pick requirements had to be met. Primary requirements were:

1. Evaluation of potential cut (muscle) eating quality relationships within veal carcases, further examined within breed and sex categories. It was hypothesised that given the young age of veal slaughter that muscle relationships could differ, due to connective tissue being less developed or less cross-linked in secondary cuts relative to the more mature cattle from which prediction models have been constructed.

2. Examination of post-mortem ageing and cooking method impact on veal cuts in relation to older animals of beef or dairy breed type.
3. Comparison of growth path and feed type outcomes and, if necessary, adjustment for region, breed and backgrounder or finisher impacts.
4. Robust comparison of consumer response to sensory samples derived from dairy versus beef breeds after adjustment for standard MSA grading criteria including marbling, ossification, hump height, rib fat, ultimate pH and ageing. The hypothesis to be checked was that for mature animals, differences were likely to be small or insignificant.
5. Ensure that potential consumer group or pick variation was not confounded requiring sufficient mixing of dairy and other MSA trial samples in a significant number of picks.

Tables 6 to 10 display the distribution of veal and dairy beef muscle samples from groups across consumer picks within each cooking method together with brief explanation of the allocations. There is further connection between cooking methods due to paired samples from individual muscles within bodies being cooked by alternative methods.

The Beef Improvement Nucleus (BIN) groups include Northern BIN (Brahman, Santa Gertrudis and Droughtmaster), Hereford BIN (Hereford and Angus x Hereford) and Angus samples which are extensively linked through other MSA data.

Table 6. Distribution of veal and dairy beef consumer samples across groups and muscles within group for grill and grill sous-vide cooking methods

GRL	GROUP																				GSV	Notes
PICK	**536.1**	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**558.1**	**558.2**	**558.3**	**558.4**	**567.1**	**567.2**	**567.3**	**571.1**	**572.1**	**573.1**	**573.2**	**580.1**	**586.1**	**Total**	**571.1**	
1551			12																	**12**		Link veal to beef (Qld Road & Rail)
1552			12																	**12**		Link veal to beef (Qld Road & Rail)
1553			12																	**12**		Link veal to beef (Qld Road & Rail)
1554			12																	**12**		Link veal to beef (Qld Road & Rail)
1555			12																	**12**		Link veal to beef (Qld Road & Rail)
1556			10	2																**12**		Link veal to beef (Qld Road & Rail)
1557			9	2	2															**13**		Link veal to beef (Qld Road & Rail)
1558			12																	**12**		Link veal to beef (Qld Road & Rail)
1559			10		2															**12**		Link veal to beef (Qld Road & Rail)
1560			10		2															**12**		Link veal to beef (Qld Road & Rail)
1564	35		1																	**36**		Test Veal cut relationships within body
1565	35		1																	**36**		Test Veal cut relationships within body
1566	36																			**36**		Test Veal cut relationships within body
1567	35	1																		**36**		Test Veal cut relationships within body
1568	36																			**36**		Test Veal cut relationships within body
1569	36																			**36**		Test Veal cut relationships within body
1570	36																			**36**		Test Veal cut relationships within body
1571	36																			**36**		Test Veal cut relationships within body
1572	36																			**36**		Test Veal cut relationships within body
1580	2	13		11	10															**36**		Link groups to Veal cut relationships
1581	2	12		12	10															**36**		Link groups to Veal cut relationships
1582	4	14		10	8															**36**		Link groups to Veal cut relationships
1583		17	1	9	9															**36**		Link groups to Veal cut relationships
1584	1	16	1	9	9															**36**		Link groups to Veal cut relationships
1585		20	2	7	7															**36**		Link groups to Veal cut relationships
1586		16		10	10															**36**		Link groups to Veal cut relationships
1587		13	4	11	8															**36**		Link groups to Veal cut relationships
1592			3																	**3**		Link veal to beef (Northern & Southern)
1593			4																	**4**		Link veal to beef (Northern & Southern)
1609			20																	**20**		Link veal to beef (Young dairy bulls)
1610			15																	**15**		Link veal to beef (Young dairy bulls)
1611			24																	**24**		Link veal to beef (Northern & Southern)
1612			24																	**24**		Link veal to beef (Northern & Southern)
1613			24																	**24**		Link veal to beef (Northern & Southern)
1614			22																	**22**		Link veal to beef (Young dairy bulls)
1617			8																	**8**		Link veal to beef (Young dairy bulls)
1618			11																	**11**		Link veal to beef (Young dairy bulls)
1638			6																	**6**		Link veal to beef (Young dairy bulls)
1640			6																	**6**		Link veal to beef (Young dairy bulls)
1641			6																	**6**		Link veal to beef (Young dairy bulls)
1642			3																	**3**		Link veal to beef (Young dairy bulls)
1645			6																	**6**		Link veal to beef (Young dairy bulls)
1684						5	5		10											**20**		Link dairy to beef (Refed cull beef cows)
1685						5	10		5											**20**		Link dairy to beef (Refed cull beef cows)
1686						5	10			5										**20**		Link dairy to beef (Refed cull beef cows)
1687						10			10											**20**		Link dairy to beef (Refed cull beef cows)
1688						5	5		10											**20**		Link dairy to beef (Refed cull beef cows)
1689						5		5	10											**20**		Link dairy to beef (Refed cull beef cows)
1690						5	5		10											**20**		Link dairy to beef (Refed cull beef cows)
1691						10		5	5											**20**		Link dairy to beef (Refed cull beef cows)
1692						10		12												**22**		Link dairy to beef (Refed cull beef cows)
1693						10		14												**24**		Link dairy to beef (Refed cull beef cows)
1694						10		14												**24**		Link dairy to beef (Refed cull beef cows)
1695						10		14												**24**		Link dairy to beef (Refed cull beef cows)
1696						10		13												**23**		Link dairy to beef (Refed cull beef cows)
1697						10		14												**24**		Link dairy to beef (Refed cull beef cows)
1698						5	5	14	5	5										**34**		Link dairy to beef (Refed cull beef cows)
1699						5		14	5											**24**		Link dairy to beef (Refed cull beef cows)
1700						5		14	5											**24**		Link dairy to beef (Refed cull beef cows)

Table 6. continued

GRL	**GROUP**																				**GSV**	**Notes**
PICK	**536.1**	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**558.1**	**558.2**	**558.3**	**558.4**	**567.1**	**567.2**	**567.3**	**571.1**	**572.1**	**573.1**	**573.2**	**580.1**	**586.1**	**Total**	**571.1**	
1701			6																	**6**		Link veal to beef (Bulls & beef cows)
1702			3																	**3**		Link veal to beef (Bulls & beef cows)
1703			4																	**4**		Link veal to beef (Bulls & beef cows)
1769						4	3		4	1										**12**		Link dairy to beef (Qld Road & Rail)
1770						2			2	2										**6**		Link veal to beef (Bulls & beef cows)
1771							2		4											**6**		Link veal to beef (Young dairy bulls)
1776									8											**8**		Link veal to beef (Young dairy bulls)
1826											6	1								**7**		Link dairy to beef (Wagyu & beef cows)
1852																					6	Grill Sous-Vide evaluation
1853																					6	Grill Sous-Vide evaluation
1854																					6	Grill Sous-Vide evaluation
1864	13	11	1	2	4						3	2								**36**		Link groups to Veal cut relationships
1865	6	10	10	4	6															**36**		Link groups to Veal cut relationships
1866	6	9	13	2	6															**36**		Link groups to Veal cut relationships
1867																					12	Grill Sous-Vide evaluation
1868			9			5	5	1			5	1	2	3						**31**		Link Veal to dairy & dry aged cow beef
1869			8			5	5			1		5		3	4					**31**		Link Veal to dairy & dry aged cow beef
1870			6						5				5	6	4					**26**		Link Veal to dairy & dry aged cow beef
1871			1			7	5		1		5		1		6					**26**		Link Veal to dairy & dry aged cow beef
1872						5	2		5		4	5		3	2					**26**		Link Veal to dairy & dry aged cow beef
1873						6			4		1		8	3	4					**26**		Link Veal to dairy & dry aged cow beef
1874						5			6		1	5		9						**26**		Link Veal to dairy & dry aged cow beef
1875						10	5		5		5	5		6						**36**		Link Veal to dairy & dry aged cow beef
1876						5			8		6	6	5	6						**36**		Link Dairy groups
1877									4		7	5		15	5					**36**		Link Dairy groups
1878							3		6		5	5	5	3	4					**31**		Link dairy to dry aged cow beef
1879									4		5	5		15	6		1			**36**		Link Dairy groups
1880									1	1	5	7		15	6					**35**		Link Dairy groups
1881						1			2		10	7	5	3	3					**31**		Link dairy to dry aged cow beef
1882											14	13	5		4					**36**		Link Dairy groups
1883											5	3	3	3	6	2	4			**26**		Link dairy to dry aged cow beef
1884														15	5	2	4			**26**		Link dairy to dry aged cow beef
1885											3	2	2		3					**10**		Link dairy to beef (Qld Road & Rail)
1886												2	2	8						**12**		Link dairy to beef (seaweed trial)
1887														12						**12**		Link dairy to beef (seaweed trial)
1888														12						**12**		Link dairy to beef (seaweed trial)
1893														5	4			8	12	**29**		Link Spanish to other dairy & beef
1894														5	4			6	12	**27**		Link Spanish to other dairy & beef
1917														3	4				12	**19**		Link Spanish to other dairy & beef
1918														3	4			3	12	**22**		Link Spanish to other dairy & beef
1919														3	4			3	16	**26**		Link Spanish to other dairy & beef
1920												3		3	2	4	2		16	**30**		Link Spanish to other dairy & beef
1921														6	2	4	2		16	**30**		Link Spanish to other dairy & beef
1922														6	2	4	2	3	16	**33**		Link Spanish to other dairy & beef
1923														6	2	4	2		16	**30**		Link Spanish to other dairy & beef
1924														6	2	4	2	3	16	**33**		Link Spanish to other dairy & beef
1925															4	6	2		16	**28**		Link Spanish to other dairy & beef
1926															5	6	2	3	15	**31**		Link Spanish to other dairy & beef
1927															4	6	2		16	**28**		Link Spanish to other dairy & beef
1928															4	6	2		16	**28**		Link Spanish to other dairy & beef
1929															4	6	2		16	**28**		Link Spanish to other dairy & beef
1930															4	6	2		16	**28**		Link Spanish to other dairy & beef
1931															4	7	2	3	18	**34**		Link Spanish to other dairy & beef
NA	2		2	1				21	1		3		2	19	165	169	6		11	**402**		Not yet allocated to Picks
Total	**357**	**152**	**366**	**92**	**93**	**180**	**70**	**155**	**145**	**15**	**93**	**82**	**45**	**205**	**286**	**236**	**39**	**32**	**268**	**2911**	**30**	

Table 7. Distribution of veal and dairy beef consumer samples across groups and muscles within group for roast cooking method.

RST	**GROUP**										**Notes**
PICK	**536.1**	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**567.1**	**567.2**	**567.3**	**Total**	
1573	26	3	7							**36**	Test Veal cut relationships within body
1574	27	3	6							**36**	Test Veal cut relationships within body
1575	26	3	7							**36**	Test Veal cut relationships within body
1576	27	3	6							**36**	Test Veal cut relationships within body
1577	28	2	6							**36**	Test Veal cut relationships within body
1578		18	6							**24**	Link to young dairy bulls
1579	26	2	8							**36**	Test Veal cut relationships within body
1615		1	14							**15**	Link to young dairy bulls
1616			27							**27**	Link to young dairy bulls
1619		25	2	6	3					**36**	Test Veal cut relationships within body
1620			24	6	6					**36**	Test Veal cut relationships within body
1621		17	4	6	9					**36**	Test Veal cut relationships within body
1622		15	16	5						**36**	Test Veal cut relationships within body
1623		8	7	16	5					**36**	Test Veal cut relationships within body
1624			10							**10**	Link to young dairy bulls
1625			8							**8**	Link to young dairy bulls
1626		6	1	6	8					**21**	Link to young dairy bulls
1627			5		18					**23**	Link to young dairy bulls
1628			3		12					**15**	Link to young dairy bulls
1629			16							**16**	Link to young dairy bulls
1630			18	1						**19**	Link to young dairy bulls
1631		16	1							**17**	Link to young dairy bulls
1632			4	14	7					**25**	Link to young dairy bulls
1633			19	2						**21**	Link to young dairy bulls
1634		7	1		8	1				**17**	Link to young dairy bulls
1635			8	5						**13**	Link to young dairy bulls
1636			3	6	6					**15**	Link to young dairy bulls
1637			7	11	4					**22**	Link to young dairy bulls
1725						4	4		2	**10**	Link to beef cows & BIN cattle
1726						6	2	2	2	**12**	Link to beef cows & BIN cattle
1727						3	2	2	2	**9**	Link to beef cows & BIN cattle
1728						4	4	2	2	**12**	Link to beef cows & BIN cattle
1729							2	2	2	**6**	Link to beef cows & BIN cattle
1732						4	2	2	2	**10**	Link to beef cows & BIN cattle
1733						10	4	2		**16**	Link to beef cows & BIN cattle
1734						6	2	2	2	**12**	Link to beef cows & BIN cattle
1736							2	2	2	**6**	Link to beef cows & BIN cattle
1737						7	2	2	2	**13**	Link to beef cows & BIN cattle
1738						4	1	2		**7**	Link to beef cows & BIN cattle
1739			3			6	1	4		**14**	Link to beef cows & BIN cattle
1740		2	22			4	2			**30**	Link to refed beef cows
1741			24			2	2	2		**30**	Link to refed beef cows
1742			19		1	4	4	2		**30**	Link to refed beef cows
1743			22	3		7		4		**36**	Test Veal cut relationships within body
NA			2	1						**3**	Not yet allocated to Picks
Total	**160**	**131**	**336**	**88**	**87**	**72**	**36**	**32**	**18**	**960**	

Table 8. Distribution of veal consumer samples across groups and muscles within group for slow cooking method.

SC2	GROUP					Notes
PICK	**536.1**	**536.2**	**536.4**	**536.5**	**Total**	
1779	8				**8**	Linked to young dairy bull & BIN
1780	13	1	1		**15**	Linked to young dairy bull & BIN
1781	12				**12**	Linked to young dairy bull & BIN
1782	2	2	1	1	**6**	Linked to young dairy bull & BIN
1784	4				**4**	Linked to young dairy bull & BIN
1786	4				**4**	Linked to young dairy bull & BIN
1787	12				**12**	Linked to young dairy bull & BIN
1788	1				**1**	Linked to young dairy bull & BIN
1792	9				**9**	Linked to young dairy bull & BIN
1793	1	4	3	3	**11**	Linked to young dairy bull & BIN
1794	1				**1**	Linked to young dairy bull & BIN
Total	**67**	**7**	**5**	**4**	**83**	

Table 9. Distribution of veal and dairy beef consumer samples across groups and muscles within group for schnitzel and Texas BBQ cooking methods.

SNZ	GROUP										TBQ	Notes
PICK	**536.1**	**536.2**	**536.3**	**536.4**	**536.5**	**567.1**	**567.2**	**567.3**	**573.2**	**Total**	**536.1**	
1662											6	Tested with range of beef types
1669											6	Tested with range of beef types
1670											6	Tested with range of beef types
1856	10	6	4	5	5	2	2	2		**36**		Linked veal and dairy groups
1857	13	4	3	9	5	1		1		**36**		Linked veal and dairy groups
1858	13	5	2	9	4	1	1	1		**36**		Linked veal and dairy groups
1859	13	5	2	9	4	1	1	1		**36**		Linked veal and dairy groups
1860	6	4	12	4	4	2	2	2		**36**		Linked veal and dairy groups
1861	12	5	6	3	4	2	2	2		**36**		Linked veal and dairy groups
1862	9	9	7	2	3	3	3			**36**		Linked veal and dairy groups
1863	13	7	5	2	3	3	3			**36**		Linked veal and dairy groups
NA			65						15	**80**		Not yet allocated to picks
Total	**89**	**45**	**106**	**43**	**32**	**15**	**14**	**9**	**15**	**368**	**18**	

Table 10. Summary of project slaughter groups and sample fabrication.

Group	Samples	Group Notes
536.1	691	18 head subset of Veal calves representing breed x backgrounder groups within MSA compliance. 38 to 40 individual samples fabricated per body from 19 muscles
536.2	335	48 head subset of Veal calves representing breed x backgrounder groups. 7 samples fabricated per body from 11 priority muscles
536.3	808	183 head subset of Veal calves from breed x backgrounder groups outside current MSA rib fat or pH standards. 5 samples collected from 3 cuts with ageing variations
536.4	228	25 head of external Veal heifer calves for linkage with average of 9 samples from 11 cuts
536.5	216	25 head of external Veal bull calves for linkage with average of 9 samples from 11 cuts
552.1	252	Selected subset of 36 head from 60 head (21 Beef, 7 Holstein, 8 Jersey x Holstein or Limo) of project dairy and beef from backgrounders fed at Charlton Feedlot for 193 days with 7 samples taken from Cube Roll and Topside primals.
558.1	70	14 Jersey steers fed at Charlton Feedlot for 234 days after backgrounding at 3 locations. 5 samples fabricated from each.
558.2	155	Subset of 20 Holstein steers fed at Charlton Feedlot for 234 days after backgrounding at 3 locations. Average of 8 samples from each.
558.3	145	Subset of 29 Jersey x Holstein steers fed at Charlton Feedlot for 234 days after backgrounding at 3 locations. 5 samples taken from each.
558.4	15	Subset of 3 beef steers fed at Charlton Feedlot for 234 days after backgrounding at 3 locations. 5 samples taken from each.
567.1	144	18 Holstein steers finished on grass and supplement in Gippsland. 8 samples from each. (Cohorts of veal and Charlton kills).
567.2	128	16 steers (9 Holstein and 7 Beef) finished on grass and supplement in the Riverina (Cohorts of veal and Charlton kills). 8 samples from each.
567.3	72	9 Holstein steers finished on grass and supplement in the Western District. 8 samples from each. (Cohorts of veal and Charlton kills).
571.1	235	68 head from Cohort 2 fed at Associated Feedlot after backgrounding. 3 to 4 samples from each.
572.1	286	143 head from Cohort 2 fed at Tullimba Feedlot after backgrounding. 2 samples from each.
573.1	236	123 head from Cohort 2 fed at Tullimba Feedlot after backgrounding. 2 samples from each.
573.2	54	15 head final Cohort 2 fed at Tullimba and processed at Bindaree. 3 to 4 samples from each.
580.1	32	10 head Cohort 2 finished on grass. 3 to 4 samples each.
586.1	268	67 head "Spanish and Australian" feed program. 4 samples from each.
588.1	66	26 head. Cohort 2 finished on grass, 3-4 samples each.
Total	**4436**	

3.5.4. Cooking Protocols

The sensory design principles are utilised within all MSA cooking methods with only the cooking method and associated standardised control procedures varied. Grill, Grill Sous-Vide, Roast, Slow Cook, Stir Fry, Schnitzel and Texas BBQ cooking methods were utilised within the project.

For grill, slow cook, stir fry, and schnitzel cooking, the 60 consumers who evaluated each pick were seated and served in 3 sittings of 20 whereas a single sitting of 60 was utilised for roast and Texas BBQ.

In brief, the grill procedure utilises a high-capacity clam shell grill (Silex S165) to cook 7 rounds of 10 steaks. Cooking temperature is set for the top and bottom plates and the cooking process is controlled by referencing a count up timer and time sheet that, from start to completion of the 7th round, dictates the time in seconds to load steaks, close the lid, take off steaks, rest and serve after halving with the 10 steaks serving 20 consumers.

The grill sous-vide method was utilised on paired samples to the standard grill protocol. Grill sous-vide samples were retained in their round sheets (Vacuum bags) and immersed in a 62°C water bath with circulation for 2 minutes 30 seconds. The vacuum bags were then removed, opened and the samples finished with a 45-second cook time on the Silex grill with a top plate temperature of 195°C and bottom plate of 210°C. Serving procedures were identical to the standard grill.

A schnitzel protocol was developed within the project recognising the widespread marketing of veal in this form. The protocol did not use crumbed product but a designated 8mm thick portion cut across the grain. The protocol was developed by modification of the MSA grill protocol with the cook time and temperatures adjusted to account for the 8mm (vs 25mm for grill) thickness. A Silex top plate temperature of 195°C and bottom plate of 210°C was specified with a total time from loading the sample to removal of 45 seconds with the top plate closed at 20 seconds. The light-weight setting was utilised and the timing between rounds set at 5 minutes to allow sufficient time for plating and serving. Plating and serving procedures were identical to grill.

The roast protocol achieved consistent doneness by removing individual roasts from a combi oven, set to 160°C on dry heat, at an internal temperature of 65°C. Roasts were ordered by size into the oven to facilitate temperature monitoring and removal. All roasts were rested for a minimum of 10 minutes prior to removal of external surfaces to produce a standard 65 x 65 x 75mm block for slicing. This size was reduced where muscle dimensions dictated but the trimming of external surfaces remained. Each trimmed block was transferred to a keeper, akin to a toast rack with 10mm tines set 1mm apart to produce a 10mm slice when a knife was run between the tines. The keeper and block were transferred to 1/9 bain-marie steamer pans held at 50°C in 4 serving bain-maries. Serving was controlled by a timing sheet with 4 individual cutters following the sheet against count up timers. As each nominated time was reached a cutter removed the designated keeper, took a fresh slice from the trimmed end, cuts the slice in two and placed each on the plates then served to the nominated two consumers.

The Texas BBQ protocol was utilised on veal brisket samples with paired samples slow cooked for comparison. The Texas BBQ protocol utilised a Green Mountain Jim Bowie model wood pellet smoker and specified standard wood chip blend. Briskets were trimmed and lightly seasoned with salt and pepper 14 hours before being placed fat down in the smoker (after the set point of 121°C was reached). When the brisket internal temperature reached 66°C it was removed and wrapped in heavy duty aluminium foil and returned to the smoker until reaching an internal temperature of 93°C at which point it was removed and rested for 30 minutes prior to separating the major two muscles and preparing each as 6mm slices. The slices were transferred to bain-maries and held at 50°C until served to consumers with serving sample and timing controlled by timing sheets, identical to that utilised for roasts, in conjunction with count-up timers. As for the roasts consumers were seated and served in a single 60 person session.

The slow cook protocol utilised 22 25mm x 25mm cubes for each sample. The cubes were browned in a hot frying pan (adjusted to achieve a “hiss” when raw cubes were added and to avoid smoking of oil) with 30ml of olive oil for 90 seconds then transferred to a 1/9 bain-marie pan pre-filled with 300ml of a mild broth. The broth was made up from 15 litres of water, 1400g of sliced onion, 1400g of sliced carrot, 450g of sliced celery and 70g of fine salt. The broth was held at a high simmer for 45 minutes at which point the vegetables were strained off prior to transferring 300ml to each 1/9 steamer pan. After adding the browned cubes, the steamer pot was placed in a bain-marie set at a rolling boil for 2 hours after which the steamer pan was removed and the cubes and liquid transferred to an airtight container and cooled. At the sensory venue 5 bain-maries were used to warm and hold the 42 samples at 50°C until serving. Serving was controlled by count-up timers and a timing sheet designating which sample was to be served to each consumer at each set time. Two cubes were served to each consumer for every sample.

The stir fry protocol also utilised cooking of samples prior to transfer to the sensory venue for holding and serving from bain-maries. Each sample consisted of 10 strips cut along the grain with a length of 75mm and 10x10mm cross section. The protocol utilised 3 woks, one being always washed and 2 in the cooking process, moved in succession across burners/hotplates to achieve different temperatures during a 3-minute cycle. A washed wok with 20ml of olive oil was placed on a burner at full heat at 0:00 minutes with the oil stirred at 20 seconds and meat added at 30 seconds. After 1 minute and 10 seconds (elapsed time of 1:40) cooking at full heat the wok was transferred to a second burner set at simmer heat where after 10 seconds, 20ml of a glaze was added and stirred prior to removing the wok at an elapsed time of 3 minutes to cool resulting in a cooking time of 2 minutes 30 seconds in total. The glaze, designed to have a neutral taste impact but keep the sample moist, was made up from 1 litre of water, 62ml of balsamic vinegar, 125ml of Kikkoman soy and 125ml of arrowroot powder.

As for the slow cook procedure the cooked stir fry strips were transferred to sealed containers to cool then transferred chilled to the sensory venue where they were transferred to 1/9 steamer pans and held for serving in 4 bain-maries set at 50°C. Serving was controlled by count-up timers and a timing sheet designating which sample was to be served to each consumer at each set time. Two strips were served to each consumer for every sample.

4 Results

4.1. Evaluation of dairy steers from grass and feedlot finished Low Growth and High Growth pathways

4.1.1. Veal cohort

The calves allocated to veal were slaughtered (Northern Co-Operative Meat Company Ltd., Casino, NSW) on November 26th, 2018, at an anticipated carcase weight of less than 130kg. Live weights were recorded before farm exit and average daily gain (ADG) was reported for the time (days) that the calf was present at the backgrounder. Calves were reared from the following backgrounders; backgrounder 1 (104 steers), backgrounder 2 (72 steers), and backgrounder 3 (65 steers) (Table 1). This resulted in 241 head that were assessed from 16 pods. There was 40 Jersey, 78 Holstein HJ, 73 Holstein, 24 British and 26 European cross steers, a total of 181 Dairy and 50 Beef calves.

To provide complementary data relating to bull and female sex a further 50 calves, 25 bulls and 25 heifers, were purchased from the same kill day and graded by MSA with cuts collected for MSA conjoint sensory testing. These data were included as an extension to the project to facilitate potential development of an MSA veal grading model. A key question related to the need for a distinct veal prediction model rather than an extension of the existing beef model structure.

MSA research personnel recorded pH and temperature decline data on all veal carcases from chiller entry and full MSA grading data the following morning (18 to 24 hours post slaughter).

4.1.2. Feedlot cohort 1

A total of 257 head were transferred to a feedlot (Charlton Feedlot Pty Ltd., Yeungroon, Vic) and inducted. Numbers of steers per backgrounder were 112 steers from the Western Districts of Victoria, 68 steers from Gippsland, and 73 steers from Southern NSW. The steers were trucked to the feedlot in late November and inducted on December 5th 2018. They were backgrounded on grazing oats prior to being placed on feed in the lot on December 27th 2018. There were 4 head recorded as deaths at the feedlot. This resulted in 249 head that were assessed from 16 pods. There were 38 Jersey, 75 HxJ, 81 Holstein, and 55 Beef steers that provided data for the final analyses. There were 5 feedlot exits and kill dates between 9th July to 19th August 2019, that reflected stage of finish or premature removal of 3 head. MSA grade and decline data were measured as described above for the veal cohort. Additionally, carcases from the final feedlot kill (n = 197) also had extensive health records, recorded by meat inspection staff at the plant.

4.1.3. Feedlot cohort 2

A total of 69 head that were backgrounded at a feedlot (Associated Feedlot, Mathoura, NSW) from 3 pods after transfer from Gippsland and remained in the feedlot for finishing were slaughtered at 110 days on feed. One steer (Jersey) died at the feedlot. There were 8 Jersey, 22 HxJ, 20 Holstein, 6 British, and 12 European steers that provided data for the final carcase analyses.

A total of 288 head were transferred to a second feedlot (Tullimba, Torryburn, NSW) and inducted. Numbers of steers per backgrounder were 69 steers each from 2 properties in the Western Districts of Victoria, 76 steers from Gippsland, and 74 steers from Southern NSW. The steers were trucked to Tullimba in 2 batches, in late June 2020 and late September 2020 and were inducted for 21 days prior to being changed to a feedlot ration. There were 4 head recorded as deaths at the feedlot (1 x British, 1 x Holstein, 2x European breed), 3 head were removed for slaughter early (Holstein), and 2 were sent to the local saleyard (2 x European breed) as they were within a withhold period at the time of their scheduled slaughter. This resulted in 279 head that were assessed from 12 pods at slaughter. Data from a steer originally recorded as a Jersey was removed as this animal was a stag and was identified as a Holstein at slaughter. There were 42 Jersey, 76 HxJ, 81 Holstein, 22 British, and 51 European steers that provided data for the final carcase analyses.

In total, across both feedlots, there were 4 kill dates between the 9th November 2020 and the 24th June 2021, that reflected stage of finish or premature removal of 3 head. Of these, the first 3 kills totalling 334 head were processed at Teys abattoir in Wagga NSW and the final 15 at Bindaree abattoir in Inverell NSW. The combined total assessed at slaughter from cohort 2 was 347 head from 15 pods. MSA grade and decline data were measured as described above for the veal cohort and cohort 1.

4.1.4. Grass fed and finished cohorts

For the grass-finished cohort 1, there were 4 Holstein pods containing a total of 37 head that were slaughtered (Greenham Gippsland Pty Ltd., Moe, VIC) on Dec 11th, 2019, in the grass-fed cohort. These were raised within the initial HG pods and were randomly allocated to the grass finished pods. There were 3 different finishers where they were fed pasture, when available and were supplemented with concentrates, if necessary, to maintain growth rates with a target of 1.2 kg/d. The final backgrounding weight was taken on the same dates as the veal calf exits and before transfer of one pod of steers to another backgrounder.

For grass-finished cohort 2, there were 4 pods containing 36 head that were slaughtered (Teys Australia, Wagga Wagga, NSW) on August 12th, 2021, and November 18th, 2021, in the grass-fed cohort. These were raised within the initial HG pods and were randomly allocated to the grass pasture finished pods. There were 4 different finishers where they were fed pasture, when available and were supplemented with concentrates, if necessary, to maintain growth rates with a target of 1.2 kg/d.

4.1.5. Growth Characteristics of low and high growth pathway grass-fed dairy steers

This report details the growth and carcase characteristics of the steers killed. After initial investigation, we considered that a LG strategy for Jersey steers would be unlikely to yield an economically viable response. This meant that the results were best analysed and presented as comparisons for the LG pods, the HG pods, and the evaluations of treatment and breed were made with the HxJ, Holstein, and Beef breeds. For cohort 1, there was a limitation in accessing beef steers at 12 weeks of age. Consequently, the beef steers entered the pods at a heavier weight and slightly older and variable age. The severe drought of 2018 limited access to beef calves and 55 less than planned were enrolled. Drought also influenced finishing strategies, as steers entered the feedlot at a younger age and lighter weight (256 vs 400kg). For cohort 2, beef steers were sourced and entered backgrounding at approximately 12 weeks of age and the study design requirements were met resulting in 15 pods, 103 Holstein, 109 HxJ, 52 JJ, 32 British and 67 Euro steers.

4.1.6. Veal calves

For the veal kill, there were 16 pods, 71 LG steers (Table 11) and 171 HG steers that provided carcase data. Due to one condemned carcase, only 170 of the HG group provided carcase data (Table 13). As birthdate was not available for the beef steers, this precluded specific daily gain analysis other than for the backgrounding period where days on feed was known. The evaluation of the effects of growth path, breed, and their interaction was therefore reported for 179 head in 12 pods. An additional 25 bull and 27 heifer veal calves were added to the consumer sensory analysis post hoc for purposes of internal comparison. All the 25 bull calves were sourced from the processor. The 27 heifer calves were sourced from the processor (10 head) and from one of the producers in the trial (17 head). The heifer calves sourced from the producer were raised alongside their veal steer cohort.

Table 11. Estimated marginal means ± SE for the effects of breed on performance for low growth path for veal calves. Models include the fixed effects of breed and the random effects of identity within a pod and backgrounder farm (N = 71).

	Breed			Significance (*P*-value)	
	Holstein x Jersey N = 20	**Holstein N = 37**	**Beef N = 14**	**Breed**	**Days[1]**
Average daily gain on farms (kg/d)	0.75 ± 0.06^{a}	0.78 ± 0.06^{a}	1.65 ± 0.10^{b}	**<0.001**	0.950
Backgrounder farm exit weight (kg)[1]	213.5 ± 9.17^{a}	247.4 ± 8.62^{b}	289.9 ± 13.05^{c}	**<0.001**	0.039
Carcase weight (kg)	93.4 ± 6.62^{a}	112.0 ± 6.45^{b}	138.9 ± 8.087^{c}	**<0.001**	0.067
Dressing percentage	43.3 ± 1.44^{a}	45.0 ± 1.43^{b}	48.0 ± 1.51^{c}	**<0.001**	0.072
Hump height (mm)	36.3 ± 1.32^{a}	36.0 ± 1.22^{a}	42.9 ± 1.95^{b}	**0.003**	0.039
Eye muscle area (cm^{2})	16.7 ± 2.41^{a}	17.2 ± 1.50^{a}	29.2 ± 2.68^{b}	**<0.001**	0.136
P8 fat depth (mm)	0.98 ± 0.14^{a}	0.93 ± 0.12^{a}	1.78 ± 0.22^{b}	**0.003**	0.349
Rib fat (mm)	0.02 ± 0.14^{a}	0.07 ± 0.13^{a}	1.44 ± 0.23^{b}	**<0.001**	0.575
Marble (Score 1 to 1190)	166.2 ± 13.26^{a}	201.7 ± 11.88^{ab}	223.2 ± 20.06^{b}	**0.013**	0.676
Fat colour score (0-9)	1.37 ± 0.1^{a}	1.21 ± 0.14^{a}	1.99 ± 0.23^{b}	**0.027**	0.839
Ossification (Score 100 to 590)	101.1 ± 0.63^{a}	100.3 ± 1.85^{a}	102.0 ± 1.01^{a}	0.431	0.423
Ultimate pH	5.87 ± 0.06^{a}	5.78 ± 0.06^{a}	5.84 ± 0.08^{a}	0.340	0.879
Colour (Score 1 to 6)	5.27 ± 0.22^{a}	5.15 ± 0.20^{a}	4.29 ± 0.33^{b}	**0.018**	0.231

[1] Days of backgrounding significant;

[a-d] Superscripts that differ denote significance P <0.05

The LG path for HxJ (0.75 ± 0.06 kg/d) and Holstein calves (0.78 ± 0.06 kg/d) did not differ in ADG (Fig 5.) but had lower growth rates than the Beef calves (1.65 ± 0.10 kg/d). Similar results were identified in the HG calves as the Jersey (0.88 ± 0.06 kg/d), HxJ (0.93 ± 0.05 kg/d), and Holstein (0.98 ± 0.05 kg/d) all had similar ADG, whereas the Beef (1.25 ± 0.06 kg/d) had a greater ADG (Table 13). While days at the backgrounder did not influence ADG in the LG group (Table 11), it did influence results for the HG group (Table 13). There was an interaction between treatment and breed, as the HG beef performance was lower than the LG Beef, while the HxJ and Holsteins with higher growth had greater ADG when compared to the LG pathway for HxJ and Holsteins (Table 13, Fig. 5).

The considerable differences in actual growth performance relative to the desired comparison of a 0.7 (LG) and 1.2 (HG) kg/day, and in particular the inverse actual result in the Beef comparison, demands some caution in result interpretation across the breed groups as does the higher backgrounder entry weights of the beef (185kg) and older age. Table 12 displays the backgrounder entry weight data by breed group with the Beef and Jersey differing significantly from the Holstein and Holstein x Jersey.

Table 12. Backgrounder entry weight (kg) within breed group (number inducted differs from number exited).

	BREED			
	Beef	**Holstein**	**Holstein x Jersey**	**Jersey**
	N= 55	**N = 74**	**N = 111**	**N = 40**
Average	184.8	119.7	111	42.0
Min	82.5	82.0	32	24.0
Max	293.0	234.0	287	103.0
Sdev	44.3	28.5	46	16.7

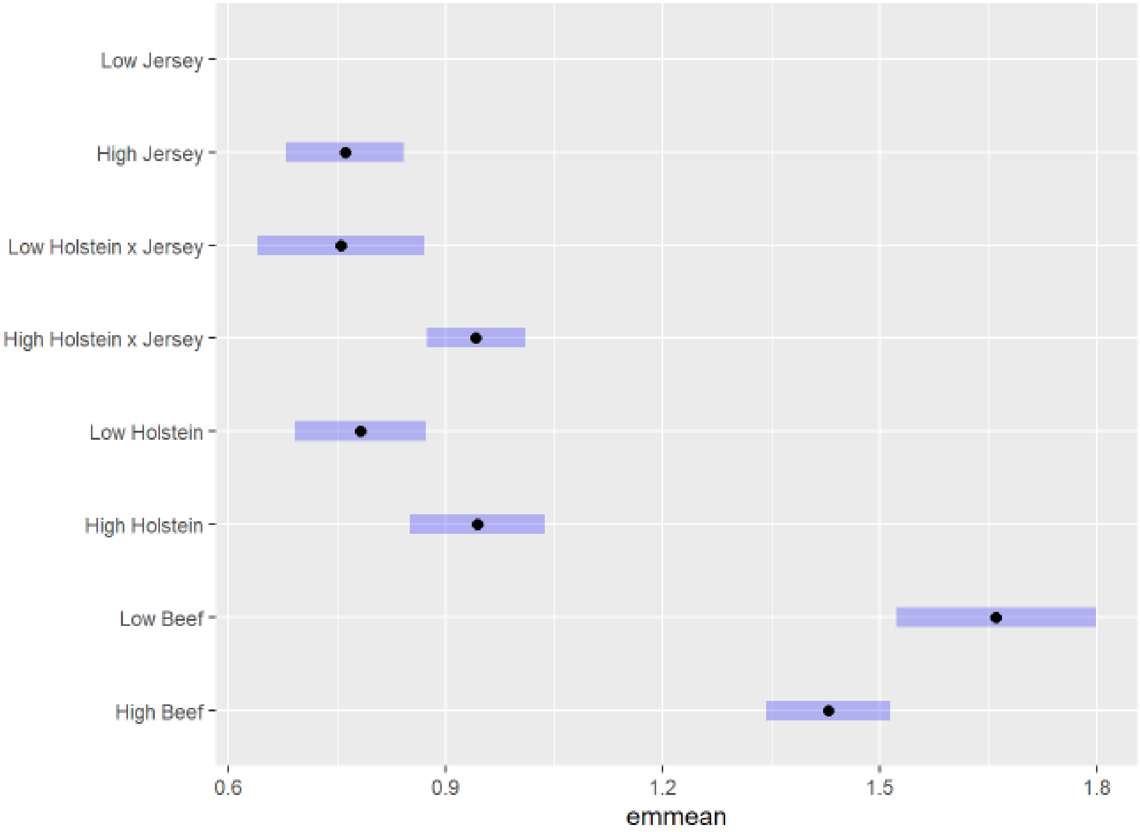
Table 13. Estimated marginal means ± SE for the effects of breed on performance for high growth path steers for veal calves. Models include the fixed effects of breed and the random effects of identity within a pod and backgrounder farm (*N = 170 otherwise N = 171).

	Breed				***P*-value**	
Outcome	**Jersey N = 40**	**Holstein x Jersey N = 58**	**Holstein N = 36**	**Beef N = 36**	**Breed**	**Days^{1}**
Average daily gain on farms (kg/d) ^{1}	0.88 ± 0.06^{a}	0.93 ± 0.05^{a}	0.98 ± 0.05^{a}	1.25 ± 0.06^{b}	**<0.001**	<0.001
Backgrounder farm exit (kg)	191.7 ± 8.23^{a}	226.5 ± 6.60^{b}	267.6 ± 7.55^{bc}	279.6 ± 9.21^{c}	**<0.001**	0.117
Carcase weight (kg)*	78.4 ± 4.50^{a}	105.4 ± 3.62^{b}	123.4 ± 4.11^{c}	132.8 ± 5.05^{c}	**<0.001**	0.129
Dressing percentage	41.1 ± 0.44^{a}	44.4 ± 0.33^{b}	46.0 ± 0.40^{c}	47.3 ± 0.50^{d}	**<0.001**	0.394
Hump height (mm)*	31.6 ± 1.12^{a}	35.9 ± 0.85^{b}	37.8 ± 1.00^{b}	43.6 ± 1.28^{c}	**0.003**	0.008
Eye muscle area (cm^{2})*	12.90 ± 2.69^{a}	18.54 ± 2.53^{ab}	21.43 ± 2.50^{c}	30.70 ± 2.98^{d}	**<0.001**	0.782
P8 fat depth (mm) *	0.98 ± 0.14^{a}	0.98 ± 0.14^{a}	0.93 ± 0.12^{a}	1.78 ± 0.22^{b}	**0.003**	0.349
Rib fat (mm)*	0.73 ± 0.20^{ab}	0.47 ± 0.17^{a}	0.41 ± 0.19^{a}	1.21 ± 0.22^{b}	**<0.001**	0.295
Marble (Score 1 to 1190)*	227.2 ± 16.75^{b}	204.8 ± 13.57^{ab}	178.8 ± 11.88^{a}	235.3 ± 18.73^{b}	**0.002**	0.433
Fat colour score (0-9)	1.05 ± 0.13^{a}	1.35 ± 0.09^{b}	1.31 ± 0.12^{b}	1.92 ± 0.15^{c}	**0.002**	0.095
Ossification (Score 100 to 590)*	100.3 ± 0.90^{a}	101.4 ± 0.60^{a}	101.8 ± 1.85^{ab}	104.2 ± 1.05^{b}	**0.087**	0.230
Ultimate pH*	5.78 ± 0.03^{a}	5.75 ± 0.02^{a}	5.76 ± 0.03^{a}	5.79 ± 0.04^{a}	0.564	0.199
Colour (Score 1 to 6)*	5.27 ± 0.22^{a}	5.27 ± 0.22^{a}	5.15 ± 0.20^{a}	4.29 ± 0.33^{b}	**0.018**	0.231

^{1}Days of backgrounding significant
$^{a-d}$ Superscripts that differ denote significance P <0.05

All three breed LG groups differed for final exit weight and number of days backgrounded influenced that result. Beef steers weighed > 42kg more than the Holsteins, while the Holsteins weighed almost 34kg more than the HxJ (Table 11). For the HG groups, Beef calves weighed an additional 9kg compared to the Holsteins, the Holsteins weighed 41kg heavier than the HxJ and the HxJ weighed nearly 35kg more than the Jersey calves (Table 13). The HG steers weighed 22kg more than the LG at exit and there was no interaction of treatment and breed; however, the two Beef groups differed by approximately 3kg in exit weight, whereas the treatment groups differed by 22kg and 16kg for the HxJ and Holstein steers, respectively (Table 14) with the LG pathway beef steers having higher ADG than the HG treatment. Differences in estimated marginal means for ADG by breed are shown in Fig. 5.

Figure 5. Estimated marginal means (emmean) plot for the effects of breed and growth path on the average (ADG) daily gain at the backgrounder for veal calves. Models include the fixed effects of breed, growth path and the random effects of identity within a pod.



4.1.7. Carcase characteristics of dairy and beef breeds for veal

Carcase weight differed among the LG breed groups with The Beef steers carcase weights (138.87 ± 8.09kg) weighed nearly 27kg more than Holsteins and the Holsteins (112.03 ± 6.45kg) weighed almost 18kg more than HxJ (93.42 ± 6.62kg) (Table 11). Similarly, carcase weight was lower (78.38 ± 4.50kg) for Jersey steers than for HxJ (105.43 ± 3.26kg) which were, again, lower than the Holstein steers (123.40 ± 4.11kg) or Beef steers (132.81± 5.05kg) for the HG groups (Table 13). Treatment effect was significant with HG steers having approximately 8kg more carcase weight than LG; however, the two Beef groups differed by approximately 1kg in carcase weight, whereas the treatment groups differed by 12kg and 10kg for the HxJ and Holstein steers, respectively (Table 14). The average weights of both treatment groups approached the target of not greater than 130kg carcase weight.

The previously observed lesser dressing percentage for Holstein steers compared to beef-breed steers, (carcase weight yield from live weight), (Buege 1988) was observed (Tables 11 and 13) although this may have been influenced by relative carcase weight and fatness at slaughter. Overall, all four breeds differed in dressing percentage (Table 13). Specifically, the LG Holstein steers had a greater dressing percentage than the HxJ steers, although the difference was only 1.65 (Table 11). For the HG group the Jersey dressing percentage was low being 41.12 and 3.32% lower than HxJ steers, 4.89% lower than Holsteins, and 6.17% lower than Beef steers (Table 13).

While treatment did not alter dressing percentage, the interaction of treatment with breed was significant (Table 14). Nour, Thonney et al. (1983) found small-frame Angus steers yielded 5.28 percentage units more carcase than Holstein steers at the same shrunk live weight. We found a 3.0% difference for the Holstein steers compared with the beef steers in the LG group and only a 1.7% difference in the HG calves (Table 14). Factors that account for this reduced yield may be increased proportion of gut (Nour, Thonney et al. 1983, Taylor and Murray 1991), reduced muscling score (Kauffman 1998), reduced subcutaneous fatness (Nour, Thonney et al. 1983), increased liver size, and increased proportion of intra-abdominal fat as mesenteric and omental fat (Taylor and Murray 1991) together with relative animal maturity at time of slaughter. The further commercially relevant relationship of lean meat or primal cut yield to live or carcase weight was not able to be measured in the veal or heavier subsequent slaughter groups but is believed an important aspect to pursue in determining processing economics as it might be expected that the difference in P8 and rib fat cover between the beef and dairy carcases would relate to different trim levels and boning room yield.

The hump height differed with breed with Beef having the highest, and Jersey the lowest hump height (Tables 11, 13 and 14). There was no significant effect of treatment on hump height, but length of time at the backgrounder was a significant covariable. The EMA was markedly different for the Beef steers in both the high and low growth path groups being higher than all other breeds. Whilst the HxJ and Holsteins did not differ with either treatment, these were both higher than the Jersey (Tables 11 and 13). Treatment differences were not significant (Table 14). The Beef pods had approximately 11 greater square cm of EMA than the Holstein and HxJ. Holsteins may have had more muscle weight at a constant rib eye area, reflecting a longer rib section for Holstein carcases than from European breed carcases (Nour, Thonney et al. 1981). Since the *longissimus thoracis et lumborum*, as a percentage of total muscle, did not differ among breeds (Berg and Butterfield 1976), the rib eye area of Holsteins has been suggested to be smaller because of a longer *longissimus thoracis et lumborum* (Schaefer 2005).

The P8 fat content of all breeds and in all growth paths was low. In the LG pods, the HxJ and Holstein steers did not differ in fat depth with 0.98 ± 0.14 and 0.93 ± 0.12mm, respectively, while the Beef steer pods were greater with 1.78 ± 0.22mm P8 fat depth. The HG Beef steers also had 1.78 ± 0.22mm and differed from the other three breeds that had <1mm of P8 fat (Table 13). The P8 fat depth therefore differed with breed, but not treatment (Table 14).

Rib fat results were very similar to the P8 fat results with low rib fat in the HxJ and Holstein pods and greater in the beef pods in both the low and high growth pathways (Tables 13 and 14). However, there was no difference between the Jersey and Beef pods in rib fat (Table 13) and no effect of growth path treatment (Table 14). Marbling scores were, as expected, low and consistent with the fat measures. However, there was a higher marbling score (223.23 ± 20.06) for the beef pods on the LG treatment than for the HxJ pods (166.19 ± 13.26).

The Holstein LG pods were intermediate and did not differ to the other breed groups. Interestingly, the HG Holstein group had the least marbling (178.81 ± 11.88) and differed to the Jersey (227.24 ± 16.75) and Beef (235.30 ± 18.73) pods with the HxJ (204.79 ± 13.57) being similar to all other breed pods. The effect of breed was significant, but treatment and the interaction of breed and treatment were not, despite both the HG Holstein and Beef having lesser marbling than the LG pods and the HxJ group having greater marbling with increased growth. Overall, the fat colour was low, being <2; however, for the LG calves, the highest fat colour score was in the Beef steers (Table 14). In the HG pods, interestingly fat colour was higher for the beef steers than all other breeds. The HxJ and Holsteins were also higher than Jersey steers, which had a score of 1 (Table 13). There was no effect of treatment on fat colour (Table 14).

The anticipated higher fat colour for the Jersey (Barton and Pleasants 1993, Tian, Pitchford et al. 2010) was not evident, possibly reflecting differences in grazing patterns as intake of carotenoids in grass will influence fat colour. Given, the higher ADG of the Beef steers and higher fat colour, it suggests that these may have been better adapted to grazing than the dairy breeds after weaning by being retained on their dams on pasture and the higher fat colour may indicate greater pasture intake.

Ossification scores were low for all pods, as expected with steers of similar age, and did not differ with breed or treatment (Tables 11, 13 and 14). The mean ultimate pH for all pods was above pH 5.7 and did not differ with breed for either the high or low pod analyses (Tables 11 and 13). However, the effect of treatment was to reduce the pH by 0.08 units to 5.74 ± 0.03 (Table 14). Meat colour score was higher for all the dairy breed pods than the Beef pods for all analyses but did not differ among dairy breeds or with treatment (Tables 11, 13 and 14).

4.1.8 Ancillary bull and heifer calves purchased for evaluation in conjunction with project steers

Additional calves were purchased from the abattoir to provide MSA data to assist with MSA veal modelling of sex, the summary data are shown in Table 15. The 31 purchased bulls comprised 25 Holsteins sourced by the abattoir from a major northern Victorian calf rearer and a further 6 high *Bos-indicus* content calves purchased in the Lismore area close to the abattoir. The 23 heifers similarly included two sources being 13 beef breed heifers sourced in the Riverina from one of the rearers in the project which were fed the HG diet and a further 10 purchased in the Lismore saleyard.

As shown these groups were similar to the beef, Holstein and Holstein x Jersey groups from the main project. The bull group had a greater hump height value than the project steers despite similar carcase weight whereas the heifers were slightly heavier and more ossified on average than the project means (Table 15). No on-farm data was available for these groups.

Table 14. Estimated marginal means ± SE for the effects of treatment[1] and breed on calves raised for veal performance. Models include the fixed effects of treatment group, breed, their interaction, and the random effects of identity within a pod and farm (N = 179).

	Treatment		Holstein x Jersey		Holstein		Beef		Significance (*P*-value)		
Outcome	Low N = 71	High N = 108	Low N = 20	High N = 37	Low N = 36	High N = 37	Low N = 14	High N = 23	Breed (B)	Treatment (T)	B×T
Average daily gain on farms (kg/d)[1]	1.01 ± 0.05	1.08 ± 0.05	0.74 ± 0.07	0.95 ± 0.06	0.85 ± 0.06	1.00 ± 0.06	1.57 ± 0.09	1.35 ± 0.07	**<0.001**	0.214	**<0.001**
Backgrounder farm exit (kg) [1]	248.0 ± 8.18	260.1 ± 7.81	212.9 ± 10.20	233.0 ± 8.98	244.7 ± 9.34	260.4 ± 9.28	293.8 ± 12.15	291.1 ± 9.99	**<0.001**	0.036	0.225
Carcase weight (kg)	112.9 ± 5.46	120.7 ± 5.30	93.1 ± 6.36	105.1 ± 5.81	110.0 ± 5.43	120.4 ± 5.93	140.2 ± 7.29	139.3 ± 6.27	**<0.001**	**0.011**	0.171
Dressing percentage	45.2 ± 0.86	46.1 ± 0.81	43.3 ± 0.92	44.8 ± 0.85	44.8 ± 0.90	46.0 ± 0.88	48.1 ± 0.99	47.7 ± 0.88	**<0.001**	0.184	**0.028**
Hump height (mm)[1]	37.8 ± 0.89	38.2 ± 0.81	36.1 ± 1.31	35.2 ± 1.07	36.5 ± 1.14	36.7 ± 1.12	43.0 ± 1.67	44.0 ± 1.27	**<0.001**	0.619	0.497
Eye muscle area (cm^2)	21.1 ± 2.26	22.7 ± 2.07	17.1 ± 2.92	17.8 ± 2.46	18.0 ± 2.64	20.1 ± 2.59	30.4 ± 3.55	32.3 ± 2.80	**<0.001**	0.425	0.922
P8 fat depth (mm)	1.18 ± 0.11	1.23 ± 0.14	0.97 ± 0.18	1.01 ± 0.14	0.97 ± 0.15	1.00 ± 0.15	1.74 ± 0.24	1.83 ± 0.17	**0.002**	0.670	0.981
Rib fat (mm)	0.46 ± 0.16	0.66 ± 0.14	0.03 ± 0.21	0.49 ± 0.17	0.11 ± 0.19	0.33 ± 0.18	1.46 ± 0.25	1.35 ± 0.19	**<0.001**	0.231	0.170
Fat colour score (0-9)	1.46 ± 0.08	1.37 ± 0.06	1.39 ± 0.14	1.09 ± 0.10	1.12 ± 0.12	1.25 ± 0.12	2.07 ± 0.19	1.89 ± 0.13	**<0.001**	0.270	0.160
Marble (score 100 to 1190)	197.1 ± 7.36	191.6 ± 5.87	167.6 ± 13.50	190.1 ± 9.99	198.2 ± 11.17	176.0 ± 10.92	230.0 ±17.81	216.5 ± 12.77	**0.012**	0.650	0.116
Ossification (score 100 to 590)	101.9 ± 0.56	102.1 ± 0.44	101.0 ± 0.95	101.0 ± 0.70	100.3 ± 0.80	101.8 ± 0.78	101.8 ± 1.24	103.8 ± 0.89	0.198	0.109	0.451
Ultimate pH	5.82 ± 0.03	5.74 ± 0.03	5.86 ± 0.04	5.70 ± 0.04	5.77 ± 0.04	5.76 ± 0.04	5.85 ± 0.05	5.77 ± 0.04	0.635	0.001	**0.045**
Colour (score 1 to 6)	4.95 ± 0.14	4.96 ± 0.11	5.28 ± 0.22	5.55 ± 0.16	5.13 ± 0.19	5.12 ± 0.18	4.31 ± 0.29	4.03 ± 0.20	**<0.001**	0.974	0.374

[1] Days of backgrounding significant

Table 15. Summary carcase data for purchased bull and heifer veal calves

	CarcWt	P8	HUMP	EMA	RiBFat	U-Oss	U-MB	A-MC	A-FC	pH-U
BULLS (N = 31)										
Average	121.6	0.9	51.0	19.7	0.6	101.3	208.0	5.3	1.1	5.9
Min	85.2	0	35	13	0	100	110	3.0	0.0	5.6
Max	139	2	90	39	2	110	330	6.0	2.0	6.49
StDev	12.77	0.40	15.11	5.07	0.56	3.46	75.08	0.94	0.58	0.24
HEIFERS (N = 23)										
Average	140	2	43	36	3	121	244	4.9	1.8	6
Min	103.4	0	30	17	1	100	19	3.0	1.0	5.51
Max	180.4	8	60	75	5	140	360	6.0	3.0	6.33
StDev	24.04	2.18	7.52	20.06	1.19	13.92	90.70	0.92	0.89	0.20

4.1.9. MSA grade eligibility for veal calves

It should be noted that no calf from either the main experiment or supplementary kill met all MSA minimum screening requirements requiring both a rib fat of 3.0 mm or greater and an ultimate pH below 5.7 as indicated from Tables 11, 13 and 14. This established an immediate concern in regard to veal modelling as, on the basis of the project calves, together with the observed non-trial population being processed, a majority of calves would be likely to fail the current beef model criteria. Further the pH declines extended over 7 hours with a higher than acceptable number failing to reach the MSA beef required threshold of pH less than 5.71. Electrical stunning was utilised for the veal kill which is unusual in Australian beef plants and may have interacted with the decline rate but it would require a controlled study to determine if this was a factor.

The reason for the high pH readings was not established but low muscle glycogen levels could in part reflect the significant transport time for the calves moved from Victoria to Casino despite this following normal commercial protocol and including a 24-hour rest period on arrival with each group held separately in small grass paddocks with ad-lib hay and clean water. Where loin temperature at pH 6.0 could be calculated (all bodies that achieved an ultimate pH of less than 6.0 and had previous data points allowing calculation) there was also a concerning proportion of bodies with temperature at pH6 below 10°C which is considered the threshold for cold shortening and resultant severe toughening.

Table 16 displays summary pH and temperature data within breed type and indicates a possible breed/HSCW interaction.

Table 16. Summary pH and temperature parameters for MSA compliance and potential cold shortening.

Criteria	Beef	Holstein	Holstein x Jersey	Jersey		Heifers	Bulls
	N = 55	**N = 74**	**N = 77**	**N = 40**		**N = 23**	**N = 30**
Average HSCW (Kg)	128.2	117.9	102.2	83.1		139.6	121.6
Average Ultimate pH (pHU)	5.78	5.77	5.78	5.81		5.81	5.95
No below <5.71 (MSA eligible)	22	32	31	11		7	5
% below <5.71 (MSA eligible)	40.0%	43.2%	40.3%	27.5%		30.4%	16.7%
No above 5.7 (MSA Ungrade)	33	42	46	29		16	25
% above 5.7 (MSA Ungrade)	60.0%	56.8%	59.7%	72.5%		69.6%	83.3%
No with Temp @ pH 6 <10°C	6	21	26	21		0	9
% likely to be cold shortened	10.9%	28.4%	33.8%	52.5%		0.0%	30.0%
No with Temp @ pH 6 10°C >	33	46	41	13		12	9
Not Calculated	16	7	10	6		11	12

Results showed that whereas there was a consistent increase in the potential cold shortening % with reducing carcase weight this pattern is not evident for % over pHu 5.7 (Table 16), with all bar the Jersey group similar in the project cattle. In the additional purchased bulls and heifers, the cold shortening risk appears similar to the project groups but the bulls have a substantially higher % of pHu failures. Both these observations are concerning and a challenge that must be further evaluated if the MSA beef eligibility criteria were to be applied to veal grading.

A further concern would be the current 3mm minimum rib fat requirement for MSA eligibility with none of the project dairy steers and only 20% of the beef steers having the minimum 3mm or greater. Of the external bodies, all bulls failed to achieve 3mm rib fat although 56% of the heifers were compliant (and of heavier weight).

While rib fat would be expected to increase if the calves were fed to a heavier weight, closer to the 150Kg maximum for Veal classification, it appears unlikely that those with 0 or 1mm at the weights in these data would reliably achieve the 3mm target.

Both the temp@pH6 and rib fat minimum of 3mm MSA cut-off criteria relate to achieving a satisfactory chilling outcome. The 3mm is a calculated minimum to reduce temperature variation across the muscle and potential “two toning” through a large temperature gradient from the muscle exterior to interior, and the “abattoir window” specification to achieve pH6 between 12 and 35°C related to avoiding cold shortening or heat toughening. Cold shortening can create extreme toughness and heat shortening is associated with autolysis of the calpain system enzymes that can reduce ageing.

The lengthy pH decline time may be a function of light carcase weight and rapid cooling or perhaps associated with electrical stunning inputs. Conventionally an increase in stimulation time or change in settings would be made to increase the rate of pH decline, which in turn would increase the temperature at pH6 due to a reduced chill time. However, this would not counter the potentially extreme variation across muscles created due to little or no fat cover. A potential approach that is recommended for evaluation is application of a “step chill” process where chill temperature could be held above 12°C until the pH fell below 6. Given the light carcase weight and a higher initial chiller temperature this might be expected to occur relatively quickly. Once a time relationship to achieve pH6 was determined rapid low temp chilling could be activated at this point to maintain a satisfactory final chill within time requirements and related microbiological standards.

4.1.10. Consumer assessed eating quality of veal cuts

As this project was the first MSA evaluation of veal calves, earlier milk fed veal (MFV) relating to heavier (200kg HSCW and higher) calves processed as weaned at approximately 10 months of age, several important factors required evaluation including:

1. The sensory relationship of individual muscles – were these similar to older animals? One hypothesis was that there might be a lesser difference due to less connective tissue cross binding and toughness in locomotive muscles.
2. The impact of alternative cooking methods including consideration of novel methods largely only used for veal (schnitzel).
3. The impact of post-mortem ageing on muscles.
4. Potential sex impact, particularly for bulls. Given their young age, did they differ from steers or heifers?

As the project cattle were all steers a preliminary indication of heifers and bulls was enabled by purchase of the ancillary animals. Data obtained from the primary project cattle prior to slaughter and the additional bull and heifer data collected only post slaughter provided a base to establish parameters for MSA grading of veal, including any indication of further targeted work that might be required.

The cut collections were planned across 5 carcase groups to be assigned based on cattle supply (backgrounder, breed, sex) and MSA chiller assessment data. The group descriptions and related cut collection plan were briefly as follows:

- **Group 536.1** A subgroup of 18 carcases from the project balanced for breed within backgrounder from which a maximum practical number of muscles (19) were collected and as size permitted prepared by alternative cooking methods (5) and ageing periods (4).
- **Group 536.2** A subgroup of 48 carcases from the project balanced by breed within backgrounder from which a lesser number (11) of primary muscles were collected with similar cooking method and ageing treatments.
- **Group 536.3** A subgroup of 183 carcases from the project from which only 3 primary cuts were collected.
- **Group 536.4** A group of 25 external heifers with cut and ageing treatments equivalent to 536.2.
- **Group 536.5** A group of 25 external bulls with cut and ageing treatments equivalent to 536.2 and 536.4.

As the MSA pH decline, ultimate pH and other chiller assessment data became available it became obvious that most carcases would fail to meet MSA requirements for both rib fat and pH. Further there was a severe risk that many could be cold shortened. These issues were most severe within the Jersey cohort. Selection prioritised allocation of the most compliant cattle to 536.1 maintaining balanced selection within backgrounder and breed. The next most compliant calves from the project were allocated to 536.2, also balanced within backgrounder and breed, and the remaining and least MSA compliant cattle allocated to group 536.3. All external heifers were assigned to 536.4 and all bulls to 536.5.

Table 17 displays the number of samples within group by muscle and cooking method that were sensory tested. Counts of further sensory samples that remain in store are detailed in the appendix with 341 allocated to specific picks. The muscles are identified by MSA codes, the alpha characters indicating the industry cut name and the following 3 digits identifying the muscle and derived from the muscle names list in the Handbook of Australian Meat (HAM) (AUS-MEAT 2020). While the CUB045 and STR045 are indicated as separate cuts following conventional industry practise for veal they were collected as a single backstrap with cooking and ageing treatments balanced across the sides and positions treating the backstrap (*M.longissimus dorsi*) as a single 045 portion. The muscles and associated MSA codes are detailed in Fig.6.

Figure 6. Muscle names associated to MSA Codes.

Muscle Name	MSA Code	
M.triceps brachii caput longum	BLD096	
Mm. pectoralis profundus and pectoralis superficialis	BRI056	
M.serratus ventralis cervicis	CHK078	
M.supraspinatus	CTR085	
M.longissimus dorsi et thoracis	CUB045	
M.spinalis dorsi	CUB081	
M.semitendinosus	EYE075	
Mm.biceps brachii and associated muscles	FQSHIN	
Mm.flexor hallucis longus and associated muscles	HQSHIN	
M.rectus femoris	KNU066	
M.vastus lateralis	KNU099	
M.biceps femoris	OUT005	**
M.infraspinatus	OYS036	
M.biceps femoris	RMP005	**
M.gluteus medius	RMP131	***
M.gluteus medius	RMP231	***
M.longissimus dorsi et cervicis	STR045	
M.psoas major	TDR062	
M.semimembranosus	TOP073	

Within this list, the RMP005 and OUT005 (**) are different positions within the *M.biceps femoris* muscle with the RMP designating the location as the rump cap and OUT as the outside flat in conventional cutting. The RMP131 and RMP231 (***) are also both from the *M. gluteus medius* but are different muscle heads/positions that MSA consumer testing has found to have different eating quality outcomes. A combined group summary of consumer tested veal muscles by cook and ageing period is displayed in Table 17. Table 19 presents raw means of the clipped MQ4 values for the samples described in Table 18. From the raw means some trends can be observed for values between cuts, across cooking methods and ageing days although the results should be treated with some caution due to low sample numbers (Table 18).

Table 17. Number of veal consumer sensory samples tested by group, muscle and cooking method.

Group	**536.1**						**536.2**					**536.3**				**536.4**					**536.5**					**Grand Total**
Cooking Method	**GRL**	**RST**	**SC2**	**SNZ**	**TBQ**	**Total**	**GRL**	**RST**	**SC2**	**SNZ**	**Total**	**GRL**	**RST**	**SNZ**	**Total**	**GRL**	**RST**	**SC2**	**SNZ**	**Total**	**GRL**	**RST**	**SC2**	**SNZ**	**Total**	
Muscle																										
BLD096	18	6				24	12			8	20					6			6	12	6			4	10	66
BRI056			18		18	36																				36
CHK078	12	4	12			28	9	2	7		18					3		5		8	4		4		8	62
CTR085	26					26																				26
CUB045	18	6				24	12	3			15	106	23		129	12				12	10				10	190
CUB081	18					18																				18
EYE075	12	4		9		25	9	2		3	14					3			4	7	4			1	5	51
FQSHIN			18			18																				18
HQSHIN			19			19																				19
KNU066	18			14		32		3		9	12								6	6				6	6	56
KNU099	18			14		32		3		9	12								6	6				6	6	56
OUT005	24	7		19		50	15	4		8	27	68	12	21	101	16	2		12	30	9	1		7	17	225
OYS036	18			14		32																				32
RMP005	17					17																				17
RMP131	35					35	12	3			15					6				6	6				6	62
RMP231	18					18																				18
STR045	36	12				48	24	5			29	98	25		123	21	2			23	20	1			21	244
TDR062	18	6				24	12	3			15					6				6	6				6	51
TOP073	24	8		19		51	17	3		8	28	68	7	20	95	10	2		9	21	12	2		8	22	217
Grand Total	**330**	**53**	**67**	**89**	**18**	**557**	**122**	**31**	**7**	**45**	**205**	**340**	**67**	**41**	**448**	**83**	**6**	**5**	**43**	**137**	**77**	**4**	**4**	**32**	**117**	**1464**

Table 18. Number of consumer tested veal samples by muscle with related cooking method and days aged allocation.

Cooking Method	**GRL**						**RST**						**SC2**					**SNZ**						**TBQ**	**Grand**
Days Aged	**7**	**8**	**14**	**21**	**28**	**Total**	**7**	**8**	**14**	**21**	**28**	**Total**	**7**	**14**	**21**	**28**	**Total**	**7**	**8**	**14**	**21**	**28**	**Total**	**7**	**Total**
Muscle																									
BLD096	24		6	6	6	42	6					6						5		5	4	4	18		66
BRI056													18				18							18	36
CHK078	16		4	4	4	28	4			1	1	6	16	4	4	4	28								62
CTR085	26					26																			26
CUB045	39		40	40	39	158	11		5	10	6	32													190
CUB081	18					18																			18
EYE075	7		7	7	7	28	1		2	2	1	6						3		5	4	5	17		51
FQSHIN													18				18								18
HQSHIN													19				19								19
KNU066	18					18	3					3						35					35		56
KNU099	18					18	3					3						35					35		56
OUT005	18	16	32	33	33	132	2	2	7	7	8	26						11	4	19	13	20	67		225
OYS036	18					18												14					14		32
RMP005	9				8	17																			17
RMP131	23		6	6	24	59			2		1	3													62
RMP231	9				9	18																			18
STR045	50		51	49	49	199	12		10	10	13	45													244
TDR062	24		6	6	6	42	6			2	1	9													51
TOP073	33		33	34	31	131	4		4	9	5	22						16		17	15	16	64		217
Grand Total	**350**	**16**	**185**	**185**	**216**	**952**	**52**	**2**	**30**	**41**	**36**	**161**	**71**	**4**	**4**	**4**	**83**	**119**	**4**	**46**	**36**	**45**	**250**	**18**	**1464**

Table 19. Mean clipped MQ4 values for muscles tested by cooking method and days of post-mortem ageing.

Cooking Method	**GRL**						**RST**						**SC2**					**SNZ**						**TBQ**
Days Aged	**7**	**8**	**14**	**21**	**28**	**ALL**	**7**	**8**	**14**	**21**	**28**	**ALL**	**7**	**14**	**21**	**28**	**ALL**	**7**	**8**	**14**	**21**	**28**	**ALL**	**7**
Muscle																								
BLD096	60		65	64	62	62	48					48						74		67	59	69	68	
BRI056													54				54							61
CHK078	50		55	64	56	54	39			38	49	41	64	65	75	62	65							
CTR085	57					57																		
CUB045	62		66	66	68	66	42		51	54	41	47												
CUB081	76					76																		
EYE075	59		60	60	58	59	53		52	42	42	47						66		63	67	61	64	
FQSHIN													73				73							
HQSHIN													76				76							
KNU066	61					61	61					61						74					74	
KNU099	44					44	38					38						57					57	
OUT005	42	52	48	49	54	49	28	26	33	34	31	32						52	56	55	53	59	55	
OYS036	65					65												72					72	
RMP005	60				67	63																		
RMP131	60		58	58	65	61			46		69	54												
RMP231	60				65	63																		
STR045	57		60	60	63	60	47		38	46	39	42												
TDR062	75		74	70	78	75	69			64	54	66												
TOP073	45		50	49	50	49	33		37	35	43	37						58		59	63	69	62	

Of interest and deserving of further analysis in combination with other cattle classes, is the apparent eating quality improvement when both the schnitzel (SNZ) and Texas BBQ (TBQ) cooking methods were utilised. There are also extensive differences between muscles and with cooking method and ageing period within muscles as expected.

A preliminary comparison of the observed MQ4 relative to that predicted by the current MSA V2.0 beef prediction model was conducted with Table 20 displaying the mean residual values (Predicted MQ4 – Observed MQ4) by cut and cooking method. To maximise data points, model restrictions for maximum pHu was increased to 6.8 and meat colour restrictions were removed as being outside MSA grading. As TBQ and SNZ cook methods were not in the MSA V2.0 model these samples were also removed leaving 1192 samples. Overall, the mean residuals are impressive, averaging -3.5 (over prediction) given that no veal data was used in developing the model, that the bull calculation is not "turned on" In the grading model due to the restricted data available, and that a high proportion of animals were ungraded likely impacting their MQ4 results. While the overall mean is low this encompasses some variation. The mean residuals are very high for the shin slow cook and for KNU066, EYE075, OUT005 and TOP073 grills. Given these cuts are all higher connective tissue secondary cuts this could indicate a lesser difference to the primary cuts than in older cattle, although KNU099 doesn't fit the trend.

As seen in the Table 19, observed MQ4 means the roast residuals are also high and over predicted for all muscles. This is concerning and possibly represents either overcooking due to small sample size or potentially sample deterioration in storage due to the extended time between freezing after fabrication and testing, a consequence of COVID restrictions, although this potential impact was not observed for grill samples. It would appear however that current model approaches may be applicable to veal cuts after suitable adjustment.

Table 20. Residual MQ4 values (predicted MQ4 – observed MQ4) by cut and cooking method.

	COOKING METHOD			
Muscle	**GRILL**	**ROAST**	**SLOW COOK**	**ALL**
BLD096	-5.3	12.4		-3.0
BRI056			-4.2	-4.2
CHK078	-0.3	14.0	-3.3	-0.3
CTR085	-3.9			-3.9
CUB045	-6.0	13.2		-2.8
CUB081	-1.1			-1.1
EYE075	-7.9	7.5		-5.2
FQSHIN			-16.0	-16.0
HQSHIN			-14.6	-14.6
KNU066	-9.6	0.3		-8.2
KNU099	-1.2	10.7		0.5
OUT005	-8.4	11.5		-5.1
OYS036	5.4			5.4
RMP005	1.8			1.8
RMP131	-5.5	8.1		-4.9
RMP231	-4.5			-4.5
STR045	-5.1	10.8		-2.2
TDR062	-0.5	5.0		0.5
TOP073	-8.2	10.0		-5.6
ALL	**-5.5**	**10.7**	**-8.9**	**-3.5**

Linear statistical models were utilised to examine animal, muscle, and sensory relationships. These were restricted to the project cattle as these had an established cohort structure of breed and backgrounder and related live animal data. Due to low sample numbers the primary analysis was also restricted to the grill cooking method with the final numbers shown in Table 21.

Table 21. Number of calves utilised in analysis of grilled samples by breed and growth path treatment

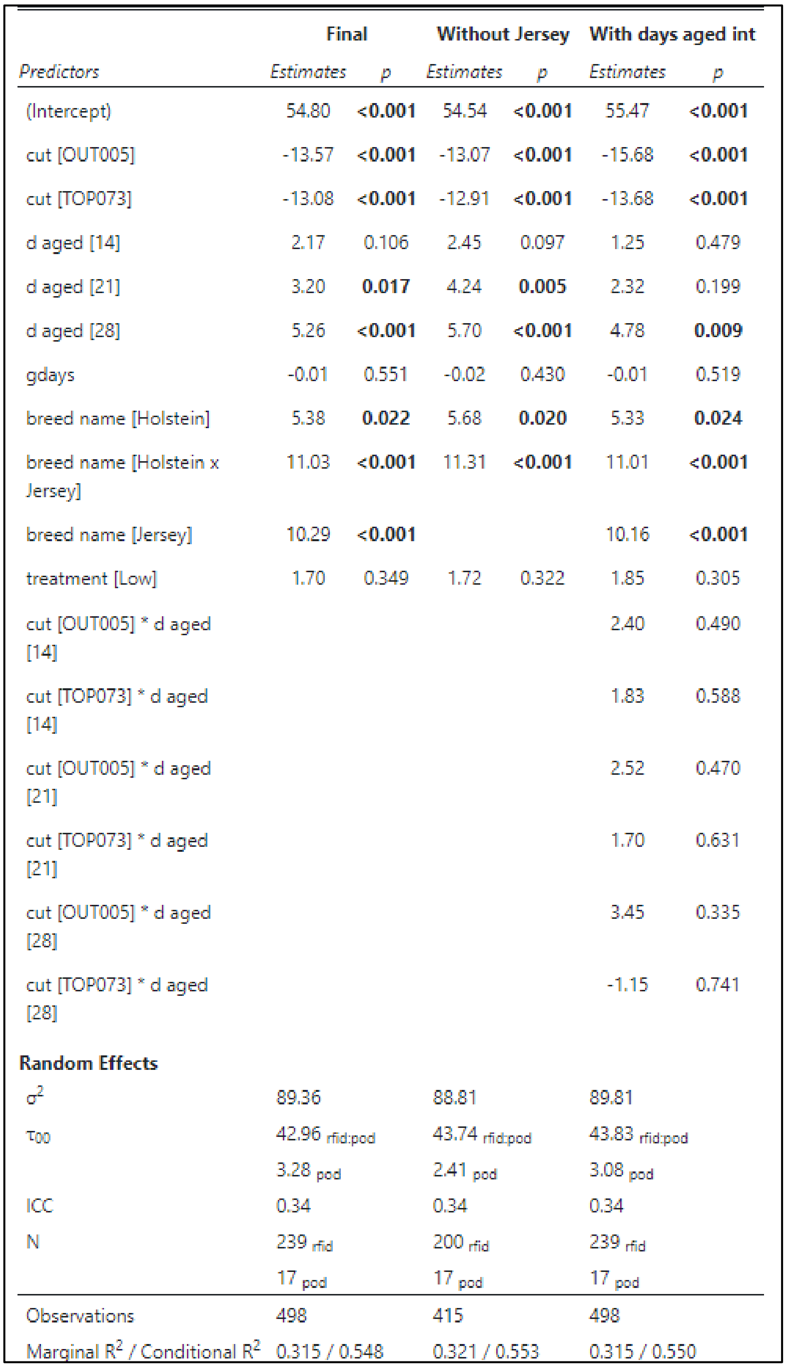
Breed type	Growth path		Total
	High	Low	
Beef	36	14	50
Holstein	36	37	73
Holstein x Jersey	58	20	78
Jersey	40	0	40
Total Head	**170**	**71**	**241**

Several models were tested with non-significant terms removed progressively. Several interactions were tested and removed including cut x position, breed x treatment (High/Low), cut x breed, cut x backgrounder days and cut x days aged. All models contained breed as a fixed effect with covariates adjusted for days at backgrounder. Random effects were Animal RFID within Pod within Backgrounder. The model output is displayed in Table 22. Analysis of the growth pathways as a single variable was not performed due to the variability of ADG associated within the growth pathways and breeds. As Jersey breed was not included in the Low Growth treatment, models were compared (see Table 22) to consider output with Jersey removed or retained. An additional model also considered an interaction between day post-mortem ageing and cut type to determine whether there were different ageing rates across the cuts. The reference intercept was beef 045 high growth pathway with only 045 (STR045 and CUB045 combined), OUT005 and TOP073 included for this analysis.

As shown in Table 22, estimates were similar across the three models with topside (TOP073) and outside flat (OUT005) muscle coefficients estimated as in the order of 13 MQ4 points (p=<0.001) below the reference 045, similar to estimates from the existing MSA V2.0 prediction model (data not shown). Marginal R2 results for each of the models indicates that removing Jersey animals (R2 = 0.32) from the analysis and considering a cut by days ageing interaction (R2 = 0.32) adds no additional value or prediction power above that of the final model.

While the growth path treatment was not significant, breed achieved significance (Holstein p=0.022, Holstein x Jersey p=<0.001 and Jersey p=<0.001). In each case the dairy breeds were estimated above the reference breed beef with the Holstein cross Jersey and Jersey breeds effect calculated as highest. Days aged also reached significance at 21 (p=0.017/0.005) and 28 days (p=<0.001) post-mortem. Estimated marginal mean plots are visualised in Fig.7 and Fig.8 provides visualisation of the MQ4 estimates for a model including a cut by breed and days aged interaction.

Table 22. Linear mixed effect models for predicting CMQ4 with cut, breed and growth pathway as fixed effects adjusted for days at the backgrounder and animal id within pod as a random intercept for veal grill samples. Estimated coefficients should be interpreted relative to the baseline level, which was breed beef, cut 045, days aged 7 and high growth pathway.



	Final		**Without Jersey**		**With days aged int**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	54.80	**<0.001**	54.54	**<0.001**	55.47	**<0.001**
cut [OUT005]	-13.57	**<0.001**	-13.07	**<0.001**	-15.68	**<0.001**
cut [TOP073]	-13.08	**<0.001**	-12.91	**<0.001**	-13.68	**<0.001**
d aged [14]	2.17	0.106	2.45	0.097	1.25	0.479
d aged [21]	3.20	**0.017**	4.24	**0.005**	2.32	0.199
d aged [28]	5.26	**<0.001**	5.70	**<0.001**	4.78	**0.009**
gdays	-0.01	0.551	-0.02	0.430	-0.01	0.519
breed name [Holstein]	5.38	**0.022**	5.68	**0.020**	5.33	**0.024**
breed name [Holstein x Jersey]	11.03	**<0.001**	11.31	**<0.001**	11.01	**<0.001**
breed name [Jersey]	10.29	**<0.001**			10.16	**<0.001**
treatment [Low]	1.70	0.349	1.72	0.322	1.85	0.305
cut [OUT005] * d aged [14]					2.40	0.490
cut [TOP073] * d aged [14]					1.83	0.588
cut [OUT005] * d aged [21]					2.52	0.470
cut [TOP073] * d aged [21]					1.70	0.631
cut [OUT005] * d aged [28]					3.45	0.335
cut [TOP073] * d aged [28]					-1.15	0.741
Random Effects						
σ^2	89.36		88.81		89.81	
τ_{00}	42.96 $_{\text{rfid:pod}}$		43.74 $_{\text{rfid:pod}}$		43.83 $_{\text{rfid:pod}}$	
	3.28 $_{\text{pod}}$		2.41 $_{\text{pod}}$		3.08 $_{\text{pod}}$	
ICC	0.34		0.34		0.34	
N	239 $_{\text{rfid}}$		200 $_{\text{rfid}}$		239 $_{\text{rfid}}$	
	17 $_{\text{pod}}$		17 $_{\text{pod}}$		17 $_{\text{pod}}$	
Observations	498		415		498	
Marginal R^2 / Conditional R^2	0.315 / 0.548		0.321 / 0.553		0.315 / 0.550	

Figure 7. Estimated marginal mean plots for the ‘Final’ veal CMQ4 grill model for breed, treatment, cut and days aged.

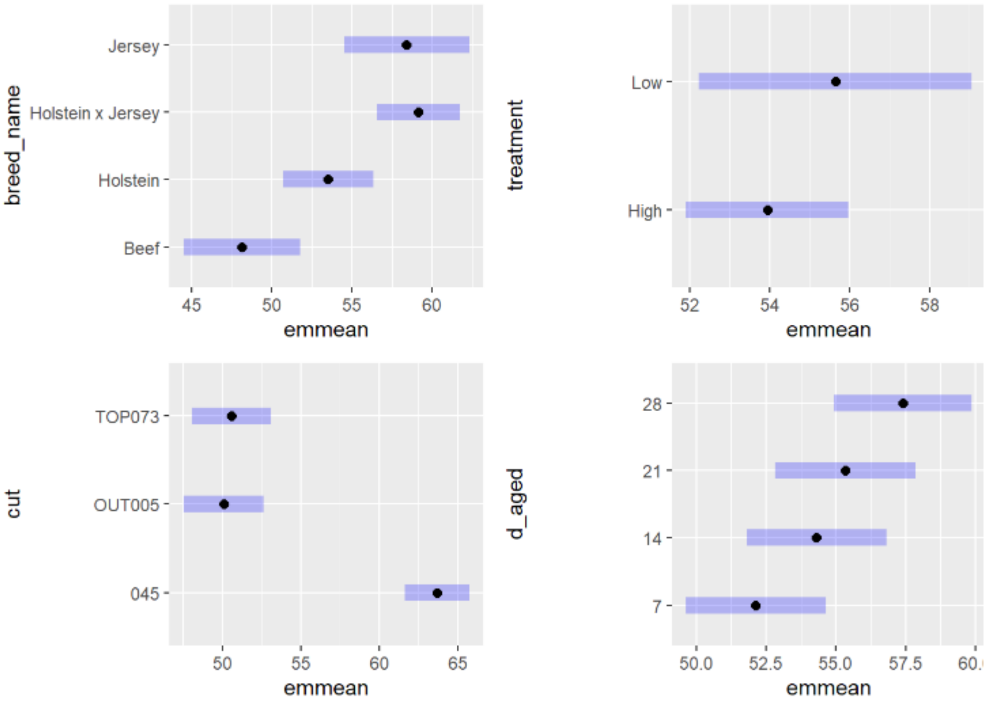


Figure 8. Visualisation of Estimated Marginal Means (EMM) for a model including cut x breed and days aged interactions.

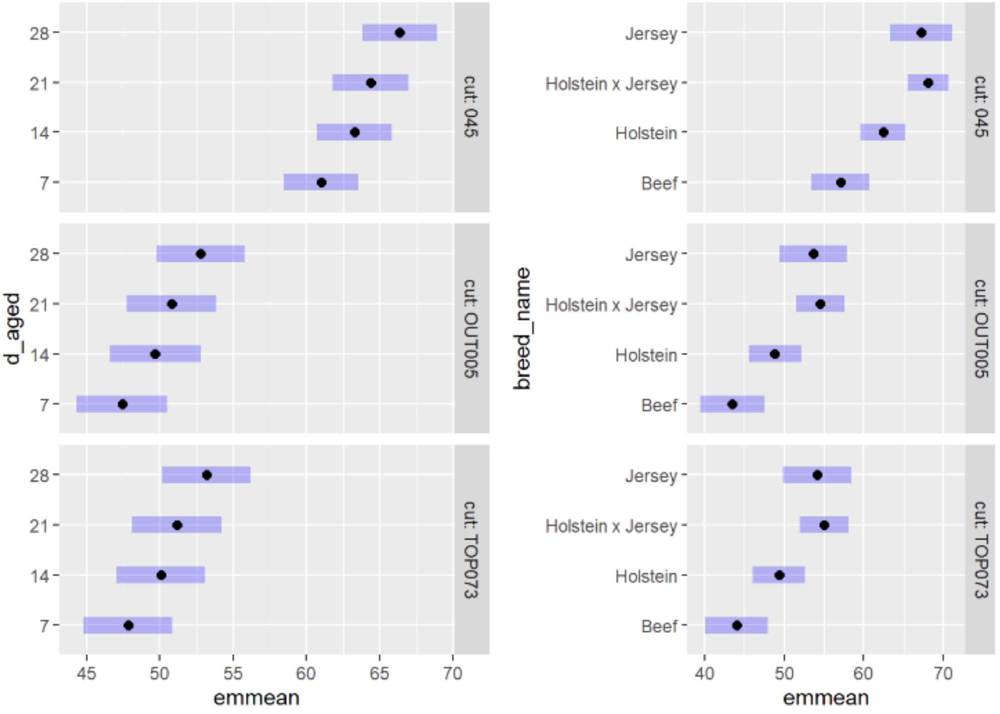
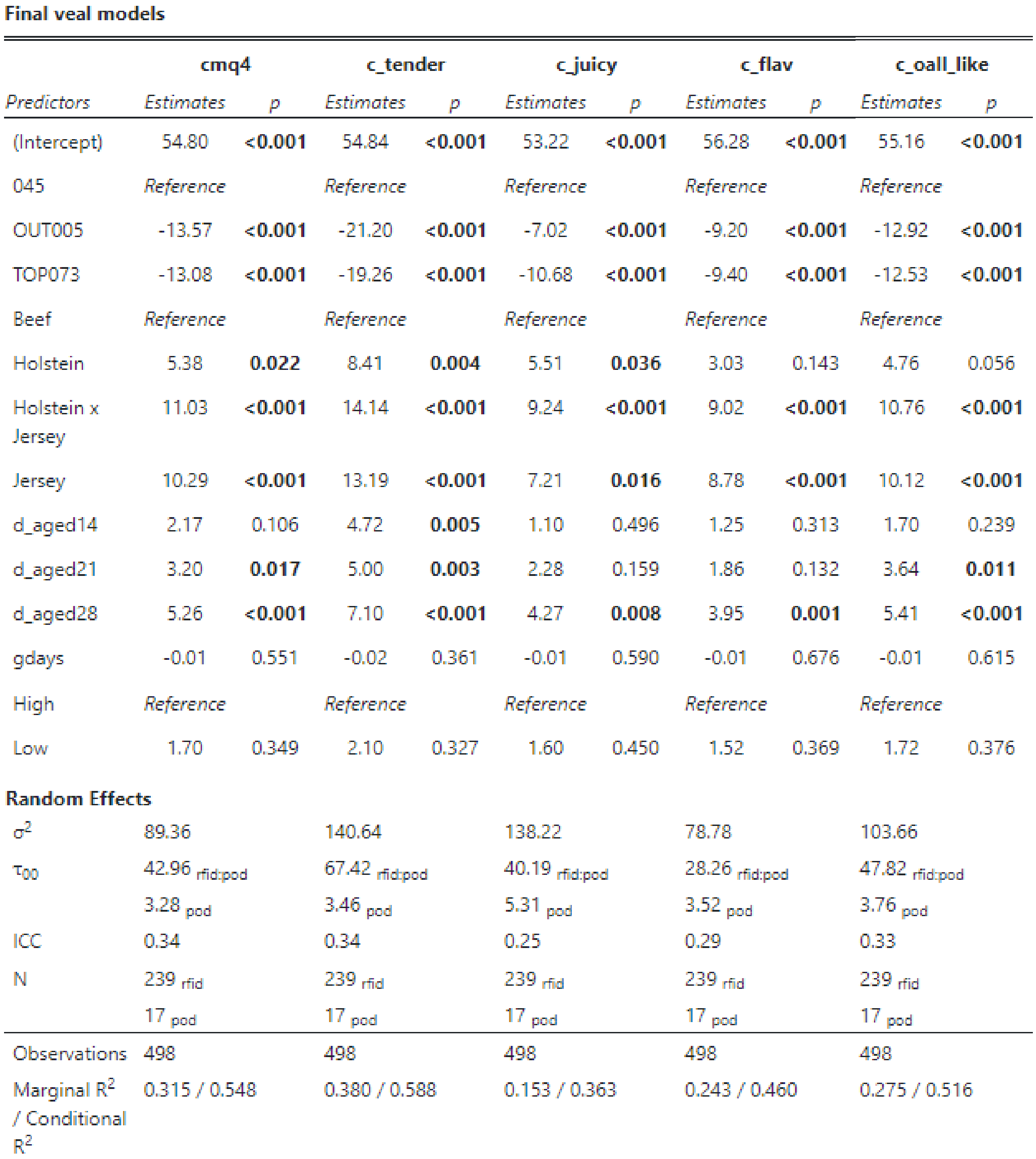


Table 23 presents individual models for CMQ4 and the component traits of tenderness, juiciness, flavour and overall satisfaction. These included the breed and days aged interactions.

Table 23. Linear mixed effect with cut, breed and growth pathway as fixed effects adjusted for days at the backgrounder and animal id within pod as a random intercept for veal grill samples. For each dependent variable (CMQ4, Tenderness, Juiciness, Flavour and Overall liking) there were 239 carcases and 498 samples.



Final veal models

	cmq4		c_tender		c_juicy		c_flav		c_oall_like	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	54.80	**<0.001**	54.84	**<0.001**	53.22	**<0.001**	56.28	**<0.001**	55.16	**<0.001**
045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
OUT005	-13.57	**<0.001**	-21.20	**<0.001**	-7.02	**<0.001**	-9.20	**<0.001**	-12.92	**<0.001**
TOP073	-13.08	**<0.001**	-19.26	**<0.001**	-10.68	**<0.001**	-9.40	**<0.001**	-12.53	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Holstein	5.38	**0.022**	8.41	**0.004**	5.51	**0.036**	3.03	0.143	4.76	0.056
Holstein x Jersey	11.03	**<0.001**	14.14	**<0.001**	9.24	**<0.001**	9.02	**<0.001**	10.76	**<0.001**
Jersey	10.29	**<0.001**	13.19	**<0.001**	7.21	**0.016**	8.78	**<0.001**	10.12	**<0.001**
d_aged14	2.17	0.106	4.72	**0.005**	1.10	0.496	1.25	0.313	1.70	0.239
d_aged21	3.20	**0.017**	5.00	**0.003**	2.28	0.159	1.86	0.132	3.64	**0.011**
d_aged28	5.26	**<0.001**	7.10	**<0.001**	4.27	**0.008**	3.95	**0.001**	5.41	**<0.001**
gdays	-0.01	0.551	-0.02	0.361	-0.01	0.590	-0.01	0.676	-0.01	0.615
High	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Low	1.70	0.349	2.10	0.327	1.60	0.450	1.52	0.369	1.72	0.376
Random Effects										
σ^2	89.36		140.64		138.22		78.78		103.66	
τ_{00}	42.96 $_{rfid:pod}$ 3.28 $_{pod}$		67.42 $_{rfid:pod}$ 3.46 $_{pod}$		40.19 $_{rfid:pod}$ 5.31 $_{pod}$		28.26 $_{rfid:pod}$ 3.52 $_{pod}$		47.82 $_{rfid:pod}$ 3.76 $_{pod}$	
ICC	0.34		0.34		0.25		0.29		0.33	
N	239 $_{rfid}$ 17 $_{pod}$		239 $_{rfid}$ 17 $_{pod}$		239 $_{rfid}$ 17 $_{pod}$		239 $_{rfid}$ 17 $_{pod}$		239 $_{rfid}$ 17 $_{pod}$	
Observations	498		498		498		498		498	
Marginal R^2 / Conditional R^2	0.315 / 0.548		0.380 / 0.588		0.153 / 0.363		0.243 / 0.460		0.275 / 0.516	

EMM effects were greatest for tenderness and differed from the standard MQ4 weightings of 0.3 for tenderness, flavour and overall and 0.1 for juiciness (Table 23). While the cut EMM were similar, the Holstein estimate for each trait was below that of the Jersey and Holstein x Jersey but again greater for tenderness. Table 23 displays EMM and Standard Errors for the effects of treatment and breed including principal MSA grading inputs. Carcase weight, hump height and rib fat were significant (p=<0.001).

Fig.9 displays distribution of marbling scores relative to carcase weight within breed type There was a trend towards a positive relationship between MSA marbling and carcase weight in the Jersey cattle. However, carcase weight range in the Jersey cattle is very small in comparison to the other breed groups and therefore further animals would be required to confirm this finding. Marbling was also significant (P=0.012) whereas ossification (p=0.198) and pHu (p=0.635) were not. Fig.10 displays the distribution within breed for these traits.

Further models were then produced with MSA grading inputs added to determine their potential impact in addition to breed, treatment and ageing input. An initial model including carcase weight, a carcase weight and breed interaction, hump height, rib fat, MSA marbling and ossification, but not including pHu, produced very similar results to the initial breed and growth treatment version, perhaps unsurprising given the low or no significance and effect sizes previously reported (see Table 14). All carcase characteristics with the exception of carcase weight were removed and ultimate pH was added to the model, resulting in a considerable change in covariate estimates (Table 24).

Figure 9. Relationship between MSA Marbling and carcase weight across the different breeds.

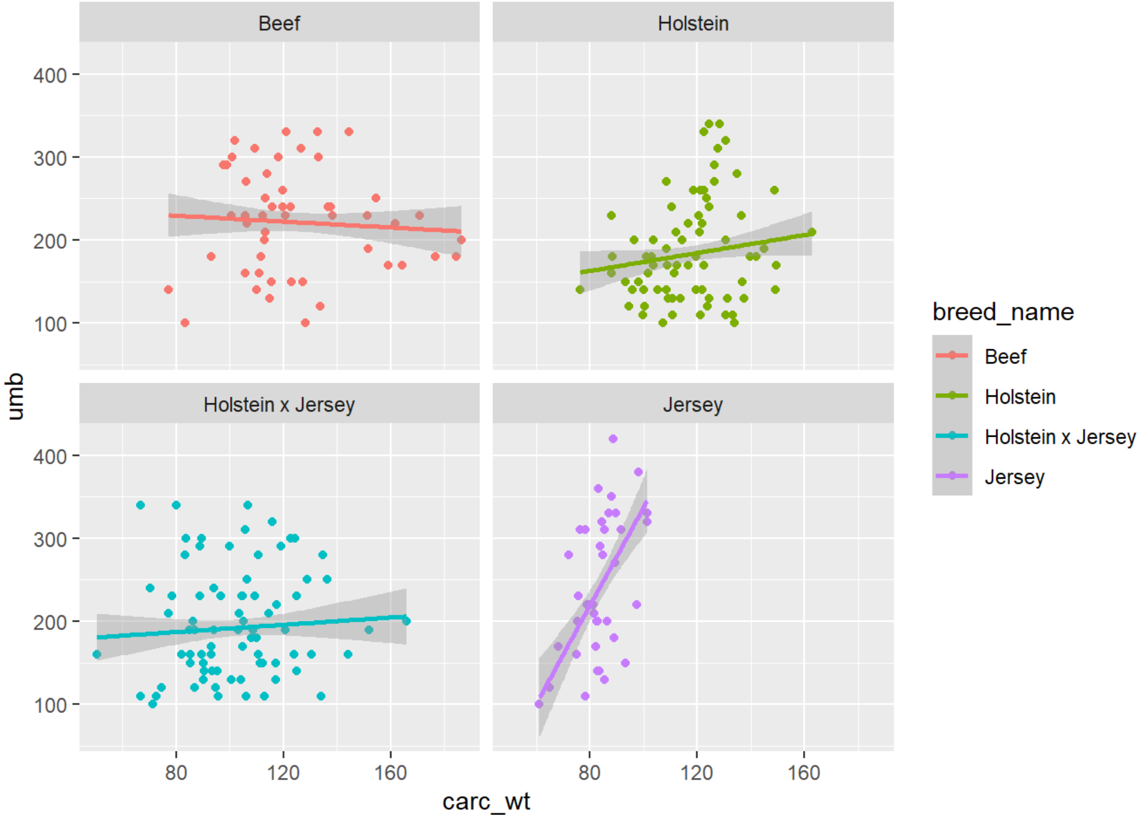


Figure 10. Distribution of carcase weight, hump height, MSA marbling and ossification.

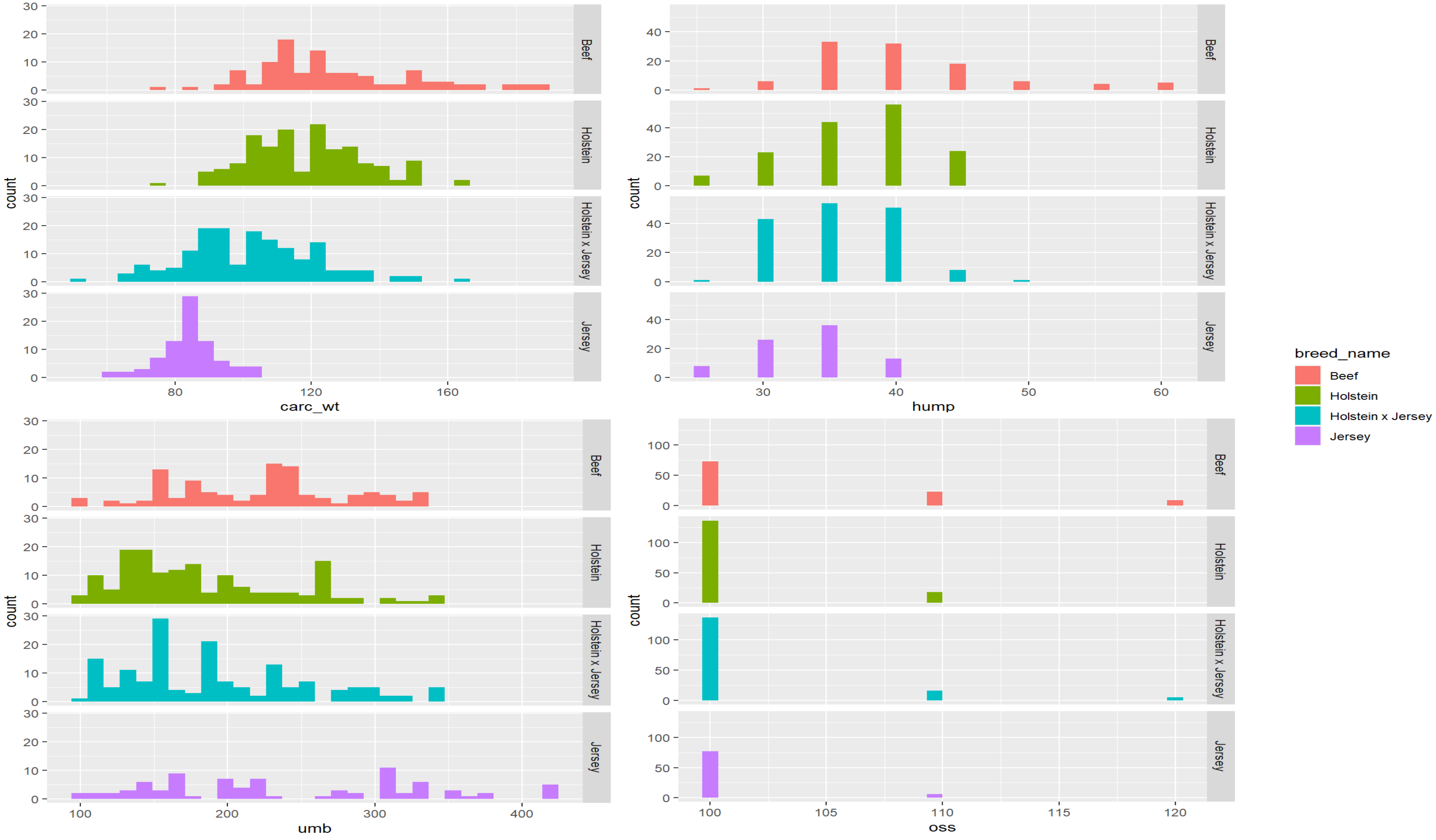
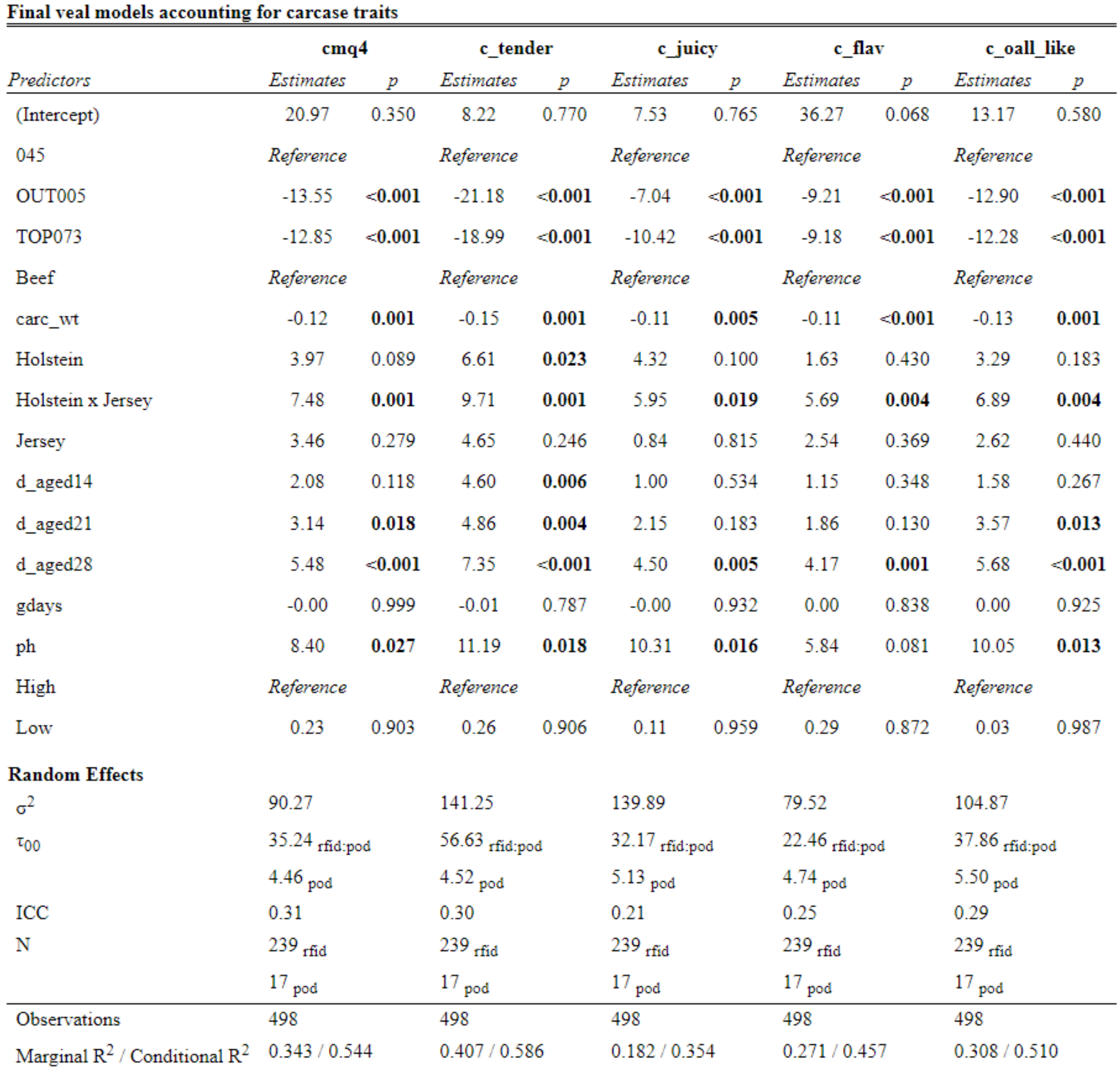


Table 24. Linear mixed effect models with cut, breed, growth pathway as fixed effects adjusted for days at the backgrounder and carcase characteristics; carcase weight and ultimate pH and animal id within pod as a random intercept for veal grill samples. For each dependent variable (CMQ4, Tenderness, Juiciness, Flavour and Overall liking) there were 239 carcases and 498 samples.



Final veal models accounting for carcase traits

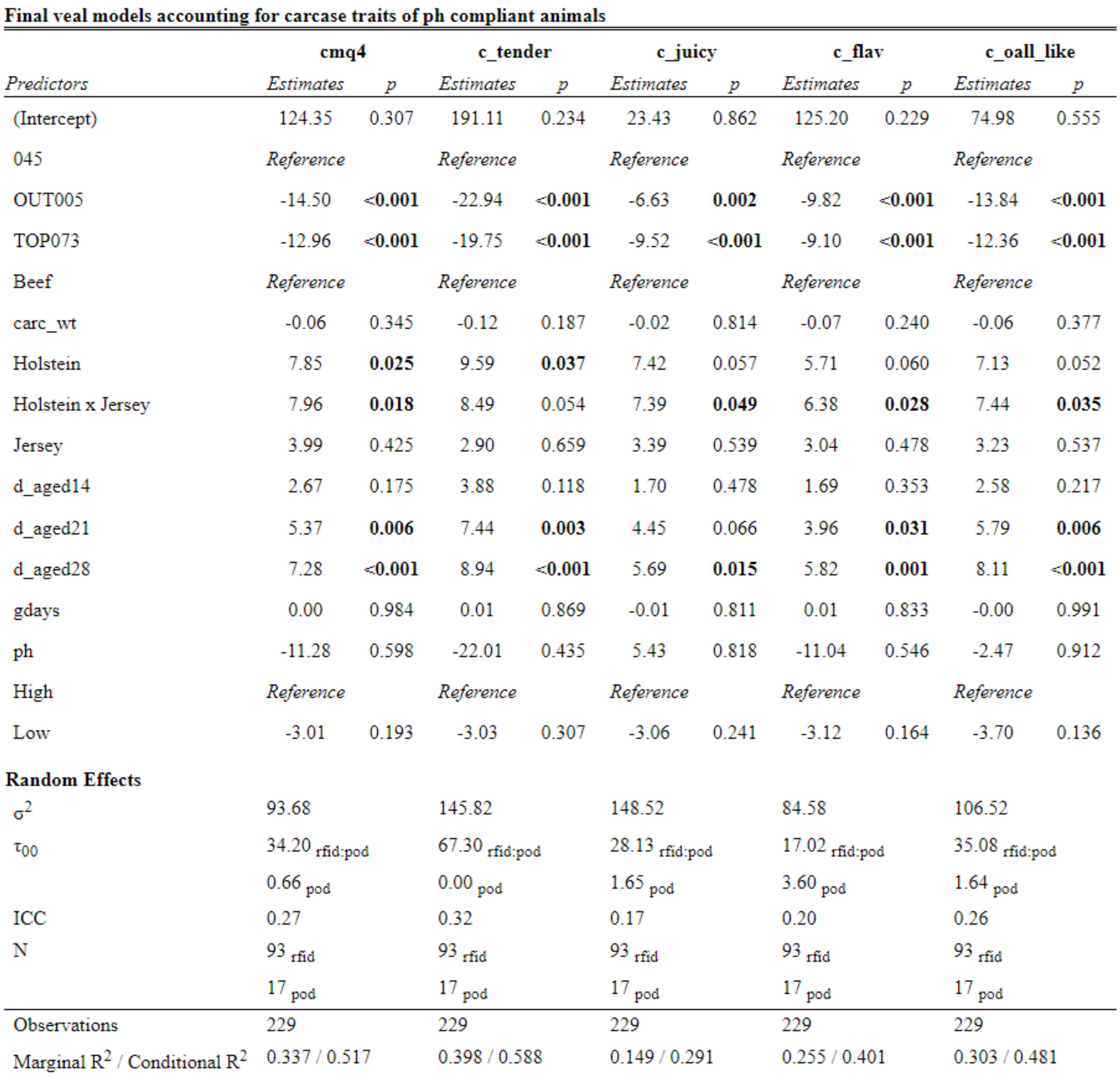
	cmq4		**c_tender**		**c_juicy**		**c_flav**		**c_oall_like**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	20.97	0.350	8.22	0.770	7.53	0.765	36.27	0.068	13.17	0.580
045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
OUT005	-13.55	**<0.001**	-21.18	**<0.001**	-7.04	**<0.001**	-9.21	**<0.001**	-12.90	**<0.001**
TOP073	-12.85	**<0.001**	-18.99	**<0.001**	-10.42	**<0.001**	-9.18	**<0.001**	-12.28	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
carc_wt	-0.12	**0.001**	-0.15	**0.001**	-0.11	**0.005**	-0.11	**<0.001**	-0.13	**0.001**
Holstein	3.97	0.089	6.61	**0.023**	4.32	0.100	1.63	0.430	3.29	0.183
Holstein x Jersey	7.48	**0.001**	9.71	**0.001**	5.95	**0.019**	5.69	**0.004**	6.89	**0.004**
Jersey	3.46	0.279	4.65	0.246	0.84	0.815	2.54	0.369	2.62	0.440
d_aged14	2.08	0.118	4.60	**0.006**	1.00	0.534	1.15	0.348	1.58	0.267
d_aged21	3.14	**0.018**	4.86	**0.004**	2.15	0.183	1.86	0.130	3.57	**0.013**
d_aged28	5.48	**<0.001**	7.35	**<0.001**	4.50	**0.005**	4.17	**0.001**	5.68	**<0.001**
gdays	-0.00	0.999	-0.01	0.787	-0.00	0.932	0.00	0.838	0.00	0.925
ph	8.40	**0.027**	11.19	**0.018**	10.31	**0.016**	5.84	0.081	10.05	**0.013**
High	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Low	0.23	0.903	0.26	0.906	0.11	0.959	0.29	0.872	0.03	0.987
Random Effects										
σ^2	90.27		141.25		139.89		79.52		104.87	
τ_{00}	$35.24_{\text{rfid:pod}}$		$56.63_{\text{rfid:pod}}$		$32.17_{\text{rfid:pod}}$		$22.46_{\text{rfid:pod}}$		$37.86_{\text{rfid:pod}}$	
	4.46_{pod}		4.52_{pod}		5.13_{pod}		4.74_{pod}		5.50_{pod}	
ICC	0.31		0.30		0.21		0.25		0.29	
N	239_{rfid}		239_{rfid}		239_{rfid}		239_{rfid}		239_{rfid}	
	17_{pod}		17_{pod}		17_{pod}		17_{pod}		17_{pod}	
Observations	498		498		498		498		498	
Marginal R^2 / Conditional R^2	0.343 / 0.544		0.407 / 0.586		0.182 / 0.354		0.271 / 0.457		0.308 / 0.510	

In this model the cut relativities remain relatively stable, but pH is significant (P=0.027) for MQ4, tenderness (P=0.018), juiciness (p=0.016) and overall liking (P=0.013) were both significant and positive. Conversely, Jersey breed estimates were no longer significant and less than Holstein. Earlier models saw a significant Jersey effect of +10.29 CMQ4 point relative to the Beef reference, the significant fixed effect of pH now appears to be explaining some of this Jersey effect and has reduced the overall Jersey effect to an insignificant +3.46 CMQ4 points above the reference indicating that pH is contributing a greater positive effect in Jersey that other parameters.

The positive effect of pH is counterintuitive for MSA graded carcases but becomes credible when the percentage of high pH (pHu >5.7) as displayed in Table 16 (Jersey 72.5% pHu > 5.7 relative to Holstein at 56.8%, Holstein x Jersey 59.7% and beef at 60%) is considered. It has been suggested that toughness (shear force) is known to increase as pH increases to a peak around pH 6 to 6.1 and then decrease substantially above 6.1 to where high pH meat is expected to be very tender and to have high water holding capacity associated with very dark meat colour, although this relationship remains to be unequivocally established.

To further investigate the influence of pHu on MEQ outcomes in the model, a further model utilising only the MSA pHu (<5.71) compliant carcases was then tested (Table 25).

Table 25. Linear mixed effect models for only carcases with ultimate pH <5.71 with cut, breed, growth pathway as fixed effects adjusted for days at the backgrounder and carcase characteristics; carcase weight and ultimate pH and animal id within pod as a random intercept for veal grill samples. For each dependent variable (CMQ4, Tenderness, Juiciness, Flavour and Overall liking) there were 93 compliant carcases and 229 samples.



Final veal models accounting for carcase traits of ph compliant animals

	cmq4		c_tender		c_juicy		c_flav		c_oall_like	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	124.35	0.307	191.11	0.234	23.43	0.862	125.20	0.229	74.98	0.555
045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
OUT005	-14.50	**<0.001**	-22.94	**<0.001**	-6.63	**0.002**	-9.82	**<0.001**	-13.84	**<0.001**
TOP073	-12.96	**<0.001**	-19.75	**<0.001**	-9.52	**<0.001**	-9.10	**<0.001**	-12.36	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
carc_wt	-0.06	0.345	-0.12	0.187	-0.02	0.814	-0.07	0.240	-0.06	0.377
Holstein	7.85	**0.025**	9.59	**0.037**	7.42	0.057	5.71	0.060	7.13	0.052
Holstein x Jersey	7.96	**0.018**	8.49	0.054	7.39	**0.049**	6.38	**0.028**	7.44	**0.035**
Jersey	3.99	0.425	2.90	0.659	3.39	0.539	3.04	0.478	3.23	0.537
d_aged14	2.67	0.175	3.88	0.118	1.70	0.478	1.69	0.353	2.58	0.217
d_aged21	5.37	**0.006**	7.44	**0.003**	4.45	0.066	3.96	**0.031**	5.79	**0.006**
d_aged28	7.28	**<0.001**	8.94	**<0.001**	5.69	**0.015**	5.82	**0.001**	8.11	**<0.001**
gdays	0.00	0.984	0.01	0.869	-0.01	0.811	0.01	0.833	-0.00	0.991
ph	-11.28	0.598	-22.01	0.435	5.43	0.818	-11.04	0.546	-2.47	0.912
High	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Low	-3.01	0.193	-3.03	0.307	-3.06	0.241	-3.12	0.164	-3.70	0.136
Random Effects										
σ^2	93.68		145.82		148.52		84.58		106.52	
τ_{00}	34.20 $_{\text{rfid:pod}}$		67.30 $_{\text{rfid:pod}}$		28.13 $_{\text{rfid:pod}}$		17.02 $_{\text{rfid:pod}}$		35.08 $_{\text{rfid:pod}}$	
	0.66 $_{\text{pod}}$		0.00 $_{\text{pod}}$		1.65 $_{\text{pod}}$		3.60 $_{\text{pod}}$		1.64 $_{\text{pod}}$	
ICC	0.27		0.32		0.17		0.20		0.26	
N	93 $_{\text{rfid}}$		93 $_{\text{rfid}}$		93 $_{\text{rfid}}$		93 $_{\text{rfid}}$		93 $_{\text{rfid}}$	
	17 $_{\text{pod}}$		17 $_{\text{pod}}$		17 $_{\text{pod}}$		17 $_{\text{pod}}$		17 $_{\text{pod}}$	
Observations	229		229		229		229		229	
Marginal R^2 / Conditional R^2	0.337 / 0.517		0.398 / 0.588		0.149 / 0.291		0.255 / 0.401		0.303 / 0.481	

When only MSA pH compliant animals were considered, it was observed that pH is no longer significant and negative as expected. Equally, by this analysis Jersey breed is no longer significantly different to beef breed whilst Holstein (p=0.025) and Holstein x Jersey (p=0.018) were significantly better for MQ4. This adds caution to the interpretation of results and the many potential biological interactions given that non-grading Jersey carcases appeared to have higher eating quality by our initial analysis when all carcases were considered together.

4.1.11. Feedlot finished dairy beef steers

There was some loss of steers from weaning to backgrounder finish; 4 were lost from cohort 1 (including veal calves) and 9 lost from cohort 2. For the British, Euro and Holstein steers, industry standard exit and carcase weights from the feedlots were achieved with acceptable ADG in both the high and low growth groups (Tables 26 and 27).

4.1.12. Cohort 1 - Feedlot finished steers

For the feedlot steers, there were 16 pods: 72 LG steers (Table 26) and 175 HG steers that provided growth and carcase data (Table 27). Four head died at the feedlot and three head were removed for slaughter early; consequently, there were effectively two kill dates approximately 6 weeks apart. Birthdates were not available for Beef steers and this precluded early ADG analysis, however, ADG was assessed during the backgrounding period at pasture, at the feedlot while backgrounding, and in the feedlot. The evaluation of the effects of growth path, breed and their interaction were reported for 190 head (Table 28).

The hypothesis was that effects of growth path in backgrounding will not be evident when pods are combined and fed in a single pen at the feedlot. This hypothesis was challenged given that a significant positive difference in each breed and the HG group during the backgrounding stage and feedlot entry weight (Table 28) was reversed in all breed groups and overall in the feedlot with LG ADG significantly greater than the HG during this time period. This indication of compensatory gain is of commercial relevance and important in feedlot economics and has likely contributed to the relative performance of the two groups during the trial.

The ADG during the backgrounder phase for these pods were very similar to those of the veal pods as these were taken to the feedlot at a similar age to the veal calves exit. This decision to induct the cattle in cohort 1 at a younger age reflected the severity of drought conditions at the time and therefore presented cattle with a younger or lighter weight entry to the lot. The HxJ (0.80 ± 0.07 kg/d) and Holsteins (0.73 ± 0.06 kg/d) had a reduced ADG compared to LG beef (1.45 ± 0.08 kg/d) pods (Table 14). The HG pod Jersey steers (0.78± 0.04 kg/d) had a reduced ADG than the HxJ (0.95 ± 0.04 kg/d) or Holstein (0.89 ± 0.04 kg/d) pods, which in turn that had lesser ADG than the HG beef (1.59 ± 0.04 kg/d). A difference in ADG between treatments was present with the LG (0.95 ± 0.05 kg/d) exceeding, and the HG (1.11 ± 0.04 kg/d) pods achieving close to, the targeted ADG (Table 28). Some caution should be taken in comparing the beef steer results in this cohort due to their entry weight and age difference (Table 26).

Table 26. Cohort 1 Low Growth steers; estimated marginal means ± SE for the effects of breed on backgrounding and feedlot performance. Models include the fixed effects of breed and the random effects of identity within a pod and farm (*N = 72, otherwise N = 74).

Outcome	Holstein x Jersey N = 20	Holstein N = 37	Beef N = 17	Breed (*P*-value)
Average daily gain on farms (kg/d) ^{1}	0.8 ± 0.07^{a}	0.73 ± 0.06^{a}	1.45 ± 0.08^{b}	**<0.001**
Backgrounder farm exit (kg)	211.1 ± 7.12^{a}	242.0 ± 5.24^{b}	275.0 ± 7.72^{c}	**<0.001**
Average daily gain feedlot background (kg/d)	1.72 ± 0.13^{a}	2.00 ± 0.10^{ab}	2.15 ± 0.14^{b}	0.06
Final entry eight to the feedlot (kg)	265.0 ± 8.10^{a}	295.1 ± 5.99^{b}	334.9 ± 8.79	**<0.001**
Average daily gain feedlot (kg/d)	1.23 ± 0.04^{a}	1.37 ± 0.03^{b}	1.28 ± 0.04^{ab}	**0.013**
Exit weight from feedlot (kg)*	542.3 ± 11.45^{a}	611.9 ± 8.56^{b}	591.1 ± 12.86^{b}	**<0.001**
Carcase weight (kg)*	263.3 ± 5.52^{a}	295.5 ± 4.11^{b}	304.8 ± 6.17^{b}	**<0.001**
Hump height (mm)*	57.0 ± 1.56^{a}	58.1 ± 1.16^{a}	68.3 ± 1.53^{b}	**<0.001**
Eye muscle area (cm^{2})	66.0 ± 1.29^{a}	68.6 ± 1.26^{a}	78.7 ± 1.89^{b}	**<0.001**
P8 fat depth (mm) *	8.15 ± 0.58^{a}	8.33 ± 0.43^{a}	16.1 ± 0.65^{b}	**<0.001**
Rib fat (mm)*	5.60 ± 0.64^{a}	5.47 ± 0.48$_{a}$	10.8 ± 0.71^{b}	**<0.001**
Marble (score 1 to 1190)*	391.0 ± 17.95^{a}	375.6 ± 13.40$_{a}$	413.1 ± 20.06^{a}	0.291
Fat colour score (0-9)	0.22 ± 0.07^{a}	0.14 ± 0.06^{a}	0.0 ± 0.13^{a}	0.156
Ossification (score 100 to 590)*	135.5 ± 2.49^{a}	133.9 ± 1.85^{a}	133.1 ± 2.78^{a}	0.798
Ultimate pH*	5.67 ± 0.04^{a}	5.66 ± 0.02^{a}	5.60 ± 0.03^{a}	0.226
Colour (score 1 to 6)*	4.10 ± 0.24^{a}	4.03 ± 0.18^{a}	2.25 ± 0.27^{b}	**<0.001**
Meat Standards Australia Index*	60.96 ± 0.52	60.86 ± 0.44	62.57 ± 0.95	0.361

^{1}Days of backgrounding significant

$^{a\text{-}d}$ Superscripts that differ denote significance P <0.05

The exit weights from the backgrounder farm differed for the LG pathway cattle (HxJ: 211.10 ± 7.12kg; Holstein: 241.99 ± 5.24kg, and beef 274.97 ± 7.72kg; Table 26). The HG pathway cattle also differed, with Jersey showing exit weights of 204.33 ± 5.58kg, HxJ 229.44 ± 4.82kg, Holstein 268.57 ± 5.32kg, and Beef 291.43 ± 5.65kg (Table 27) respectively. There was also a 19kg difference between the treatment groups (Table 28). During the backgrounding period at the feedlot the ADG were impressive with all groups gaining weight rapidly. The LG HxJ (1.72 ± 0.13 kg/d) and Holsteins (2.00 ± 0.10 kg/d) had similar gains, but the Beef calves (2.15 ± 0.14 kg/d) had greater ADG than the HxJ (Table 26). The Jersey steers gained least (1.46 ± 0.13 kg/d) during this phase, the HxJ 1.91± 0.22 kg/d, the Holstein 2.31 ± 0.23 kg/d, and Beef 2.22 ± 0.24 kg/d, respectively (Table 27). The effect of previous growth path was significant with the LG pods gaining 2.01 ± 0.16 and the HG 2.23 ± 0.14 kg/d (Table 28).

Table 27. For cohort 1 High Growth steers, estimated marginal means ± SE for the effects of breed on backgrounding and feedlot performance. Models include the fixed effects of breed and the random effects of identity within a pod and farm (*N = 172, ⁋N = 171, otherwise N = 175)

Outcome	Jersey N = 38	Holstein x Jersey N = 55	Holstein N = 52	Beef N = 38	Breed (*P*-value)
Average daily gain on farms (kg/d) ^{1}	0.78 ± 0.04^a	0.95 ± 0.04^b	0.89 ± 0.04^b	1.59 ± 0.04^c	**<0.001**
Backgrounder farm exit (kg)	204.3 ± 5.58^a	229.4 ± 4.82^b	268.6 ± 5.32^c	291.4 ± 5.65^d	**<0.001**
Average daily gain feedlot background (kg/d)	1.46 ± 0.24^a	1.91 ± 0.22^b	2.31 ± 0.23^b	2.22 ± 0.24^b	**0.007**
Final entry weight to the feedlot (kg)	244.0 ± 5.72^a	283.4 ± 4.76^b	326.3 ± 5.32^c	346.7 ± 5.72^d	**<0.001**
Average daily gain feedlot (kg/d)	0.84 ± 0.03^a	1.13 ± 0.03^b	1.33 ± 0.03^c	1.28 ± 0.03^c	**<0.001**
Exit weight from feedlot (kg)*	427.3 ± 9.33^a	532.9 ± 7.76^b	621.1 ± 8.16^c	624.0 ± 11.48^c	**<0.001**
Carcase weight (kg)*	211.6 ± 4.36^a	262.4 ± 3.64^b	304.4 ± 4.00^c	306.8 ± 4.30^c	**<0.001**
Hump height (mm) ⁋	52.8 ± 1.45^a	55.9 ± 1.21^a	60.2 ± 1.38^b	68.0 ± 1.43^c	**<0.001**
Eye muscle area (cm^2) ⁋	64.0 ± 1.53^a	68.3 ± 1.27^b	69.9 ± 1.37^b	78.3 ± 2.20^c	**<0.001**
P8 fat depth (mm) ⁋	8.13 ± 0.51^{ab}	8.67 ± 0.42^{ab}	9.24 ± 0.49^{ab}	16.0 ± 0.50^c	**<0.001**
Rib fat (mm) ⁋	4.46 ± 0.41^a	5.66 ± 0.34^b	6.45 ± 0.38^b	11.2 ± 0.41^c	**<0.001**
Marble (score 1 to 1190⁋	383.0 ± 12.10^a	389.6 ± 10.12^a	376.6 ± 11.24^a	397.0 ± 11.95^a	0.629
Fat colour score (0-9) ⁋	0.27 ± 0.08^a	0.11 ± 0.07^a	0.20 ± 0.08^a	0.15 ± 0.11^a	0.266
Ossification (score 100 to 590) ⁋	138.9 ± 1.99^a	136.2 ± 1.66^{ab}	136.7 ± 1.84^a	131.3 ± 1.96^b	**0.046**
Ultimate pH⁋	5.77 ± 0.03^a	5.72 ± 0.02^{ab}	5.68 ± 0.02^b	5.60 ± 0.03^b	**0.002**
Colour (score 1 to 6)*	4.62 ± 0.17^a	4.07 ± 0.14^b	3.67 ± 0.16^b	2.11 ± 0.17^c	**<0.001**
MSA Index^2	57.76 ± 0.46a	59.85 ± 0.37b	60.41 ± 0.41b	64.21 ± 0.71c	**<0.001**

^{1} Days in feedlot significant; ^{2} 168 carcases evaluated

$^{a\text{-}c}$ Superscripts that differ denote significance P <0.05

The entry weights to the feedlot were, because of the backgrounding at the lot, approximately 50kg higher than at backgrounder farm exit and for the LG steers, all breeds differed in weight (HxJ: 265.00 ± 8.10kg; Holstein: 295.14 ± 5.99kg; Beef 334.94 ± 8.79kg, Table 28). Similarly, weights differed by breed for the HG groups with Jersey being 244.03 ± 5.72kg, the HxJ 283.38 ± 4.76kg, Holsteins 326.27 ± 5.32kg, and Beef 346.7 ± 5.72kg (Table 27). Overall, there was a 22kg difference between treatment pods in weight at the end of feedlot backgrounding (Table 28).

The LG path Holsteins had the greatest ADG (1.37 ± 0.03 kg/d) when compared with the HxJ (1.23 ± 0.04 kg/d) and beef (1.28 ± 0.04 kg/d) that were equivalent in performance. For the HG steers, Jersey cattle showed was least growth (0.84 ± 0.03 kg/d), HxJ were intermediate (1.13 ± 0.03 kg/d), and the Holstein (1.33 ± 0.03 kg/d) and Beef (1.28 ± 0.03 kg/d) were highest and comparable to each other.

Steers on the LG pathway compensated for earlier performance once in the lot and gained 1.30 ± 0.03kg/d, whereas the HG steers gained 1.24 ± 0.03 kg/d (Table 28). Consequently, the exit weight from the feedlot was not significantly greater at exit for the HG steers (9kg; Table 28) than their LG counterparts. For the LG steers, the Holstein (611.89 ± 8.56kg) and Beef (591.13 ± 12.86kg) weighed more than the HxJ (542.25 ± 11.45kg) (Table 26). For the HG pods, the Jersey steer weight at exit was least (427.31 ± 9.33 kg), the HxJ were of intermediate weight (532.93 ± 7.76kg), and the heavier breeds Holstein (621.09 ± 8.16kg) and Beef (624.04 ± 11.48kg) did not differ (Table 27).Treatment effects were not significant for carcase measures (Table 28), likely reflecting the significantly higher feedlot ADG for the LG steers and compensatory growth once in the feedlot. The potential for compensatory growth appears to be greatest when steers are about 25–30 % of mature size (Hogg, 1991), as these steers were.

4.1.13. Cohort 1 - Feedlot-finished carcase characteristics

Carcase weights and fat measures of all breeds and growth paths were adequate for the needs of local markets (Mulley et al., 2014). The P8 fat depth in the LG pods, the HxJ, and Holstein steers did not differ (8.15 ± 0.58 and 8.33 ± 0.43mm, respectively), while the Beef steer pods were greater with 16.1 ± 0.65mm (Table 26). The HG Beef steers had 16.0 ± 0.50mm and differed from the other three breeds that were all similar with 8 to 9mm of P8 fat (Table 27). The rib fat results were very similar to the P8 fat results with lower rib fat in the HxJ and Holstein pods and greater in the Beef pods for the LG and HG pods (Tables 26 and 27). Specifically, 2 Holstein, 2 HxJ and 4 Jersey carcases presented with less than 2mm of rib fat, therefore impacting ability for MSA grading. In contrast, all Holstein steers finished on pasture had >3mm rib fat. Unlike the veal steers, the Jersey steers had the lowest rib fat at feedlot exit (Table 27). Marbling scores did not differ for the LG or HG breeds, nor with treatment (Tables 26-28) reinforcing differences in accumulation between the subcutaneous and intra-muscular fat deposition pools.

All groups had marbling scores between 375 to 413 (Tables 26-28) comparing favourably to typical MSA graded domestic cattle. Hump heights only differed for Beef against the HxJ and Holsteins for the LG steers (Table 26), but in the HG steers, the Jersey and HxJ had the least hump height and differed from the Holstein and Beef that had the greatest hump heights (Table 27).

The EMA was markedly different for the Beef steers in the HG and LG path groups being higher than all other breeds, and while the HxJ and Holsteins did not differ with either treatment, these were higher than the Jersey (Tables 26, 27 and 28). Treatment differences were not significant (Table 28). The HxJ and Holsteins were approximately 10cm^2 lower in EMA than the Beef breeds, a finding surprisingly consistent with the veal calves. The latter finding reinforces the possibility that the difference reflects differences in conformation of *longissimus thoracis et lumborum* rather than a difference in the mass of the muscle as a percentage of total muscle mass although this suggestion would need to be validated by measurement of primal cuts.

While the ossification scores did not differ for LG pods, the Jersey and Holstein HG steers had higher ossification scores than the Beef by approximately 7 and 5 units, respectively, with the HxJ were similar to all other groups (Table 27). The ultimate pH did not differ among breeds in the LG pods, but for the HG pods, the Jersey steers had pH 5.77 ± 0.03 and differed from the Holstein (5.68 ± 0.02) and Beef steers (5.60 ± 0.03). The HxJ exhibited pH 5.72 ± 0.02 and were similar to all other steer groups. As MSA criteria includes a maximum ultimate pH of 5.7, those above this threshold would be excluded from MSA grades.

Table 28. For cohort 1 steers, estimated marginal means ± SE for the effects of treatment and breed on backgrounding and feedlot performance. Models include the fixed effects of treatment group, breed and the random effects of identity within a pod and farm (*N = 187, ⁋ N = 186, otherwise N = 190).

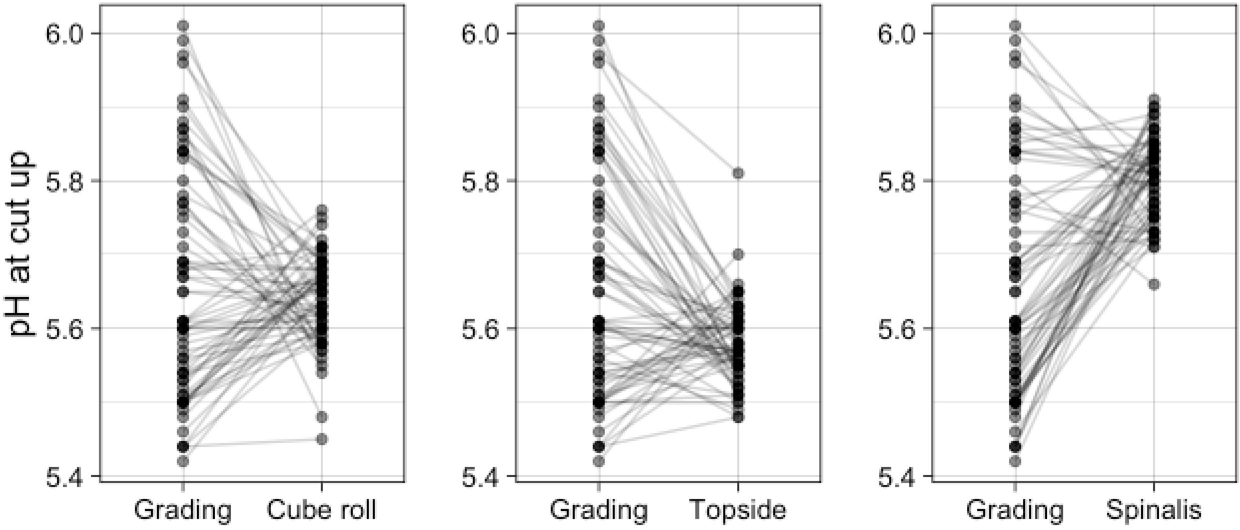
	Treatment		Holstein x Jersey		Holstein		Beef		Significance (*P*-value)		
Outcome	Low N = 74	High N = 116	Low N = 20	High N = 36	Low N = 37	High N = 42	Low N = 17	High N = 38	Breed (B)	Treatment (T)	B×T
Average daily gain on farms (kg/d) [1]	0.95 ± 0.05	1.11 ± 0.04	0.79 ± 0.07	0.94 ± 0.06	0.78 ± 0.06	0.96 ± 0.06	1.37 ± 0.08	1.49 ± 0.06	**<0.001**	**0.002**	0.779
Backgrounder farm exit (kg)	242.8 ± 4.27	262.2 ± 3/61	209.8 ± 7.51	227.5 ± 5.76	234.7 ± 6.12	258.3 ± 6.14	288.2 ± 8.45	303.1 ± 6.73	**0.001**	**0.002**	0.753
Average daily gain feedlot background (kg/d)	2.01 ± 0.16	2.23 ± 0.14	1.73 ± 0.24	2.02 ± 0.19	1.98 ± 0.20	2.28 ± 0.20	2.32 ± 0.19	2.37 ± 0.22	**0.052**	0.150	0.722
Final entry weight to the feedlot (kg)	298.0 ± 4.48	319.8 ± 3.21	265.0 ± 8.48	281.7 ± 6.32	295.5 ± 6.24	328.0 ± 5.85	334.9 ± 9.20	346.7 ± 6.15	**<0.001**	**0.005**	0.271
Average daily gain feedlot (kg/d)	1.30 ± 0.03	1.24 ± 0.03	1.23 ± 0.04	1.12 ± 0.04	1.36 ± 0.04	1.31 ± 0.03	1.28 ± 0.05	1.26 ± 0.04	**<0.001**	**0.037**	0.452
Exit weight from feedlot (kg)*	584.3 ± 6.40	593.5 ± 5.10	532.4 ± 12.18	531.6 ± 9.58	599.1 ± 9.47	618.2 ± 8.38	615.9 ± 14.74	620.8 ± 10.81	**<0.001**	0.353	0.554
Carcase weight (kg)*	288.6 ± 3.15	292.9 ± 2.47	262.0 ± 6.01	261.3 ± 4.72	293.8 ± 4.67	303.4 ± 4.13	304.9 ± 7.27	310.1 ± 5.33	**<0.001**	0.373	0.525
Hump height (mm)⁋	61.4 ± 1.06	61.3 ± 0.86	57.8 ± 1.95	56.7 ± 1.59	59.1 ± 1.57	61.4 ± 1.43	68.5 ± 2.53	65.9 ± 2.00	**0.006**	0.738	0.247
Eye muscle area (cm^2)⁋	70.8 ± 1.00	72.2 ± 0.79	67.3 ± 1.91	68.7 ± 1.56	70.4 ± 1.54	70.3 ± 1.39	75.0 ± 2.51	78.3 ± 1.98	**0.004**	0.230	0.544
P8 fat depth (mm)⁋	10.6 ±0.41	11.0 ± 0.31	8.17 ± 0.73	8.84 ± 0.59	8.34 ± 0.60	9.26 ± 0.54	16.1 ± 0.94	15.6 ± 0.74	**<0.001**	0.506	0.431
Rib fat (mm)⁋	7.07 ± 0.34	7.71 ± 0.27	5.77 ± 0.65	6.42 ± 0.53	5.69 ± 0.52	6.53 ± 0.47	10.3 ± 0.85	10.7 ± 0.67	**<0.001**	0.162	0.903
Marble (score 1 to 1190)⁋	390.4 ± 9.85	383.8 ± 7.95	388.5 ± 18.46	383.0 ± 15.00	372.2 ± 14.83	371.0 ± 13.47	418.3 ± 23.93	402.9 ± 18.90	0.220	0.551	0.891
Fat colour score (0-9)⁋	0.11 ± 0.04	0.18 ± 0.03	0.21 ± 0.08	0.13 ± 0.07	0.13 ± 0.07	0.23 ± 0.07	0.00 ± 0.11	0.17 ± 0.08	0.589	0.165	0.125
Ossification (score 100 to 590)⁋	134.3 ± 1.50	135.1 ± 1.08	135.5 ± 2.77	136.2 ± 1.70	133.9 ± 2.07	136.7 ± 1.89	133.1 ± 3.10	131.3 ± 2.01	0.286	0.755	0.600
Ultimate pH⁋	5.64 ± 0.02	5.65 ± 0.01	5.67 ± 0.03	5.70 ± 0.03	5.66 ± 0.03	5.67 ± 0.02	5.58 ± 0.05	5.59 ± 0.04	**0.091**	0.608	0.875
Colour (score 1 to 6)⁋	3.55 ± 0.14	3.40 ± 0.12	3.97 ± 0.24	3.89 ± 0.10	3.87 ± 0.20	3.58 ± 0.18	2.67 ± 0.31	2.65 ± 0.25	**0.003**	0.399	0.730
Meat Standards Australia Index⁋[2]	61.32 ± 0.28	61.11 ± 0.23	60.73 ± 0.52	60.09 ± 0.43	60.56 ± 0.42	60.43 ± 0.39	63.04 ± 0.71	63.25 ± 0.57	**0.001**	0.5258	0.690

[1] Days of backgrounding significant

[2] Days in feedlot significant

In addition to collecting ultimate pH at grading, pH was also measured at cut-up approximately 6 days later. Evident in Fig. 11 below is the lack of relationship between ultimate pH at grading measured in the *M. longissimus dorsi* and pH recorded some days later in the *M. longissimus dorsi* (STR045/CUB045), *M. spinalis dorsi* (CUB081) and the *M. semimembranosus* (TOP073) at cut-up. Ultimate pH measured at grading has a much wider range than pH taken later at cut-up that points towards pH taken at grading being likely not yet at ultimate. This relationship between timing and pH measurement warrants further investigation. Alternatively, the lower fat thickness relative to HSCW may result in faster muscle temperature reduction in the dairy and a related slower pH decline rate.

Figure 11: The relationship between pH measured in the *M. longissimus dorsi* at grading and pH measured days later in more muscles at cut-up.



When colour score was considered, the LG Beef steers had lower (2.25 ± 0.27) colour scores than the other two groups. Similarly, the HG Beef pod steers had a lower score (2.11 ± 0.17) than all other breeds with the HxJ (4.07 ± 0.14) and Holsteins (3.67± 0.16) being similar, but lower than the Jersey steers (4.62± 0.17) in colour, aligning with their higher pHu. While MSA imposes no meat colour criteria, commercial plant criteria often impose penalties for meat colour exceeding 3 or 4 meaning that the Jersey steers would be subject to this penalty and reflective of the number of Jersey carcases that graded MSA in this study (Table 26).

The MSA index did not differ for the LG steers breeds (Table 26) but did differ for the HG steers with Jersey steers being lower than HxJ and Holstein, that were slightly lower than Beef steers. It is likely that these results were influenced by the amount of time on feed (Table 27). The effect of treatment was not significant for MSA Index, but Beef steers generally achieved a higher MSA Index than their HxJ or Holstein counterpart (Table 28).

The high fat colour and failure to achieve a pH ≤5.7 resulted in a failure to grade for some carcases. For LG steers, 25% (5/20) for HxJ, 27% (10/37) and 6% (1/17) Holstein steers failed to grade. For the HG steers, 58% (22/38) of Jersey steers, 43% (23/54) of HxJ steers, 32% (14/44) of Holstein steers but only 5% (2/38) of Beef steers failed to grade. This is a significant finding in terms of commercial value. Again, no significant effect of treatment was observed on grading, nor of days in the lot.

Figure 12. Compliance for MSA rib fat minimum of 3mm by breed group.

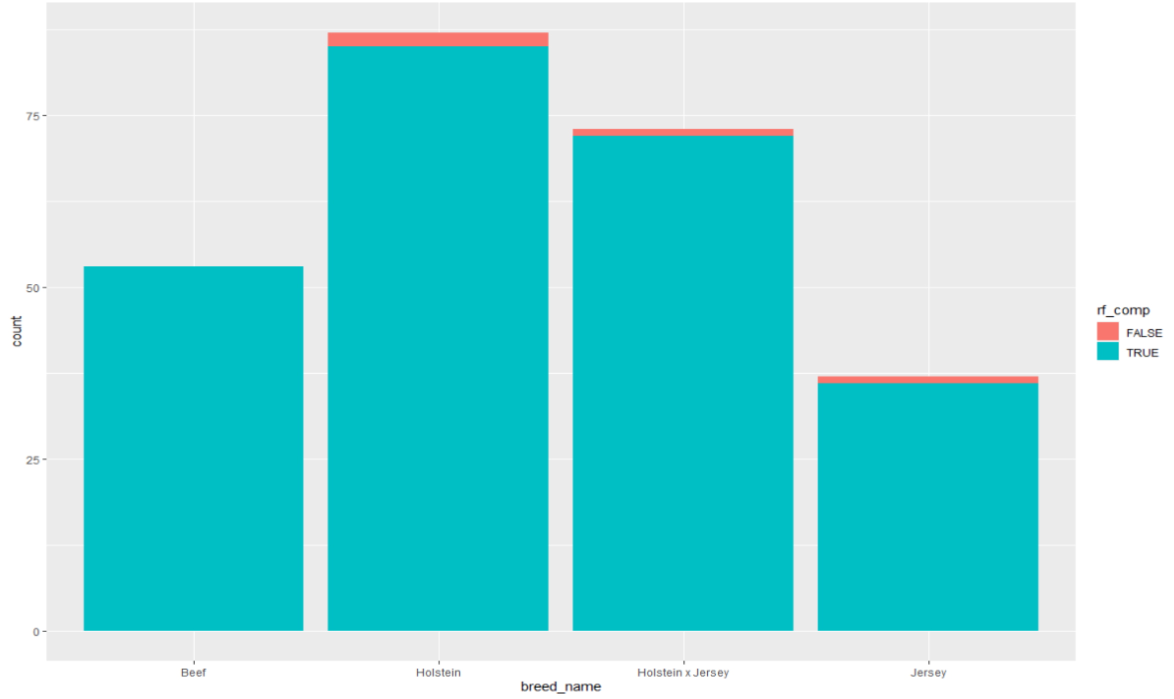
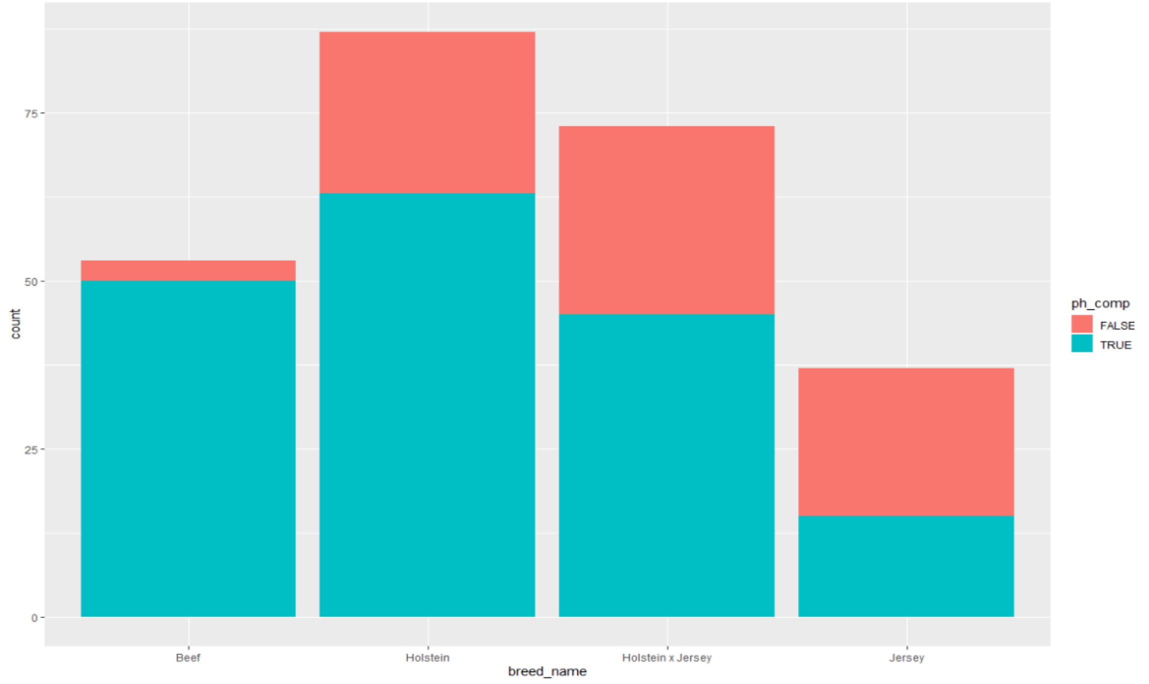


Figure 13. Compliance for MSA ultimate pH by breed group.



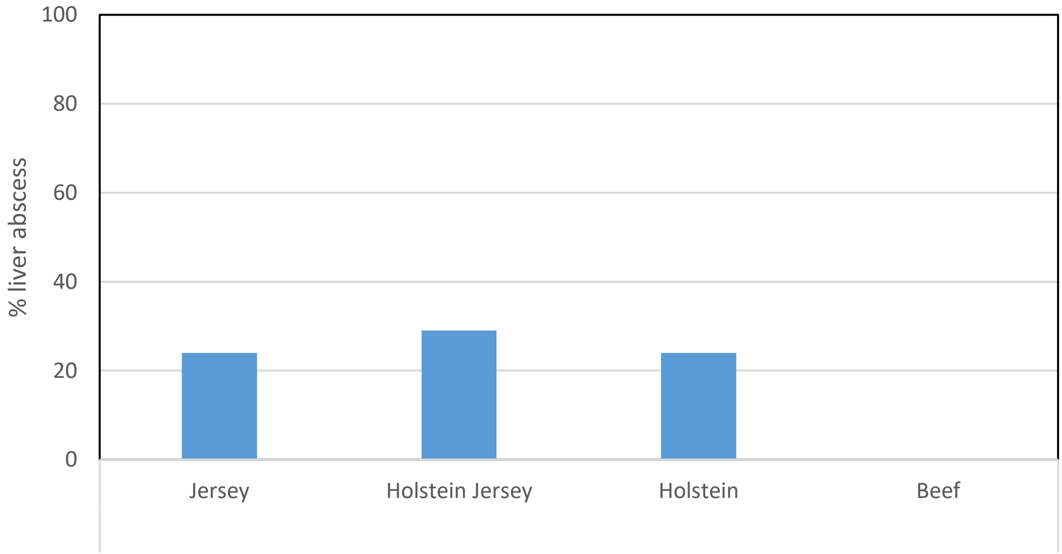
No abattoir viscera examination was reported for the first cohort 1 feedlot kill but a detailed report was provided for the second. A summary of the reported conditions is displayed in Table 29.

Table 29. Reported viscera conditions for cohort 1 (kill date 19/8/2019) by breed group.

	GROUP			
	558.1	**558.2**	**558.3**	**558.4**
Breed	**Jersey**	**Holstein**	**Hol x Jers**	**Beef**
Viscera Health Notes				
Enteritis		3	1	
Liver Abscess (Grade 1)	6	11	14	
Liver Abscess (Grade 1), Enteritis		4		
Liver Abscess (Grade 1), Pericarditis	2	4	3	
Liver Abscess (Grade 1), Pericarditis, Pleurisy (Grade 1)			1	
Liver Abscess (Grade 1), Pleurisy (Grade 1)	1			
Liver Abscess (Grade 2)		1		
Liver Abscess (Grade 2), Enteritis		3	1	
Liver Fluke	5	14	11	1
Nephritis, Liver Fluke		1		
Nephritis, Pneumonia		1		
Pericarditis	2	5	3	
Pericarditis, Liver FLuke			2	
Pleurisy (Grade 2), Liver Abscess (Grade 2)		1		
Tongue Abscess		1		
Tongue Abscess, Liver Fluke			1	
Total viscera conditions noted	16	49	37	1
Total Head in Group	37	85	69	3
% of Group	43.2%	57.6%	53.6%	33.3%

The percentage of liver abscess across the different breeds is also of interest. Liver abscess rates were 0% for the beef cattle in cohort 1 and 24% for the Jersey, 29% for the Jersey cross and 24% for the Holstein cattle as displayed in Fig.14.

Figure 14. Percentage of liver abscess noted at slaughter for cohort 1 cattle by breed.



4.1.14. Cohort 1 - Feedlot-finished sensory outcomes

The cohort 1 feedlot steers were processed on two dates with differing selection criteria driven by commercial factors (Table 30). The beef steers reached a finished state earlier than the dairy breeds, reflecting both heavier initial weight and fatness and maturity pattern. The feedlot management consequently included the majority of the Beef cattle in the first kill with a lesser number of Holstein and Holstein x Jersey and no Jersey cattle. The initial (group 552.1) collections were consequently limited to a subset of 38 head from the 60 processed.

All MSA compliant Holstein (7 head) and Holstein x Jersey (5 head) were selected together with 26 of the beef animals as there were only 3 remaining project beef animals at the feedlot. To the extent possible, selections were made from all pods to ensure a mix of breed, backgrounder and growth treatments. Due to budget constraints only some key indicator cuts were collected at the abattoir after MSA grading for sensory testing. A summary of raw mean values within breed and kill group is displayed in Table 30 with linear model estimates shown previously in Tables 26 – 28. The number of cattle in each breed category from which selected cuts were collected in both kills is shown as well as the total number graded (Table 30).

It is noted that the first kill was predominantly beef breeds which were poorly represented in the final kill group and that less than half of the cattle fed were able to be collected for sensory testing (Table 30). Comparisons of the means in Table 30 were run against each subset collected to confirm that they were representative of the group. The first kill was effectively identical across all traits means within breed as were the final kill other than a 5kg higher HSCW for the Holstein group, 10kg lower HSCW for the HxJ and 6kg lighter HSCW for the Jersey. Other than HSCW each subgroup utilised for sensory sample fabrication had lower pHu (5.6 vs 5.66 (Holstein), 5.64 vs 5.7 (Holstein x Jersey), 5.64 vs 5.78 (Jersey)) than the group mean reflecting a preference for carcases within MSA criteria. Table 31 summarises the muscles utilised for sensory evaluation within each Cohort 1 group including the cooking methods and days ageing post-mortem. Five roasts were fabricated from the TOP073 to be consolidated with other grill and roast comparisons for linkage.

Table 30. Cohort 1 feedlot raw means by breed within kill date for growth and carcase measures

Group 552.1 Feedlot 1, Abattoir 2					**Kill Date 9/7/2019**																		
Breed	**Group**	**No Hd**	**Hd Sensory**	**CarcWt**	**P8**	**HUMP**	**EMA**	**RiBFat**	**U-Oss**	**U-MB**	**A-MB**	**A-MC**	**A-FC**	**pH-U**	**BEntWt**	**GGAIN**	**Gdays**	**G-ADG**	**FEntWt**	**FGAIN**	**FDOF**	**FADG**	**FinalWt**
Holstein*	552.1	7	7	303	8	62	72	6	143	363	1.4	3.6	0.1	5.70	148	128	125	1.00	285	325	215	1.5	610
Holstein x Jersey	552.1	5	5	265	8	63	72	5	128	378	1.4	3.6	0.4	5.75	122	126	134	0.95	260	291	215	1.37	550
Beef	552.1	48	26	306	16	69	82	12	131	397	1.7	2.5	0.1	5.59	191	95	61	1.62	297	287	215	1.35	584
Group 558 Feedlot 1, Abattoir 2					**Kill Date 19/8/2019**																		
Breed	**Group**	**No Hd**	**Hd Sensory**	**CarcWt**	**P8**	**HUMP**	**EMA**	**RiBFat**	**U-Oss**	**U-MB**	**A-MB**	**A-MC**	**A-FC**	**pH-U**	**BEntWt**	**GGAIN**	**Gdays**	**G-ADG**	**FEntWt**	**FGAIN**	**FDOF**	**FADG**	**FinalWt**
Jersey	558.1	37	14	212	8	53	63	4	139	383	1.5	4.6	0.2	5.78	95	111	145	0.78	213	196	256	0.77	409
Holstein*	558.2	85	20	300	9	59	69	6	135	375	1.4	3.9	0.2	5.66	128	127	133	0.95	263	317	256	1.24	580
Holstein x Jersey	558.3	69	29	262	9	56	67	6	137	391	1.5	4.1	0.1	5.70	122	101	113	0.91	237	270	256	1.05	507
Beef	558.4	3	3	307	14	60	74	9	140	477	2.3	3.7	0.3	5.65	195	100	68	1.54	294	298	256	1.17	592

*Holstein includes 1 Montbeliarde x Holstein in each kill

Note: Final weight in kill date 19/8/2019 was calculated from HSCW

Table 31: Summary of cohort 1 feedlot steer muscle x cook x days aged consumer evaluated sensory samples.

		Cook	GRILL		ROAST		Total
Muscle & Group	**Group description & notes**	**Days Aged**	**7**	**21**	**7**	**21**	
CUB045		**Kill Date**					
552.1	36 of 60 head (21 Beef, 7 HH, 8 HJ)	9/07/2019	36	36			72
558.1	14 Jersey	19/08/2019	14	14			28
558.2	18 Holstein including freeze thaw comparison	19/08/2019	37	38			75
558.3	29 Holstein x Jersey	19/08/2019	29	29			58
558.4	3 Beef breed	19/08/2019	3	3			6
CUB081							
552.1	36 of 60 head (21 Beef, 7 HH, 8 HJ)	9/07/2019	17	17			34
558.1	14 Jersey	19/08/2019	7	6			13
558.2	18 Holstein including freeze thaw comparison	19/08/2019	10	10			20
558.3	29 Holstein x Jersey	19/08/2019	13	14			27
558.4	3 Beef breed	19/08/2019	1	1			2
OUT005							
558.1	14 Jersey	19/08/2019	7	7			14
558.2	18 Holstein	19/08/2019	11	11			22
558.3	29 Holstein x Jersey	19/08/2019	14	14			28
558.4	3 Beef breed	19/08/2019	1	1			2
TOP073							
552.1	36 of 60 head (21 Beef, 7 HH, 8 HJ)	9/07/2019	35	35	5	5	80
558.1	14 Jersey	19/08/2019	6	6			12
558.2	18 Holstein including freeze thaw comparison	19/08/2019	8	9			17
558.3	29 Holstein x Jersey	19/08/2019	13	14			27
558.4	3 Beef breed	19/08/2019	2	2			4
TOTAL			**264**	**267**	**5**	**5**	**541**

The remainder of the cohort 1 feedlot cattle (Groups 558.1 to 558.4) were processed 41 days after the initial group. Sixty-four head were selected for cut collection and sensory evaluation: 14 Jersey, 20 Holstein, 29 Holstein x Jersey and the remaining 3 Beef steers. Again, a maximum number of pods, backgrounder, growth path and breed combinations were selected. Both cube rolls were collected from 18 of the Holstein cattle with alternate left and right sides frozen immediately after boning in the plant plate freezer reflecting common processing for a large proportion of secondary cuts. The matching pairs were fabricated into consumer samples following standard MSA sensory protocols. The frozen samples were subsequently thawed with rotated positions 7 or 21 days prior to sensory testing and consumer tested within the same picks as their counterparts (see 4.3.1 for detail). For this collection outside flats (OUT005) and topsides (TOP073) were collected to provide a secondary cut comparison to the cube roll (CUB045 and CUB081 muscles), the relativity of muscles being an important component of prediction modelling and of central importance in establishing if these varied in relation to veal. The raw CMQ4 means for the tested samples are displayed in Table 32 with the untested samples remaining in frozen storage detailed in the appendix.

Table 32. Average CMQ4 values by muscle, cook and days aged within group.

Cook	GRILL		ROAST		Mean
Days Aged	7	21	7	21	
CUB045 Av	**71.0**	**72.3**			**71.6**
552.1	70.6	72.4			71.5
558.1	74.6	77.1			75.8
558.2	72.3	73.1			72.7
558.3	67.9	69.7			68.8
558.4	71.4	62.3			66.9
CUB081 Av	**80.6**	**81.3**			**81.0**
552.1	81.7	83.2			82.4
558.1	85.2	81.7			83.6
558.2	75.5	82.5			79.0
558.3	80.7	78.5			79.5
558.4	81.6	73.6			77.6
OUT005 Av	**43.6**	**43.5**			**43.5**
558.1	47.3	44.9			46.1
558.2	39.0	38.9			39.0
558.3	44.6	45.3			44.9
558.4	52.3	58.6			55.4
TOP073 Av	**46.8**	**48.9**	**32.7**	**34.7**	**46.8**
552.1	44.0	47.8	32.7	34.7	44.4
558.1	62.9	58.4			60.7
558.2	45.6	42.8			44.1
558.3	48.1	51.0			49.6
558.4	42.5	52.4			47.5

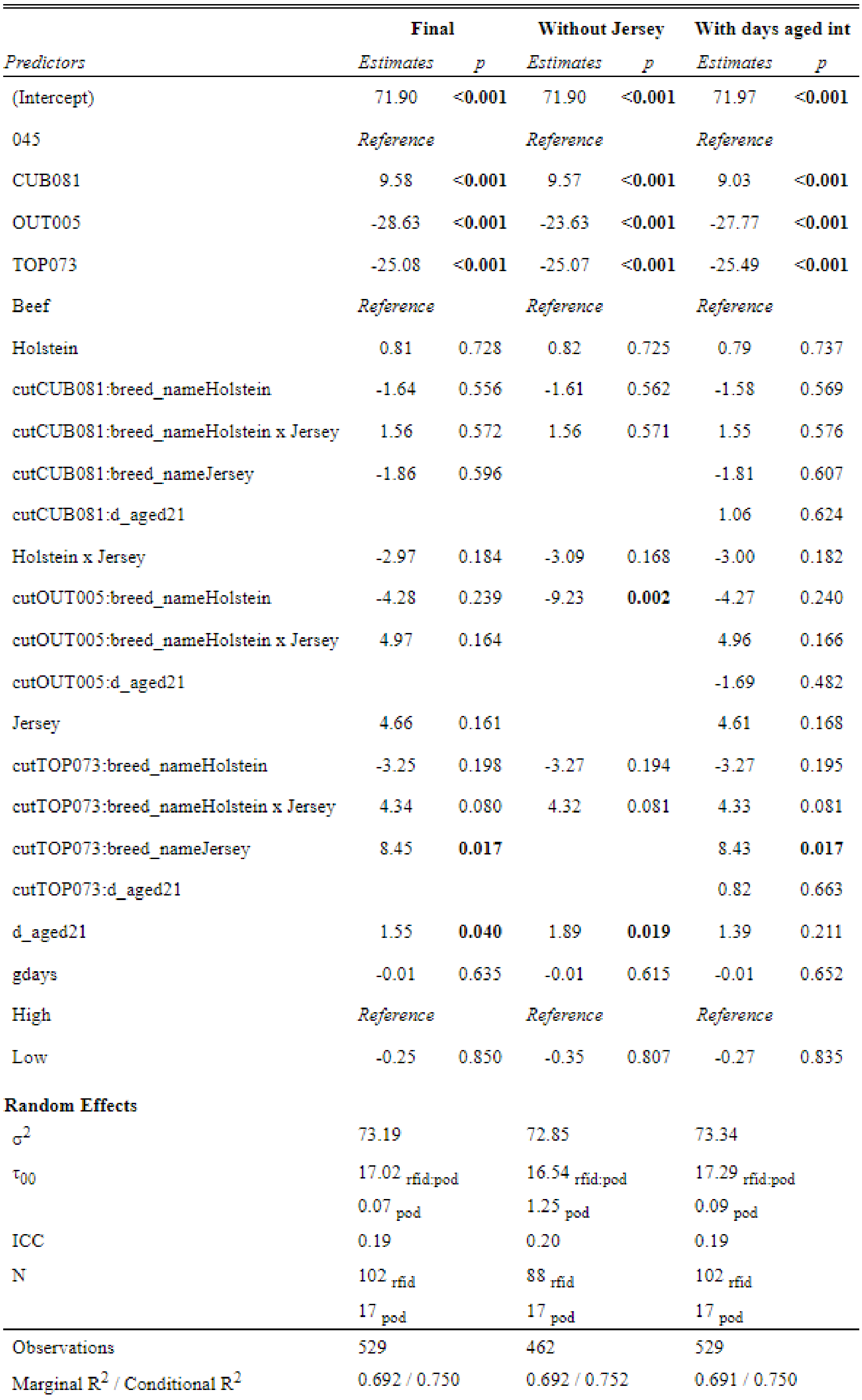
Av=Average.

It was observed that the grill scores for both cube roll muscles are high, being substantially above the 63.5 cut off for MSA 4* for the CUB045 (*M.longissimus dorsi et thoracis*) and above the 5* cut off for MSA 5* for the CUB081 (*M.spinalis dorsi*) (Table 32). Other than the 3 Beef cuts which appear aberrant in 558.4 relative to 552.1 which included 21 Beef, a moderate ageing improvement is shown between 7 and 21 days post-mortem.

It is worthy of note that mean CMQ4 grill values exceed those observed in the veal cohort by around 5 points (Table 19, CMQ4 66.6 at 21 days for CUB045 relative to 71.0 in Table 32 and CMQ4 75.5 for CUB081 relative to 80.6 in Table 32). This emphasises the need for further evaluation of the processing impact on veal carcases which might have been expected to score higher given their very young age.

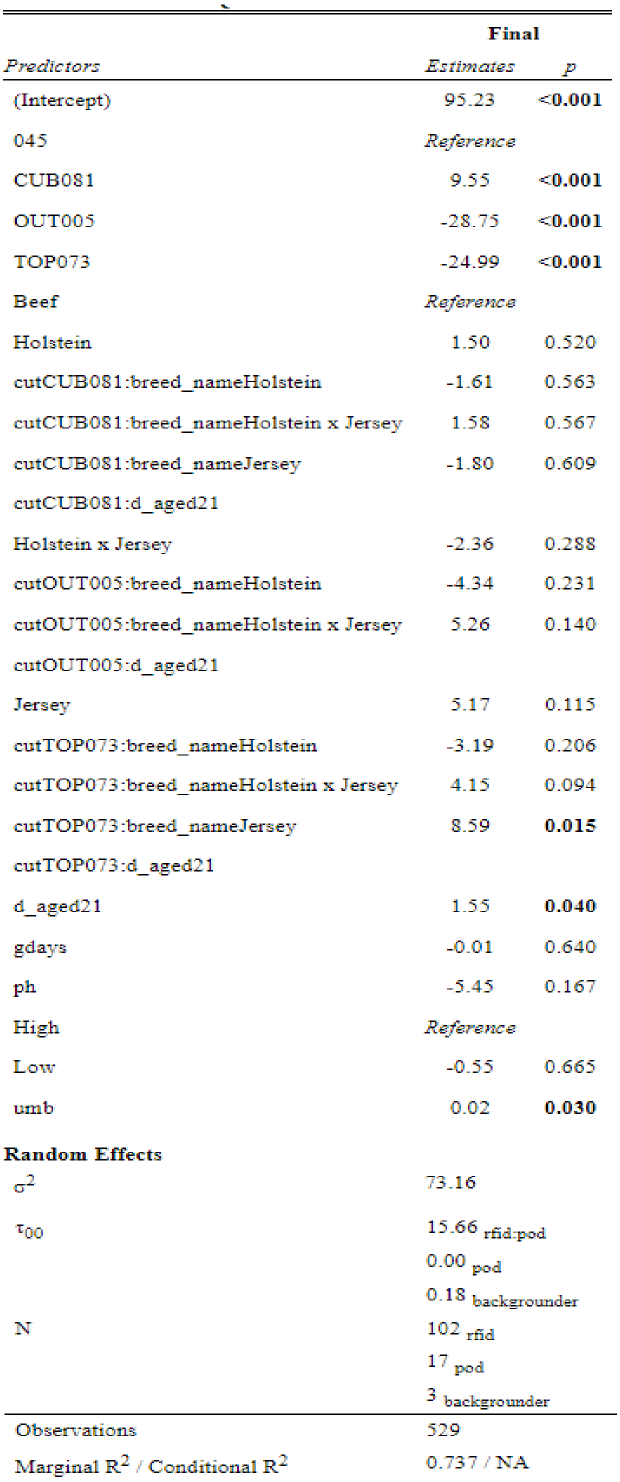
Several statistical models were tested with non-significant terms removed progressively. Several interactions were tested and removed including cut x position, breed x treatment (High/Low), cut x backgrounder days and cut x days aged. All models contained breed and growth path as a fixed effect and interaction between breed and cut, with covariates adjusted for days at backgrounder and days aged post-mortem, random effects were Animal RFID within pod, backgrounder was included initially but was removed as it explained zero variance due to pods being linked with specific backgrounders. The model output is displayed in Table 33.

Table 33. Linear mixed effect models for predicting CMQ4 with cut, breed and growth pathway as fixed effects with days at the backgrounder as a covariate and animal id within pod as a random intercept for feedlot finished grill samples. Estimated coefficients should be interpreted relative to the baseline level, which is for breed beef, cut 045, days aged 7 and high growth pathway.



	Final		**Without Jersey**		**With days aged int**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	71.90	**<0.001**	71.90	**<0.001**	71.97	**<0.001**
045	*Reference*		*Reference*		*Reference*	
CUB081	9.58	**<0.001**	9.57	**<0.001**	9.03	**<0.001**
OUT005	-28.63	**<0.001**	-23.63	**<0.001**	-27.77	**<0.001**
TOP073	-25.08	**<0.001**	-25.07	**<0.001**	-25.49	**<0.001**
Beef	*Reference*		*Reference*		*Reference*	
Holstein	0.81	0.728	0.82	0.725	0.79	0.737
cutCUB081:breed_nameHolstein	-1.64	0.556	-1.61	0.562	-1.58	0.569
cutCUB081:breed_nameHolstein x Jersey	1.56	0.572	1.56	0.571	1.55	0.576
cutCUB081:breed_nameJersey	-1.86	0.596			-1.81	0.607
cutCUB081:d_aged21					1.06	0.624
Holstein x Jersey	-2.97	0.184	-3.09	0.168	-3.00	0.182
cutOUT005:breed_nameHolstein	-4.28	0.239	-9.23	**0.002**	-4.27	0.240
cutOUT005:breed_nameHolstein x Jersey	4.97	0.164			4.96	0.166
cutOUT005:d_aged21					-1.69	0.482
Jersey	4.66	0.161			4.61	0.168
cutTOP073:breed_nameHolstein	-3.25	0.198	-3.27	0.194	-3.27	0.195
cutTOP073:breed_nameHolstein x Jersey	4.34	0.080	4.32	0.081	4.33	0.081
cutTOP073:breed_nameJersey	8.45	**0.017**			8.43	**0.017**
cutTOP073:d_aged21					0.82	0.663
d_aged21	1.55	**0.040**	1.89	**0.019**	1.39	0.211
gdays	-0.01	0.635	-0.01	0.615	-0.01	0.652
High	*Reference*		*Reference*		*Reference*	
Low	-0.25	0.850	-0.35	0.807	-0.27	0.835
Random Effects						
σ^2	73.19		72.85		73.34	
τ_{00}	$17.02_{\text{rfid:pod}}$		$16.54_{\text{rfid:pod}}$		$17.29_{\text{rfid:pod}}$	
	0.07_{pod}		1.25_{pod}		0.09_{pod}	
ICC	0.19		0.20		0.19	
N	102_{rfid}		88_{rfid}		102_{rfid}	
	17_{pod}		17_{pod}		17_{pod}	
Observations	529		462		529	
Marginal R^2 / Conditional R^2	0.692 / 0.750		0.692 / 0.752		0.691 / 0.750	

Table 34. Linear mixed effect models for predicting CMQ4 with cut, breed and growth pathway as fixed effects with days at the backgrounder and carcase characteristics as covariates, animal id within pod as a random intercept for feedlot finished grill samples. Estimated coefficients should be interpreted relative to the baseline level, which is for breed beef, cut 045, days aged 7 and high growth pathway.



	Final	
Predictors	*Estimates*	*p*
(Intercept)	95.23	**<0.001**
045	*Reference*	
CUB081	9.55	**<0.001**
OUT005	-28.75	**<0.001**
TOP073	-24.99	**<0.001**
Beef	*Reference*	
Holstein	1.50	0.520
cutCUB081:breed_nameHolstein	-1.61	0.563
cutCUB081:breed_nameHolstein x Jersey	1.58	0.567
cutCUB081:breed_nameJersey	-1.80	0.609
cutCUB081:d_aged21		
Holstein x Jersey	-2.36	0.288
cutOUT005:breed_nameHolstein	-4.34	0.231
cutOUT005:breed_nameHolstein x Jersey	5.26	0.140
cutOUT005:d_aged21		
Jersey	5.17	0.115
cutTOP073:breed_nameHolstein	-3.19	0.206
cutTOP073:breed_nameHolstein x Jersey	4.15	0.094
cutTOP073:breed_nameJersey	8.59	**0.015**
cutTOP073:d_aged21		
d_aged21	1.55	**0.040**
gdays	-0.01	0.640
ph	-5.45	0.167
High	*Reference*	
Low	-0.55	0.665
umb	0.02	**0.030**
Random Effects		
σ^2	73.16	
τ_{00}	$15.66_{\text{rfid:pod}}$ 0.00_{pod} $0.18_{\text{backgrounder}}$	
N	102_{rfid} 17_{pod} $3_{\text{backgrounder}}$	
Observations	529	
Marginal R^2 / Conditional R^2	0.737 / NA	

As Jersey breed was not included in the Low Growth treatment, models were compared (see Table 34) to consider output with Jersey removed or included. An additional model also considered an interaction between day post-mortem ageing and cut type to determine whether there were different ageing rates across the cuts. The reference intercept was beef 045 from the high growth pathway with only 045 (STR045 and CUB045 combined), CUB081, OUT005 and TOP073 included for this analysis. Outputs of this analysis are shown in Table 35.

As shown in Table 35, the estimates were similar across all three models with the spinalis (CUB081) coefficient consistently 9-10 points above the 045, the topside (TOP073) and outside flat (OUT005) muscles coefficients estimated as in the order of 25 to 28 MQ4 points ($p = < 0.001$) below the reference 045. This is a much larger difference than that observed between the leg cuts and the 045 in the veal cattle. Marginal R^2 results for each of the models indicates that removing Jersey animals ($R^2 = 0.69$) from the analysis and/or considering a cut by days ageing interaction ($R^2 = 0.68$) does not improve the accuracy of the prediction model.

Neither the growth path treatment nor breed was a significant predictor of MQ4, with Jersey trending towards being significantly better than Beef. However, there was a significant interaction between breed and cut with the linear mixed model results (Table 36) showing that this was being driven by Jersey Topside values ($p = 0.009$) which were significantly higher than its beef counterparts. This was the case for all sensory variables except flavour and juiciness, where the interaction was no longer significant. Days aged reached significance for 21 ($p = 0.04$), similar to that of the earlier veal model, however feedlot animals had less days ageing samples than their veal counterparts which may have influenced this finding.

When considering the carcase traits in the model, only MSA marbling was significant in predicting MQ4 ($p = 0.03$). The relationship between MQ4 and MSA marbling is displayed in Fig. 15.

Figure 15. Relationship between MQ4 and MSA marbling using predicted values from final cohort 1 model

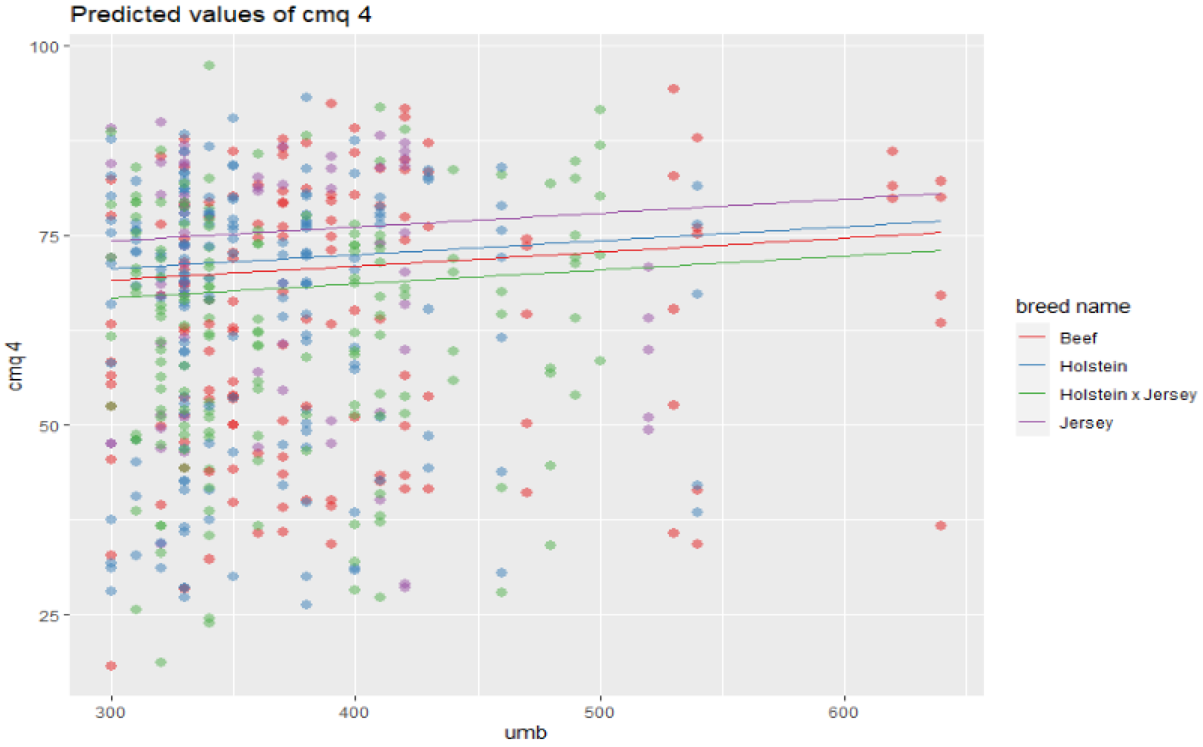


Table 35. Linear mixed effect models with cut, breed, growth pathway as fixed effects adjusted for days at the backgrounder and carcase characteristics; MSA marbling and ultimate pH and animal id within pod as a random intercept for cohort 1 feedlot grill samples. For each dependent variable (CMQ4, Tenderness, Juiciness, Flavour and Overall liking) there were 93 compliant carcases and 229 samples.

	CMQ4		**Tender**		**Juicy**		**Flavour**		**Overall Liking**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	95.23	**<0.001**	109.59	**<0.001**	74.30	**0.001**	91.11	**<0.001**	97.59	**<0.001**
045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
CUB081	9.55	**<0.001**	11.23	**<0.001**	13.49	**<0.001**	7.80	**<0.001**	9.44	**<0.001**
OUT005	-28.75	**<0.001**	-39.98	**<0.001**	-16.81	**<0.001**	-21.11	**<0.001**	-29.77	**<0.001**
TOP073	-24.99	**<0.001**	-30.39	**<0.001**	-23.49	**<0.001**	-21.00	**<0.001**	-25.10	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Holstein	1.50	0.520	4.10	0.134	0.20	0.933	0.14	0.952	0.78	0.753
cutCUB081:breed_nameHolstein	-1.61	0.563	-3.85	0.257	1.41	0.659	-0.40	0.887	-1.77	0.544
cutCUB081:breed_nameHolstein x Jersey	1.58	0.567	-2.54	0.450	2.17	0.492	3.18	0.253	3.13	0.279
cutCUB081:breed_nameJersey	-1.80	0.609	-3.96	0.357	-2.80	0.488	-0.36	0.919	-1.97	0.593
Holstein x Jersey	-2.36	0.288	1.14	0.659	-2.59	0.260	-4.49	**0.044**	-3.54	0.132
cutOUT005:breed_nameHolstein	-4.34	0.231	-6.89	0.118	-5.51	0.180	-3.78	0.300	-3.71	0.329
cutOUT005:breed_nameHolstein x Jersey	5.26	0.140	4.56	0.292	4.67	0.247	3.24	0.367	6.28	0.093
Jersey	5.17	0.115	7.68	**0.045**	5.68	0.096	2.17	0.510	5.13	0.140
cutTOP073:breed_nameHolstein	-3.19	0.206	-5.62	0.068	-2.23	0.436	-1.18	0.642	-3.05	0.248
cutTOP073:breed_nameHolstein x Jersey	4.15	0.094	2.83	0.348	2.93	0.299	4.00	0.109	5.04	0.052
cutTOP073:breed_nameJersey	8.59	**0.015**	11.43	**0.008**	5.06	0.204	8.04	**0.023**	7.79	**0.035**
d_aged21	1.55	**0.040**	1.66	0.072	1.54	0.075	1.14	0.134	1.55	**0.050**
gdays	-0.01	0.640	-0.02	0.318	-0.02	0.287	0.01	0.716	-0.00	0.770
ph	-5.45	0.167	-7.65	0.090	-2.82	0.467	-4.70	0.233	-5.69	0.174
High	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Low	-0.55	0.665	-0.47	0.748	-1.49	0.311	-0.84	0.506	-0.69	0.608
umb	0.02	**0.030**	0.02	0.068	0.03	**0.001**	0.02	**0.039**	0.02	0.053
Random Effects										
σ^2	73.16		109.27		96.51		74.44		80.28	
τ_{00}	$15.66_{\text{rfid:pod}}$		$17.79_{\text{rfid:pod}}$		$9.40_{\text{rfid:pod}}$		$15.51_{\text{rfid:pod}}$		$18.18_{\text{rfid:pod}}$	
	0.00_{pod}		0.00_{pod}		1.86_{pod}		0.00_{pod}		0.00_{pod}	
	$0.18_{\text{backgrounder}}$		$1.27_{\text{backgrounder}}$		$0.00_{\text{backgrounder}}$		$0.00_{\text{backgrounder}}$		$0.08_{\text{backgrounder}}$	
N	102_{rfid}		102_{rfid}		102_{rfid}		102_{rfid}		102_{rfid}	
	17_{pod}		17_{pod}		17_{pod}		17_{pod}		17_{pod}	
	$3_{\text{backgrounder}}$		$3_{\text{backgrounder}}$		$3_{\text{backgrounder}}$		$3_{\text{backgrounder}}$		$3_{\text{backgrounder}}$	
Observations	529		529		529		529		529	
Marginal R^2 / Conditional R^2	0.737 / NA		0.753 / NA		0.656 / NA		0.647 / NA		0.722 / NA	

Table 36. Average Cohort 2 feedlot carcase and animal data for breed within growth path by group (kill date).

Group 571.1 Feedlot 2, Abbatoir 2 **Kill Date 9/11/2020**

Breed	Growth Path	No Hd	CarcWt	P8	HUMP	EMA	RiBFat	U-Oss	U-MB	A-MB	A-MC	A-FC	pH-U	MSA IDX	Age	BEntWt	GGAIN	Gdays	G-ADG	FEntWt	FGAIN	FDOF	FADG	FinalWt	EfinWt	LADG
British	High Jersey	6	305	17	70	78	12.3	110	447	2.0	2.8	0.0	5.51	62.2	NA	204	212	155	1.37	416	146	110	1.33	562	562	NA
Euro	High Holstein	6	331	17	92	90	11.3	142	463	2.3	3.0	0.0	5.53	58.8	NA		217	155	1.40	482	126	110	1.14	608	608	NA
Euro	High Jersey	0																								
Euro	Low Holstein	6	300	13	88	82	11.0	118	442	2.0	3.5	0.0	5.54	59.0	NA	290	176	155	1.13	437	120	110	1.09	557	557	NA
Holstein	High Holstein	10	299	8	65	68	8.2	119	395	1.4	4.5	0.1	5.60	60.0	452	226	210	155	1.36	436	162	110	1.47	598	598	1.32
Holstein	Low Holstein	10	274	7	60	70	6.3	122	381	1.4	4.3	0.2	5.64	59.1	453	228	187	155	1.21	415	128	110	1.16	543	543	1.20
HH x JJ	High Holstein	8	244	8	65	69	6.9	130	390	1.6	5.1	0.1	5.75	57.8	423	177	182	155	1.17	358	142	110	1.29	500	500	1.18
HH x JJ	High Jersey	7	249	8	61	64	7.6	116	401	1.6	4.6	0.1	5.67	59.5	424	171	183	155	1.18	353	152	110	1.39	506	506	1.19
HH x JJ	Low Holstein	7	234	7	63	65	6.3	123	429	1.9	4.7	0.9	5.77	58.8	428	172	170	155	1.09	342	137	110	1.24	479	479	1.12
Jersey	High Jersey	8	195	7	56	61	5.9	115	435	2.0	5.6	0.6	5.84	58.4	439	143	156	155	1.01	299	124	110	1.13	423	423	0.96
All Group	All	68	268	10	67	71	8.1	121	416	1.8	4.4	0.2	5.66	59.3	438	196	188	155	1.21	392	138	110	1.26	530	530	1.17

Group 572.1 Feedlot 3, Abattoir 2 **Kill Date 23/11/2020**

Breed	Growth Path	No Hd	CarcWt	P8	HUMP	EMA	RiBFat	U-Oss	U-MB	A-MB	A-MC	A-FC	pH-U	MSA IDX	Age	BEntWt	GGAIN	Gdays	G-ADG	FEntWt	FGAIN	FDOF	FADG	FinalWt	EfinWt	LADG
British	High Jersey	12	323	19	71	83	15.6	116	466	2.2	2.5	0.1	5.49	66.0	NA	207	164	136	1.24	371	213	142	1.64	584	603	NA
Euro	High Holstein	7	303	15	87	82	9.4	124	346	1.1	3.5	0.3	5.47	61.9	NA	211	159	152	1.04	357	182	142	1.40	539	556	NA
Euro	High Jersey	6	308	19	69	87	13.5	125	362	1.2	2.2	0.0	5.45	63.4	NA	247	151	114	1.32	389	164	142	1.26	553	568	NA
Euro	Low Holstein	14	313	14	79	84	9.1	128	363	1.1	3.1	0.1	5.54	62.3	NA	254	105	133	0.84	360	192	142	1.47	551	569	NA
Holstein	High Holstein	18	289	9	64	73	7.0	123	406	1.5	4.4	0.1	5.65	63.3	465	216	141	152	0.96	352	183	142	1.40	534	551	1.15
Holstein	Low Holstein	22	281	9	62	73	6.4	124	426	1.9	4.3	0.1	5.65	63.4	470	210	113	159	0.81	329	207	142	1.59	536	555	1.14
HH x JJ	High Holstein	22	256	9	63	72	7.1	132	418	1.8	4.5	0.0	5.69	62.6	472	202	136	145	0.97	333	161	143	1.23	494	509	1.05
HH x JJ	High Jersey	8	257	8	62	70	5.5	129	366	1.3	4.6	0.1	5.68	61.7	471	121	173	200	0.87	291	213	142	1.64	504	523	1.07
HH x JJ	Low Holstein	14	253	8	62	70	5.4	128	404	1.5	4.4	0.2	5.68	62.4	473	181	111	163	0.76	297	193	143	1.48	490	508	1.04
Jersey	High Jersey	20	203	8	55	65	4.4	127	390	1.6	5.0	0.5	5.78	61.6	454	159	114	133	0.88	269	139	142	1.07	409	422	0.90
All Group	All	143	272	11	65	74	7.6	126	402	1.6	4.1	0.2	5.64	62.9	467	200	131	148	0.93	329	182	142	1.40	512	528	1.06

Group 573.1 Feedlot 3, Abattoir 2 **Kill Date 1/2/2021**

Breed	Growth Path	No Hd	CarcWt	P8	HUMP	EMA	RiBFat	U-Oss	U-MB	A-MB	A-MC	A-FC	pH-U	MSA IDX	Age	BEntWt	GGAIN	Gdays	G-ADG	FEntWt	FGAIN	FDOF	FADG	FinalWt	EfinWt	LADG
British	High Jersey	12	319	15	63	82	12.2	127	464	2.2	3.1	0.7	5.54	64.6	NA	184	207	223	0.93	377	201	123	1.83	578	603	NA
Euro	High Holstein	12	366	16	80	98	10.3	136	415	1.7	2.7	1.2	5.51	63.0	NA	264	204	226	0.91	456	193	123	1.75	649	673	NA
Euro	High Jersey	1	401	30	60	111	20.0	140	420	2.0	2.0	1.0	5.49	64.1	NA	270	218	243	0.90	500	196	123	1.78	696	721	NA
Euro	Low Holstein	11	332	13	90	95	9.4	127	385	1.5	2.7	0.9	5.49	62.1	NA	264	167	225	0.75	418	175	123	1.59	593	615	NA
Holstein	High Holstein	13	307	9	60	73	7.2	132	370	1.3	3.7	1.0	5.63	61.9	529	153	206	243	0.85	366	218	123	1.98	584	611	1.10
Holstein	Low Holstein	8	289	7	53	75	5.9	129	364	1.3	3.6	1.0	5.57	62.3	529	154	182	243	0.75	343	210	123	1.91	554	580	1.05
HH x JJ	High Holstein	14	270	8	57	73	5.6	129	405	1.5	4.4	1.5	5.63	62.5	527	191	172	223	0.78	342	192	123	1.75	533	478	0.87
HH x JJ	High Jersey	14	282	9	58	72	6.4	132	379	1.4	4.4	1.1	5.54	62.2	526	199	173	223	0.78	354	186	123	1.69	539	563	1.03
HH x JJ	Low Holstein	13	277	8	61	74	5.1	128	386	1.5	4.2	1.5	5.59	62.4	531	197	167	221	0.76	340	197	123	1.79	538	563	1.01
Jersey	High Jersey	22	211	7	53	67	4.1	129	388	1.5	4.6	1.9	5.66	61.6	526	136	157	225	0.70	279	147	123	1.33	425	444	0.81
All Group	All	120	288	10	63	78	7.2	130	396	1.5	3.9	1.3	5.58	62.5	528	190	180	227	0.79	357	187	123	1.70	544	559	0.95

Group 573.2 Feedlot 3, Abattoir 4 **Kill Date 24/6/2021**

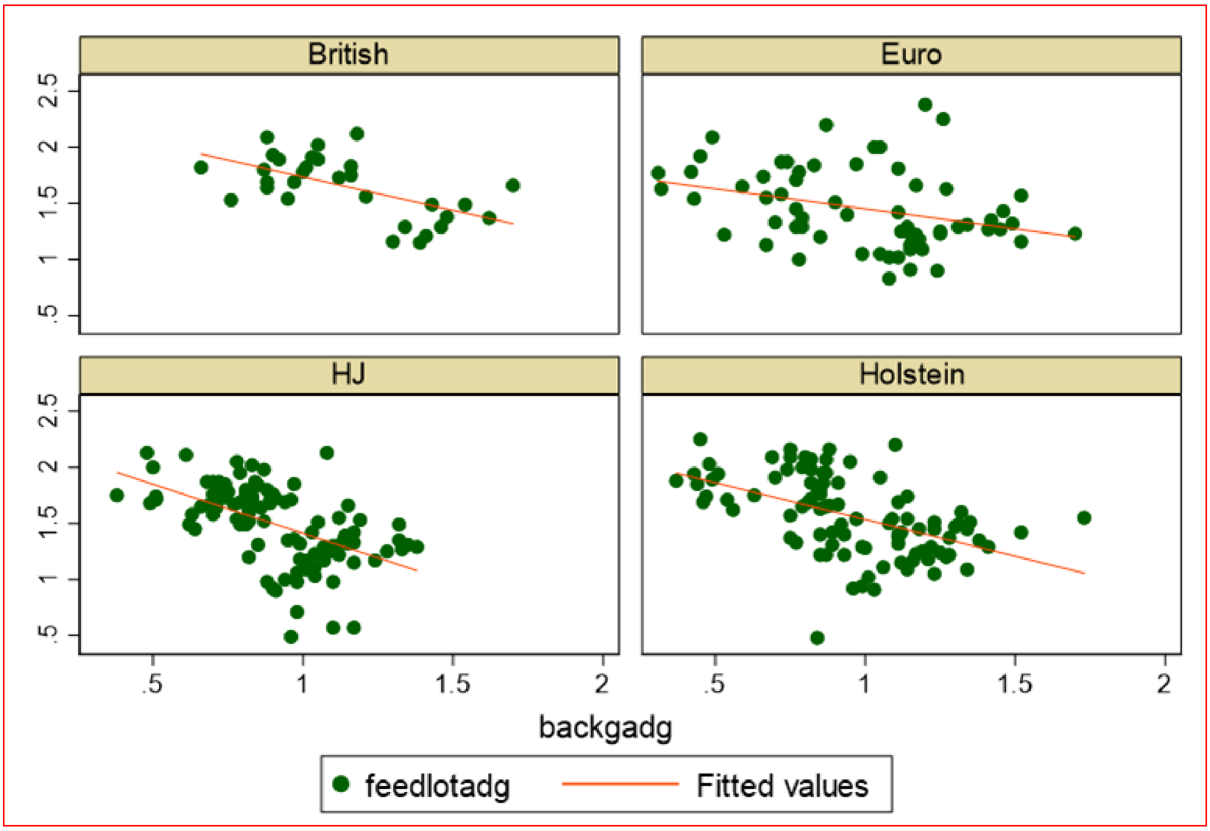
Breed	Growth Path	No Hd	CarcWt	P8	HUMP	EMA	RiBFat	U-Oss	U-MB	A-MB	A-MC	A-FC	pH-U	MSA IDX	Age	BEntWt	GGAIN	Gdays	G-ADG	FEntWt	FGAIN	FDOF	FADG	FinalWt	EfinWt	LADG
Holstein	High Holstein	7	326	7	56	69	5.4	127	359	1.1	3.6	0.7	5.45	62.3	504	72	188	183	1.03	230	359.5	267	1.35	589	635	1.17
Holstein	Low Holstein	8	304	3	53	69	4.8	129	365	1.3	2.6	0.9	5.47	62.0	506	78	158	183	0.86	199	354.0	267	1.33	553	598	1.09
All Group	All	15	315	5	54	69	5.1	128	362	1.2	3.1	0.8	5.46	62.2	505	75	172	183	0.94	213	357	267	1.34	570	615	1.13

4.1.15. Cohort 2 - Feedlot finished steers

For cohort 2 feedlot steers, there were 15 pods, 120 LG steers (Table 36, 37 & 38) and 243 HG steers that provided growth and carcase data (Table 36 & 39). As for cohort 1, birthdates and birth weights were not available for beef steers and this precluded ADG analysis on a lifetime basis. The ADG was assessed during the backgrounding period at pasture and in the feedlot. Table 37 displays mean carcase and animal data within breed and growth path for individual groups (kill dates). The final group of 15 head differ in all being Holstein steers from a single source farm and backgrounder. Some care should be taken in evaluating the finishing gain kg (FGAIN) as the final feedlot weight dates varied from 1 to 30 days prior to slaughter date. The calculations for ADG and lifetime ADG (LADG) are made from the recorded weights (FEntWt and Final Wt) and days between entry and the final weighing. The actual feedlot period (FDOF) shown is the actual days from entry to exit with the estimated final weight (EfinWt) calculated by adding the FADG multiplied by the days between the final and exit dates (Table 36).

It is noted that there are substantial differences within and between the various breeds and kill date groups. The dairy cattle age at slaughter varied from 438 to 528 days with significant differences in their backgrounding (Gdays 148 – 227) and finishing (FDOF 110 – 267) days. There were also differences in ADG between groups and across the backgrounding and finishing periods with the highest finishing average ADG negatively related to backgrounding ADG in the raw data as displayed in Fig.15. This would be consistent with cohort 1 where compensatory growth was observed for the low growth treatment in the finishing phase, but the treatment effect was not significant when analysed for cohort 2 with all groups aggregated and the fitted models adjusting for backgrounder days, backgrounder and feedlot weights and ADG in combination with pod and kill date.

Figure 16. Raw values plots for backgrounder ADG (x axis) and feedlot ADG (y axis) by breed group



There were also clear breed effects within the dairy breeds with the Jersey cattle having lower carcase weights (195 to 211 kg), lower backgrounder entry weight (BEntWt), FEntWt and Final Wt and lower ADG (Table 37) in both feeding periods at similar age despite being only fed within the HG treatment. They also had lower hump height and EMA but higher pHu. Each of these observations raises concern in regard to a commercial meat pathway for purebred Jersey cattle under current MSA models given the relationships to production profitability. The Holstein X Jersey cattle were superior to the Jersey and intermediate between Jersey and Holstein for all growth and carcase weight and yield attributes suggestive of hybrid benefit. The Holstein groups were similar to the beef groups for growth performance and carcase weight but had lower P8 and ribfat and smaller EMA. The British breed steers tended to have higher marbling in combination with much greater P8 and rib fat. Marbling was similar across the dairy breeds and all breeds exhibited similar ossification.

Entry weight to backgrounding (GEntWt) varied from 75 to 200 kg with the first 3 groups between 190 to 200kg. The FEntWt varied further, with the first 3 groups ranging from 329 to 392 kg and the fourth at 267 kg, as did DOF with a range from 110 to 267 days. Interestingly the final group with the lightest BEntWt had the heaviest carcase weight of 315 kg and, understandably, the longest days on feed at 267 days.

Cohort 2 evaluation of the effect of growth path, breed and their interaction were reported for 304 head (Table 38) with all groups analysed within a single analysis. While group (kill date) was significant, and also confounded with feedlot and abattoir, they were deemed to be adjusted by including pod as a random effect.

The hypothesis for this cohort was that effects of growth path in backgrounding phase will not be evident when fed in their pods at the feedlot. In contrast to cohort 1 where steers were combined in a single lot following backgrounding, Cohort 2 showed no significant treatment effects with LG steers having a lower ADG and backgrounder and feedlot exit weight, lower carcase weight, less P8 fat depth and rib fat and a tendency ($P < 0.1$) to higher meat colour score and lower MSA index (Table 38).

For the LG steers, backgrounder ADG did not differ among breeds ($P = 0.085$) and weight at entry to the backgrounder did not influence responses. The ADG for all breeds were 0.82 ± 0.12 kg/d for HxJ to 0.88 ± 0.12 kg/d for the Euro steers and consistent with the target performance for the study. Exit weight from the backgrounder for the three breeds did not differ but was influenced by entry weight to backgrounding (Table 38). The feedlot exit weights for the Euro (525 ± 15kg), Holsteins (559 ± 15kg) and HxJ (543 ± 15kg) did not differ, but the Euro steers performed below expectations as these weighed less, possibly indicating that rations fed did not support the phenotypic potential for growth. The lack of difference in exit weight with days on feed as a covariable was reflected in the feedlot gain as the Euro steers gained less total weight (178 ± 20kg), than the Holstein (208 ± 20kg) or HxJ (201 ± 20kg). The Euro (295 ± 9kg) and Holstein (295 ± 8kg) had heavier carcase weights than the HxJ (280 ± 9kg).

The feedlot exit weights and carcase weights were influenced by days at the feedlot, entry weight and difference in slaughter days. The feedlot ADG was similar for the Holstein (1.62 ± 0.15 kg/d) and the HxJ (1.57 ± 0.15 kg/d), but surprisingly greater than the Euro steers (1.38 ± 0.15 kg/d) and was influenced by exit background weight. The Euro steers had much greater hump height and eye muscle area than the other two breeds (Table 38). Entry weight to backgrounding influenced hump height and feedlot days, slaughter day and exit backgrounder weight all influenced eye muscle area. The P8 fat depth was also much greater for the Euro steers (13.0 ± 0.7mm) than the Holstein (6.3 ± 0.4mm) or HxJ (5.8 ± 0.5mm). Interestingly covariables did not influence P8 fat depth (Table 38). The

HxJ steers (411 ± 14 units) had higher marbling than the Euro steers (369 ± 15 units) but did not differ to the Holsteins (401 ± 11 units). Entry weight from backgrounding influenced these results (Table 38). However, the fat colour of the HxJ, similar to the marbling score, did not differ to the Holsteins but was greater than the Euro steers (Table 38) and was influenced by days in the feedlot. Ultimate pH was higher for both the HxJ (5.66 ± 0.02) and Holsteins (5.62 ± 0.02) than the Euro steers (5.52 ± 0.02) and was influenced by slaughter day.

Table 38 shows the consistent observation that meat colour score was higher in the dairy breed (HxJ and Holstein) than the Euro steers. Again, this is also in line with the higher ultimate pH across the dairy breed groups relative to beef. Meat colour was influenced by slaughter day. Importantly, MSA index did not differ among breeds and exceeded 60 with a low standard error indicating good meat quality and consistency of that outcome (Table 38). MSA index was influenced by the days on the feedlot and slaughter days.

In contrast to the LG steers, backgrounder ADG differed among breeds and weight at entry to the backgrounder influenced responses for the HG steers. For the HG steers, both the British 1.16 ± 0.09 kg/d and Euro steers 1.16 ± 0.09 kg/d achieved gains consistent with the study target of 1.2 kg/d and did not differ to each other but were greater than the Holsteins 1.02 ± 0.09 kg/d, that were greater than the HxJ 0.93 ± 0.08 kg/d. The HxJ gains exceeded the Jersey steers 0.81 ± 0.09 kg/d and results were influenced by entry weight to backgrounding (Table 39).

Interestingly, exit weight from the backgrounder was greatest for the Euro steers (379 ± 11kg) but did not differ from the British (377 ± 10kg) which did not differ from the Holsteins (365 ± 10kg). The Holstein steers weighed more than the HxJ (351 ± 10kg) which also weighed more than the Jersey steers (319 ± 10kg) and exit weight was influenced by entry weight to backgrounding (Table 39). The feedlot exit weights for the Euro (557 ± 17kg), British (568 ± 17kg) and Holsteins (565 ± 16kg) did not differ, while the HxJ (521 ± 15kg) weighed less, but more than the Jersey steers (445 ± 16kg).

Exit weight from the feedlot was influenced only by the exit background weight. The Holstein (204 ± 10kg) and British breeds (197 ± 10kg) gained the most weight in the feedlot, but the British steers did not differ to the Euro steers that gained similar weight (183 ± 10kg) to the HxJ steers (180 ± 9kg) and the Jersey steers gained the least weight (137 ± 10kg) (Table 39). The British (313 ± 9kg) and Euro (310 ± 9kg) steers had heavier carcase weights than the Holsteins (297 ± 9kg) that were heavier than the HxJ (267 ± 8kg) that were heavier that the Jersey steers (221 ± 9kg). The carcase weights were influenced by feedlot entry weight.

The feedlot ADG was greatest for the Holstein (1.69 ± 0.08 kg/d) and British steers (1.61 ± 0.08 kg/d). The latter were not significantly greater than the Euro steers (1.50 ± 0.08 kg/d) which did not differ from the HxJ (1.49 ± 0.07 kg/d), but the Jersey steers gained the least per day (1.12 ± 0.08 kg/d). The Euro steers had considerably greater hump height (79.0 ± 2.3cm) and eye muscle area (89.1 ± 1.6cm^2) than other breeds (Table 39). The British breed steers had greater hump height (67.0 ± 2.1cm) and EMA (81.2 ± 1.5cm^2) than the Holstein (61.4 ± 1.9cm and 72.0 ± 1.2cm^2), HxJ (61.4 ± 1.6cm and 70.7 ± 1.0cm^2), and Jersey steers (56.1 ± 1.9cm and 65.9 ± 1.9cm^2) (Table 39).

Table 37. For cohort 2 Low Growth path steers; estimated marginal means ± SE for the effects of breed on backgrounding and feedlot performance. Models include the fixed effects of breed and the random effects of identity within a pod and farm (*N = 117, otherwise N = 114).

	Breed			*P*-value			
Outcome	Holstein x Jersey N = 50	Holstein N = 34	European N = 33	Breed	Feedlot d	Entry or exit backgrounder weight	Slaughter d
Average daily gain on farms (kg/d)*	0.82 ± 0.12	0.87 ± 0.12	0.88 ± 0.12	0.085	NA	0.382	NA
Background exit weight (kg)*	348.9 ± 15.26	353.9 ± 15.17	347.2 ± 15.46	0.407	NA	**<0.001**	NA
Exit Feedlot Weight (kg)	543.4 ± 22.04^{a}	559.4 ± 21.63^{a}	525.0 ± 22.36^{b}	0.004	**<0.000**	**<0.001**	**0.007**
Feedlot gain (kg)	201.5 ± 20.10^{a}	207.9 ± 19.87^{a}	178.5 ± 20.28^{b}	0.001	**<0.001**	**0.035**	**0.096**
Carcase weight (kg)	280.0 ± 8.76^{a}	295.1 ± 8.39^{b}	295.2 ± 9.29^{b}	0.014	**<0.001**	**<0.001**	0.115
Feedlot average daily gain (kg/d)	1.57 ± 0.15^{a}	1.62 ± 0.15^{a}	1.38 ± 0.15^{b}	<0.001	0.621	**0.040**	0.450
Hump height (mm)	63.3 ± 1.89^{a}	59.8 ± 1.58^{a}	80.9 ± 2.10^{b}	<0.001	0.650	**<0.001**	0.798
Eye muscle area (cm^{2})	71.4 ± 1.43^{a}	73.3 ± 1.19^{a}	84.1 ± 1.59^{b}	<0.001	**0.004**	**<0.001**	**<0.001**
P8 fat depth (mm)	7.60 ± 0.67^{a}	7.49 ± 0.58^{a}	12.98 ± 0.73^{b}	<0.001	0.120	0.250	0.615
Rib fat (mm)	5.79 ± 0.46^{a}	6.26 ± 0.39^{a}	8.83 ± 0.5^{b}	<0.001	0.368	**0.002**	0.269
Marble (Score 1 to 1190)	411.4 ± 13.66^{a}	401.0 ± 11.4^{ab}	368.6 ± 15.20^{b}	0.121	0.193	**0.011**	0.187
Fat colour score (0-9)	0.77 ± 0.17^{a}	0.47 ± 0.16^{ab}	0.44 ± 0.17^{b}	0.001	**0.027**	0.143	0.078
Ossification (Score 100 to 590)	129.7 ± 2.40^{a}	125.8 ± 2.05^{ab}	121.7 ± 2.65^{b}	0.075	0.407	**<0.001**	0.103
Ultimate pH	5.66 ± 0.02^{a}	5.61 ± 0.02^{a}	5.52 ± 0.02^{b}	<0.001	0.818	0.918	**0.024**
Colour (Score 1 to 6)	4.33 ± 0.15^{a}	4.02 ± 0.13^{a}	2.76 ± 0.17^{b}	<0.001	0.630	0.470	**0.029**
Meat Standards Australia Index	61.7 ± 0.42	62.1 ± 0.38	61. ± 0.45	0.175	**0.001**	0.601	**<0.001**

$^{a-b}$ Superscripts that differ within a row denote significance P < 0.05

Table 38. For cohort 2 High Growth path steers; estimated marginal means ± SE for the effects of breed on backgrounding and feedlot performance. Models include the fixed effects of breed and the random effects of identity within a pod and farm. (*N = 237, otherwise N = 230).

Outcome	Breed					*P*-value			
	Jersey N = 50	Holstein x Jersey N = 50	Holstein N = 73	British N = 31	European N = 33	Breed	Feedlot d	Entry or exit backgrounder weight	Slaughter d
Average daily gain on farms (kg/d)*	0.81 ± 0.09^{a}	0.93 ± 0.08^{b}	1.02 ± 0.09^{c}	1.16 ± 0.09^{d}	1.16 ± 0.09^{d}	<0.001	NA	**0.003**	NA
Background exit weight (kg)*	319.2 ± 10.18^{a}	351.1 ± 9.71^{b}	365.2 ± 10.02^{c}	377.0 ± 10.33^{cd}	379.3 ± 10.55^{d}	<0.001	NA	**<0.001**	NA
Exit Feedlot Weight (kg)	445.2 ± 16.28^{a}	521.3 ± 15.49^{b}	565.1 ± 16.20^{c}	567.5 ± 16.53^{c}	557.4 ± 17.07^{c}	<0.001	0.179	**<0.001**	0.707
Feedlot gain (kg)	137.3 ± 9.84^{a}	180.0 ± 9.21^{b}	204.4 ± 9.78^{c}	196.6 ± 10.05^{cd}	183.2 ± 10.48^{bd}	<0.001	0.065	**0.050**	0.058
Carcase weight (kg)	221.0 ± 8.90^{a}	266.6 ± 8.45^{b}	297.2 ± 8.84^{c}	312.8 ± 9.06^{d}	310.3 ± 9.40^{d}	<0.001	0.119	**<0.001**	0.376
Feedlot average daily gain (kg/d)	1.12 ± 0.08^{a}	1.49 ± 0.07^{b}	1.69 ± 0.08^{c}	1.61 ± 0.08^{cd}	1.50 ± 0.08^{bd}	0.001	**<0.001**	0.079	**0.026**
Hump height (mm)	56.1 ± 1.92^{a}	61.4 ± 1.61^{b}	61.4 ± 1.86^{b}	67.0 ± 2.08^{c}	79.0 ± 2.31^{d}	<0.001	0.112	**0.014**	0.153
Eye muscle area (cm^2)	65.9 ± 1.24^{a}	70.7 ± 0.96^{b}	72.0 ± 1.21^{b}	81.2 ± 1.47^{c}	89.1 ± 1.60^{d}	<0.001	**0.011**	0.060	**<0.001**
P8 fat depth (mm)	8.30 ± 0.58^{a}	8.60 ± 0.48^{a}	8.38 ± 0.57^{a}	16.5 ± 0.65^{b}	15.30 ± 0.72^{b}	<0.001	0.505	**0.001**	0.827
Rib fat (mm log transformed)	5.15 ± 0.44^{a}	6.58 ± 0.34^{b}	7.01 ± 0.43^{b}	13.4 ± 0.52^{c}	10.00 ± 0.57^{d}	<0.001	0.140	**<0.001**	0.091
Marble (Score 1 to 1190)	407.3 ± 10.57^{a}	398.4 ± 8.16^{a}	388.7 ± 10.35^{a}	458.2 ± 12.55^{b}	381.5 ± 13.66^{a}	<0.001	0.693	**0.006**	0.270
Fat colour score (0-9)	1.12 ± 0.19^{a}	0.57 ± 0.18^{b}	0.47 ± 0.19^{b}	0.27 ± 0.19^{c}	0.44 ± 0.20^{bc}	<0.001	**0.017**	0.187	**0.035**
Ossification (Score 100 to 590)	126.6 ± 2.26^{a}	129.1 ± 1.73^{a}	124.6 ± 2.23^{ab}	119.4 ± 2.55^{c}	130.9 ± 2.80^{ad}	0.001	0.267	0.495	**0.006**
Ultimate pH	5.73 ± 0.03^{a}	5.65 ± 0.02^{b}	5.61 ± 0.02^{b}	5.52 ± 0.03^{c}	5.50 ± 0.03^{c}	<0.001	0.512	0.147	0.104
Colour (Score 1 to 6)	4.86 ± 0.14^{a}	4.51 ± 0.1^{b}	4.15 ± 0.14^{c}	2.58 ± 0.17^{d}	2.58 ± 0.19^{d}	<0.001	0.308	0.168	**<0.001**
Meat Standards Australia Index	61.4 ± 0.33^{a}	61.6 ± 0.28^{a}	62.1 ± 0.33^{b}	64.6 ± 0.36^{c}	61.5 ± 0.40^{ab}	<0.001	**0.004**	**0.002**	**<0.001**

$^{a-d}$ Superscripts that differ denote significance P <0.05

Exit weight for the backgrounder influenced hump height whereas feedlot days influenced EMA. Exit weight from backgrounding influenced hump height and feedlot days, slaughter day and background weight all influenced EMA. The P8 fat depth was also much greater for the British (16.5 ± 0.7mm) and Euro steers (15.3 ± 0.7 mm) than the Holstein (8.4 ± 0.6mm), HxJ (8.6 ± 0.5mm) or Jersey (8.3 ± 0.6mm). Only exit backgrounder weight influenced P8 fat depth (Table 39).

Rib fat results differed slightly from P8 fat depth as British steers had higher rib fat than Euro steers and these differed from all other breeds. The Holstein and HxJ had more rib fat than the Jersey steers and results were influenced by the exit backgrounder weight (Table 39). The British steers (458 ± 13 units) had higher marbling than all other breeds which did not differ (Table 39) with the Holsteins having (389 ± 10 units), the Euro steers (381 ± 14 units), HxJ (398 ± 8 units) and Jersey (407 ± 11 units).

These results indicate the possibility that Jersey and Jersey cross cattle have more propensity to marble than produce fat at P8 or rib fat. However, the Jersey cattle had the highest fat colour score, even though this score was low (1.1 ± 0.2 score 1 to 9). Entry weight from backgrounding and slaughter days influenced these results (Table 39). Ultimate pH was highest for the Jersey cattle (5.73 ± 0.03) and intermediate for the HxJ (5.65 ± 0.02) and Holsteins (5.61 ± 0.02) and least for the British (5.52 ± 0.03) and Euro steers (5.52 ± 0.03), was not influenced by covariables but was not significantly different. Table 39 shows the observation consistent with others in this study that meat colour score was higher in the dairy breeds (Jersey, HxJ and Holstein) than the British Euro steers. The meat colour differed among the dairy breeds (Table 39).

Meat colour was influenced by slaughter day. The MSA index was greatest for the British steers (64.6 ± 0.3), but all breeds exceeded 60 with a low standard error indicating good meat quality and consistency of that outcome (Table 39 and Fig. 16A). The MSA index was least for the Jersey steers (61.4 ± 0.3) and intermediate for the HxJ (61.6 ± 0.3) and Euro steers (61.5 ± 0.4) while the Holsteins (62.1 ± 0.3) were comparable to the Euro, but lower than the British steers (Table 39, Fig. 16A). MSA index was influenced by the days on the feedlot, backgrounder exit weight and slaughter days Table 39). Similar to Cohort 1, liver abscess was more prevalent in dairy than European/British steers across all growth pathways (Fig. 17B).

In contrast to cohort 1 where there were few differences attributable to the growth path treatment or the interaction between breed and treatment (Table 28), many of the outcomes for cohort 2 differed with treatment and interactions between breed and treatment (Table 40). There are several differences between the two cohorts including greater numbers of steers in cohort 2, reduced impacts of drought and maintaining cattle in their cohorts in two alternative feedlots rather than having all cohorts in a single feedlot pen. Other differences related to the use of two feedlots feeding different rations, being in different climatic zones and with greater transport distances to Wagga Wagga and a second abattoir utilised for the final small 15 head group.

Prior to feedlot entry, ADG at the backgrounder differed with breed, treatment and the interaction of breed with treatment. Except for the HxJ, steers gained weight consistent with the study targets and ADG differed by 0.18 kg/d between treatments (Table 40). The latter result was reflected in a weight difference of 32kg at exit from the backgrounder between high and low growth path treatments. Again, the backgrounder exit weight differed with breed, treatment and the interaction of breed with treatment. Both ADG and weight gain at the backgrounder were influenced by weight at backgrounder entry (Table 40. Growth path did not influence feedlot ADG with a difference of only 0.04 kg/d, but breed did influence gain.

The Holstein cattle had the greatest ADG in the feedlot with both the low and high growth path steers gaining more per day than the combined Euro and British, Beef breed steers. This result was reflected in the exit weight from the feedlot with Holsteins having similar weights to the Beef steers, a result similar to cohort 1 (Table 28 compared to Table 40). The higher growth path steers weighed approximately 30kg more than low growth steers, a similar difference to the exit weight difference at backgrounding and supporting the finding that ADG in the feedlot did not differ with treatment.

These results are consistent with the study design which fed identical rations to the two treatment groups in the feedlots and demonstrated that while treatment differences achieved in backgrounding were preserved, there was no additional advantage from growth path achieved in the feedlot. For cohort 1, in which pods, therefore treatments, were in a single pen and single feedlot, differences between treatments in backgrounder exit weights were no longer evident at feedlot exit (Table 28). Feedlot exit weights differed for breed and the interaction of breed and treatment. For ADG and feedlot exit weight, the low growth path Holsteins performed well, gaining and weighing more than the low growth Beef or HxJ (Table 40).

All steers were MSA graded within 24 hours of slaughter with the percentage meeting the MSA related processor standards displayed in Fig. 17A. The description of processor grades 1-8 refers to the traditional MSA standard boning groups which are reported to producers in this processor feedback to provide a supplier reference relative to previous grading under the old system. The boning groups however are a poor guide to eating quality of individual cuts which is more accurately reflected in the MSA Index.

Viscera reports were received for the first 3 kill groups (same abattoir as Cohort 1) and are summarised in Table 41. Viscera was not reported at the abattoir utilised for the final feedlot kill.

Livers were also inspected and data collected with the percentage of abscess displayed in Fig.17B.

Table 39. For cohort 2 steers, estimated marginal means ± SE for the effects of treatment growth path and breed on backgrounding and feedlot performance. Models include the fixed effects of treatment group, breed and the random effects of identity within a pod and farm (*N = 304, otherwise N = 294).

Outcome	Treatment		Holstein x Jersey		Holstein		Beef		Significance (*P*-value)		
	Low N = 117	High N = 187	Low N = 50	High N = 50	Low N = 34	High N = 73	Low N = 33	High N = 64	Breed (B)	Treatment (T)	B×T
Average daily gain on farms (kg/d)*[1]	0.85 ± 0.10	1.03 ± 0.10	0.82 ± 0.10	0.93 ± 0.10	0.86 ± 0.10	1.03 ± 0.10	0.90 ± 0.11	1.15 ± 0.10	**<0.001**	**0.001**	**0.001**
Background exit weight (kg)*[1]	345.7 ± 11.89	377.0 ± 10.86	342.9 ± 12.34	364.5 ± 11.07	347.0 ± 12.34	364.5 ± 11.07	347.4 ± 12.51	388.6 ± 11.10	**<0.001**	**<0.001**	**0.018**
Feedlot average daily gain (kg/d)	1.53 ± 0.14	1.57 ± 0.13	1.53 ± 0.14	1.49 ± 0.14	1.62 ± 0.14	1.69 ± 0.14	1.44 ± 0.14	1.53 ± 0.14	**<0.001**	0.504	0.095
Exit feedlot weight[2,3]	534.2 ± 21.68	564.8 ± 20.89	526.6 ± 22.38	540.0 ± 21.24	548.8 ± 22.12	582.7 ± 21.63	527.7 ± 22.66	574.3 ± 21.24	**<0.001**	**0.003**	**0.015**
Feedlot gain (kg)[2,3]	191.9 ± 18.01	195.4 ± 17.63	191.0 ± 18.43	186.0 ± 17.85	202.8 ± 18.27	210.0 ± 18.06	181.5 ± 18.59	190.9 ± 17.84	**<0.001**	0.576	0.146
Carcase weight (kg)[1]	282.2 ± 8.23	299..0 ± 7.64	269.5 ± 8.89	275.8 ± 7.99	284.9 ± 8.64	306.2 ± 8.34	293.8 ± 9.14	317.9 ± 7.88	**<0.001**	**0.027**	**0.021**
Hump height (mm)[1,2]	67.3 ± 1.88	65.6 ± 1.56	63.3 ± 2.41	62.94 ± 1.88	58.7 ± 2.22	61.2 ± 2.14	80.8 ± 2.59	73.3 ± 1.90	**<0.001**	0.379	**0.005**
Eye muscle area (cm^2)[1,2,3]	76.0 ± 1.05	75.8 ± 0.81	71.1 ± 1.58	71.34 ± 1.14	73.0 ± 1.41	72.1 ± 1.38	84.9 ± 1.73	84.8 ± 1.18	**<0.001**	0.870	0.893
P8 fat depth (mm)[1]	9.22 ± 0.47	11.1 ± 0.42	7.86 ± 0.68	8.71 ± 0.54	7.33 ± 0.60	8.76 ± 0.60	12.8 ± 0.74	16.2 ± 0.56	**<0…001**	**<0.001**	**0.033**
Rib fat (mm log transformed)[1]	6.84 ± 0.35	8.58 ± 0.28	5.64 ± 0.55	6.74 ± 0.40	6.08 ± 0.48	7.29 ± 0.0.48	9.00 ± 0.60	12.0 ± 0.42	**<0.001**	**<0.001**	0.057
Marble (Score 1 to 1190)[1]	393.3 ± 7.23	405.4 ± 5.66	405.6 ± 13.01	401.9 ± 9.13	399.7 ± 11.16	391.2 ± 11.02	372.7 ± 14.29	424.3 ± 9.80	0.768	0.154	**0.015**
Fat colour score (0-9)[2,3]	0.57 ± 0.16	0.46 ± 0.16	0.84 ± 0.17	0.57 ± 0.17	0.50 ± 0.17	0.42 ± 0.17	0.34 ± 0.18	0.38 ± 0.17	**<0.001**	0.065	**0.040**
Ossification (Score 100 to 590)[2]	125.5 ± 2.31	126.5 ± 1.84	128.3 ± 2.98	131.1 ± 2.25	124.7 ± 2.74	123.1 ± 2.60	123.2 ± 3.20	124.9 ± 2.27	**0.007**	0.707	0.481
Ultimate pH[2,3]	5.60 ± 0.02	5.59 ± 0.02	5.65 ± 0.02	5.64 ± 0.02	5.61 ± 0.02	5.61 ± 0.02	5.53 ± 0.02	5.51 ± 0.02	**<0.001**	0.495	0.706
Colour (Score 1 to 6)[3]	3.77 ± 0.11	3.76 ± 0.10	4.31 ± 0.17	4.45 ± 0.13	3.99 ± 0.15	4.21 ± 0.15	2.92 ± 0.18	2.51 ± 0.14	**<0.001**	0.865	**0.033**
Meat Standards Australia Index[2,3]	61.7 ± 0.41	62.4 ± 0.35	61.7 ± 0.48	61.6 ± 0.39	62.2 ± 0.45	62.7 ± 0.43	61.4 ± 0.50	63.2 ± 0.39	**0.008**	0.061	**<0.000**

[1] Entry weight significant $P < 0.05$

[2] Days in the feedlot significant $P < 0.05$

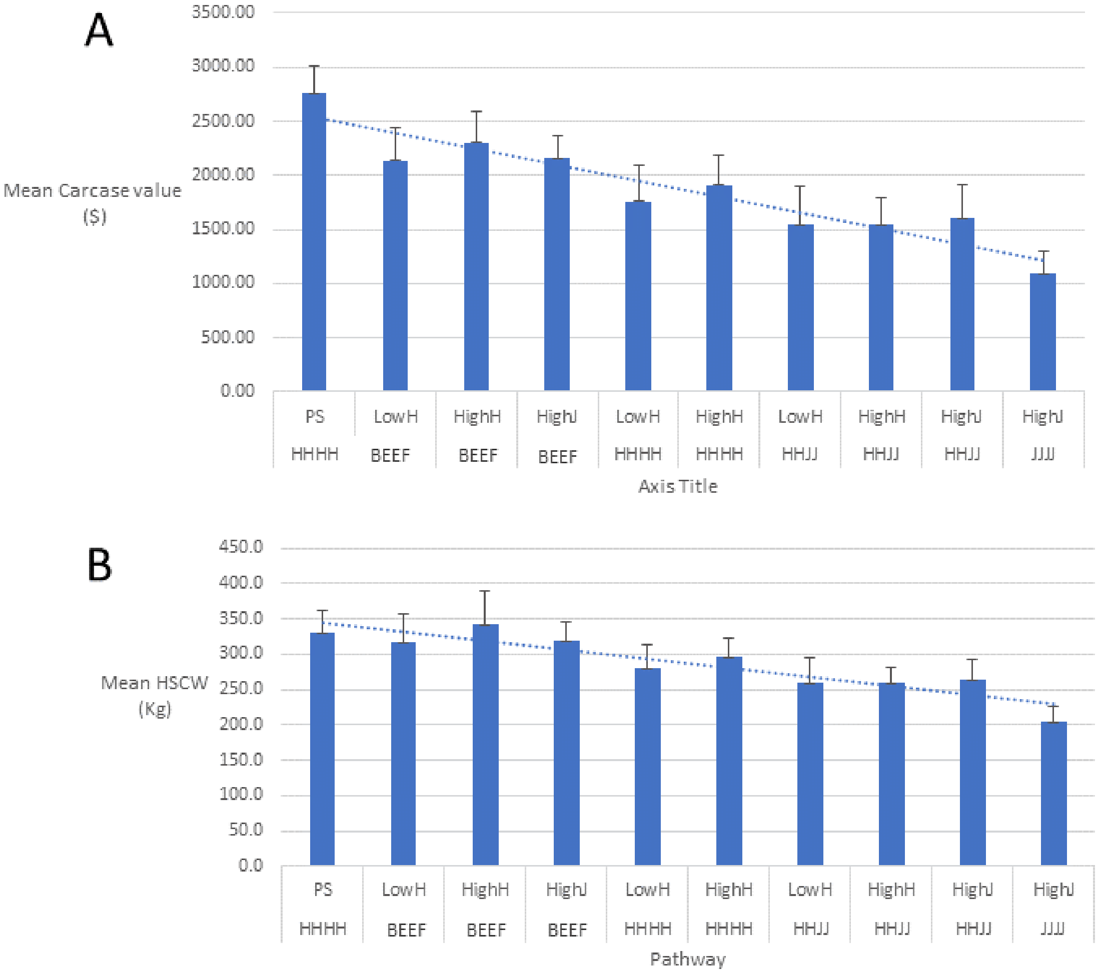
[3] Difference in days to slaughter significant $P < 0.05$

Table 40. Summary of viscera defects by breed type within kill group

	British	Euro	Hol x Jers	Holstein	Jersey	Total
Group 571.1 Feedlot 2, Abbatoir 2 Kill date 9/11/2020						
Enteritis/Peritonitis, Liver Abscess (Grade 2)				1		1
Liver Abscess (Grade 1)		3	6	5	1	15
Liver Abscess (Grade 1), Enteritis /Peritonitis, Lung Abscess			1			1
Liver Abscess (Grade 1), Pericarditis			1	1		2
Liver Abscess (Grade 1), Pleurisy (Grade 1)				1		1
Liver Adhesions	1	1	2	5		9
Liver Fluke			2			2
Lung Abscess, Liver Adhesions					1	1
Pleurisy (Grade 1)			1	1		2
Total visera conditions noted	1	4	13	14	2	34
Total head in group	6	12	22	20	8	68
% of group	16.7%	33.3%	59.1%	70.0%	25.0%	50.0%
Group 572.1 Feedlot 3, Abattoir 2 Kill date 23/11/2020						
	British	**Euro**	**Hol x Jers**	**Holstein**	**Jersey**	**Total**
Enteritis/Peritonitis			1			1
Liver Abscess (Grade 1)		5	5	1	1	12
Liver Abscess (Grade 2)			1			1
Liver Adhesions		2	5	2	1	10
Liver Adhesions, Carcase Abscess			1			1
Liver Cyst, Lung Cyst			1			1
Liver Fluke		1				1
Nephritis		1		1		2
Nephritis, Liver Abscess (Grade 1), Enteritis/Peritonitis			1			1
Pericarditis		1	2			3
Pericarditis, Liver Adhesions				1		1
Pneumonia				1	1	2
Total visera conditions noted	0	10	17	6	3	36
Total head in group	12	27	44	40	20	143
% of group	0.0%	37.0%	38.6%	15.0%	15.0%	25.2%
Group 573.1 Feedlot 3, Abattoir 2 Kill date 1/2/2021						
	British	**Euro**	**Hol x Jers**	**Holstein**	**Jersey**	**Total**
Enteritis / Peritonitis, Liver Adhesions	1					1
Enteritis / Peritonitis, Pericarditis				1		1
Liver Abscess (Grade 1)					1	1
Liver Abscess (Grade 1), Enteritis / Peritonitis					1	1
Liver Abscess (Grade 1), Pericarditis				1		1
Liver Abscess (Grade 1), Tongue Abscess				1		1
Liver Adhesions	2	3	3	1	3	12
Lung Abscess, Liver Adhesions			1			1
Pericarditis				3		3
Pericarditis, Liver Adhesions	2	1		1	1	5
Telangiectasia		1				1
Tongue Abscess				1	2	3
Total visera conditions noted	5	5	4	9	8	31
Total head in group	12	24	41	24	22	123
% of group	41.7%	20.8%	9.8%	37.5%	36.4%	25.2%

Figure 17. Cohort 2 - percentage of A) steers achieving MSA based processor grades 1-8 and B) liver abscess noted at slaughter, by breed and pathways.

BEEF – any European breed including Angus; HHHH, Holstein; HHJJ, Holstein Jersey F1; JJJJ, Jersey. PS, pasture finished. Growth pathways: HighH, High Holstein; LowH, Low Holstein; HighJ, High Jersey.



4.1.16. Cohort 2- Carcase characteristics of feedlot finished dairy steers

Carcase weights met or exceeded the study target of 280 to 300kg for all beef and Holstein groups and a proportion of the Holstein cross Jersey. The Jersey steers on average had carcase weights under 210 kg. Carcase weights differed for treatments by almost 17kg for cohort 2. Breed and the interaction of breed and treatment differed for carcase weight (Table 40). Hump height differed with breed and the interaction of breed and treatment. The Beef steers had markedly higher hump height and EMA than the Holstein and HxJ cattle. The EMA was not influenced by treatment or the interaction of breed and treatment.

The P8 fat and rib fat depth differed among breed and with treatment and for P8 fat the interaction between breed and treatment (Table 40). Both P8 fat and rib fat differed by approximately 2mm between treatments a result that differed to cohort 1 where treatment was not significant. The beef breeds had greater P8 and rib fat depth than the Holstein and HxJ steers (Table 40). Marble score did not differ with breed or treatment but did differ for the interaction of breed and treatment. The beef steers had greater marble score for high growth steers, whereas the low growth Holstein and HxJ steers had numerically greater marble score. Fat colour score differed with breed, but not treatment (Table 42). The interaction of breed and treatment was significant, but all score means were low being less than 1 on the 0 to 9 scale.

Only breed influenced ossification score with the HxJ being higher. The consistent finding of higher ultimate pH and meat colour for the Holstein and HxJ steers than Beef steers, and being highest in the Jersey, was evident in Cohort 2, but there was no difference for treatment or the interaction of breed and treatment for ultimate pH. However, for meat colour the interaction of breed and treatment was significant. The MSA index differed among breeds and with an interaction of breed and treatment. For the Beef steers the difference between the high and low growth path steers was nearly 2, whereas there was little difference in MSA index between growth paths for the Holstein and HxJ steers. Meat colour was higher in Holstein and HxJ steers compared to Beef steers. The MSA index was higher for the high growth path steers by 1.7 units. Breed and breed interactions with treatment were also significant with the high growth beef having the greatest index and the low growth beef the lowest MSA index (Table 40, Fig. 17A). A significant difference in MSA rib fat (minimum 3mm) and pH (maximum of 5.7 pHu) to MSA compliance was observed between different breed types (Table 42) with poorest compliance observed in dairy compared to beef breeds (Fig. 18) and in High compared to Low growth pathways (Table 43, Fig. 18).

Table 41. Pearson's Chi-squared test for rib fat and pH compliance across breed types in cohort 2.

Carcase Trait	X-squared	df	breed p-value
Rib fat compliance	16.64	4	0.0022
pH compliance	47.052	4	1.49E-09

Figure 18. Distribution of rib fat and pH compliance across breed types in cohort 2

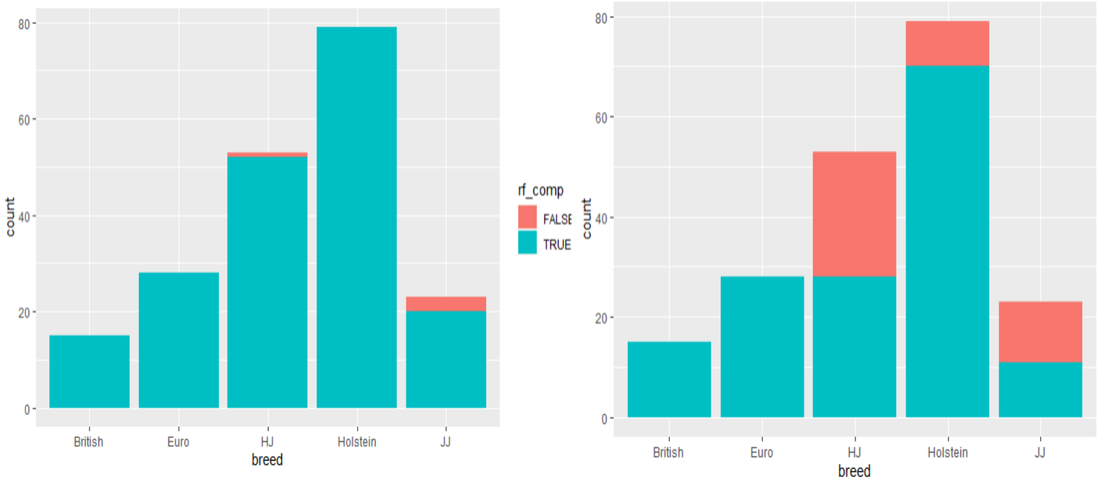
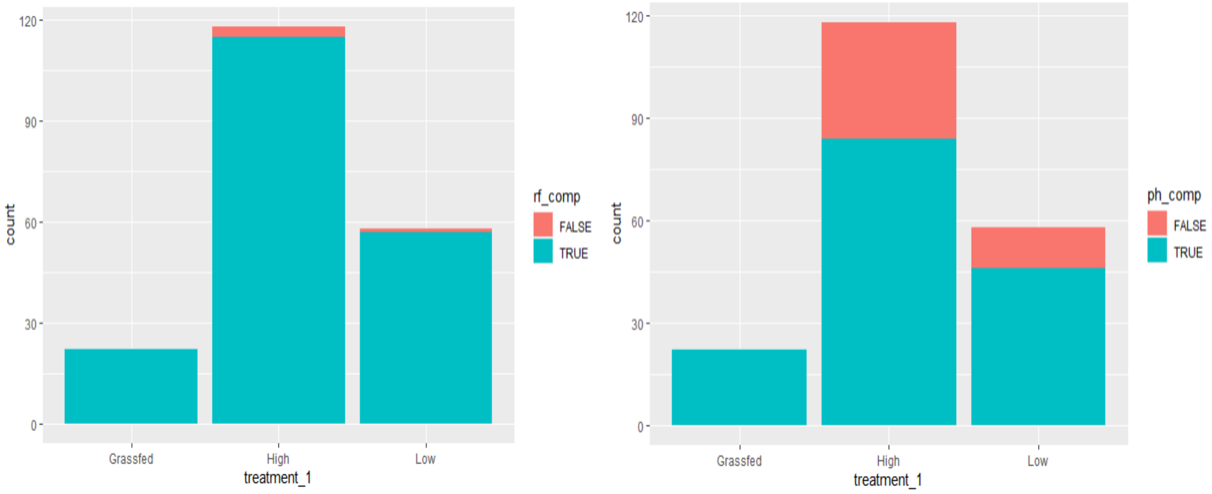


Table 42. Pearson's Chi-squared test for rib fat and pH compliance across growth pathways in cohort 2.

Carcase Trait	X-squared	Df	growth pathway p-value
Rib fat compliance	0.64	2	0.72
pH compliance	8.92	2	1.10E-02

Figure 19. Distribution of rib fat and pH compliance across growth pathways in cohort 2.



4.1.17. Cohort 2 - Feedlot-finished sensory outcomes

The cohort 2 feedlot cattle were fed at Associated and Tullimba feedlots, with different pods being assigned to each location. They were harvested on 4 dates with the major 3 kills processed at Teys Wagga as were the cohort 1 feedlot groups, and a final group at Bindaree, located at Inverell NSW. Consumer tested sample numbers, all grilled and aged for 7 days, are displayed in Table 44 together with average MQ4 values by cut. Consumer samples were prepared from all carcases in Cohort 2 with collection of cube roll and topside from the first kill and only a cube roll from the subsequent 3 kills.

Table 43. Grilled 7 day aged consumer samples tested from Cohort 2 feedlot steers by muscle, group, feedlot and kill date with average CMQ4 values.

Muscle x Group	Feedlot	Abattoir	Kill Date	No of Samples	Average CMQ4
CUB045					
571.1	Associated	Teys Wagga	9/11/2020	51	67.6
572.1	Tullimba	Teys Wagga	23/11/2020	58	62.7
573.1	Tullimba	Teys Wagga	1/02/2021	38	50.1
573.2	Tullimba	Bindaree	24/06/2021	12	50.6
Total				**159**	**60.3**
CUB081					
571.1	Associated	Teys Wagga	9/11/2020	68	78.9
572.1	Tullimba	Teys Wagga	23/11/2020	63	77.1
573.1	Tullimba	Teys Wagga	1/02/2021	38	73.2
573.2	Tullimba	Bindaree	24/06/2021	12	69.6
Total				**181**	**76.5**
TOP073					
571.1	Associated	Teys Wagga	9/11/2020	**68**	**42.2**
ALL				**408**	**64.5**

From Table 44, there are apparent MQ4 differences across the kill dates, with declining scores, most noticeable for the CUB045, at later dates. Both the 573.1 and 573.2 groups were placed on feed on a common and later date to the earlier groups. These two later groups differed substantially however in backgrounder entry weight (573.1: 190;573.2: 75 kg), feedlot entry weight (573.1: 357; 573.2: 213kg) with 573.1 heavier for each but having lower DOF days on feed (573.1: 123; 573.2: 267), a lighter exit weight (573.1: 544; 573.2: 570kg) and carcase weight (573.1: 288; 573.2: 315kg) (Table 37.) The 573.2 group had the lowest average entry weight of all groups but the highest final and carcase weights after the longest time on feed. It is noted that the raw mean MQ4 values differ from the Cohort 1 seven day aged grilled raw means being 9.5 points lower for the CUB045, 3.8 for the CUB081 and similar for the TOP073 (1.6 lower).

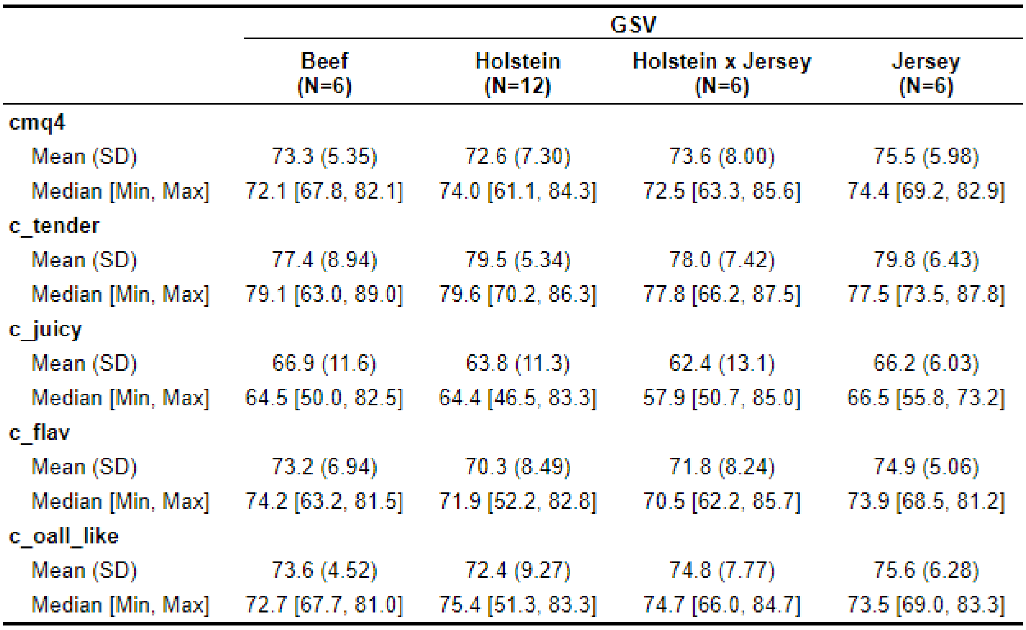
No immediate explanation for the lower CUB045 MQ4 scores in groups 573.1 and 573.2 (Table 44) is apparent from the live animal or grading data with both suggesting potential small differences of much lower magnitude. Both groups entered the feedlot at a later date with one, but not all in 573.1, common calf source and backgrounder. The cohort 2 pasture steers also have a similar lower score pattern and share some suppliers and backgrounders. This observation is confirmed by comparing the MSA V2.0 model predicted MQ4 values to those observed (a negative value indicating model under prediction and a positive value indicating prediction over the observed value). These residuals are displayed in Table 45 with substantial overprediction in both the later feedlot (572.1, 573.1 and 573.2) and pasture (580.1 and all 588) groups. This contrasts with an average residual of -1.9 MQ4 for cohort 1 (data not shown) and similar - 0.2 average residual for group 571.1. It is possible that animals in this cohort were impacted by bushfire conditions in their locality, although this hypothesis as an explanatory factor for the difference in MQ4 values from cohort 1 to cohort 2 would need to be investigated.

Table 44. Residuals for predicted less observed MQ4 for all tested cohort 2 grill samples.

		Days Aged		
GROUP	**Muscle**	**7**	**21**	**Average All**
571.1	CUB045	-2.8		-2.8
	CUB081	-2.3		-2.3
	TOP073	4.0		4.0
571.1 Total		**-0.2**		**-0.2**
572.1	CUB045	1.1		1.1
	CUB081	-1.1		-1.1
572.1 Total		**-0.1**		**-0.1**
573.1	CUB045	13.7		13.7
	CUB081	2.8		2.8
573.1 Total		**8.2**		**8.2**
573.2	CUB045	13.2		13.2
	CUB081	6.8		6.8
573.2 Total		**10.0**		**10.0**
580.1	CUB045	11.7	6.1	8.9
	CUB081	6.3		6.3
580.1 Total		**9.0**	**6.1**	**8.0**
588.1	CUB045	18.4	10.0	14.2
	CUB081	18.3		18.3
588.1 Total		**18.3**	**10.0**	**15.5**
588.2	CUB045	12.7	12.4	12.6
	CUB081	11.2		11.2
588.2 Total		**12.0**	**12.4**	**12.1**
588.3	CUB045	14.5	4.3	9.4
	CUB081	15.9		15.9
588.3 Total		**15.2**	**4.3**	**11.6**
Average Residual		**3.7**	**7.9**	**4.0**

A check was made across sensory picks for any abnormal pattern in grill sensory results by filtering to all grill picks that contained 5 or more samples from cohort 2 groups. Box plots for each muscle code that included dairy samples were then produced including all samples (including non-dairy) in each pick. As illustrated in Fig. 19, no abnormal pattern was evident suggesting that the sensory process was not related to the abnormally low results. As noted, while sensory samples were taken from all cohort 2 carcases, only a proportion have been tested. It is recommended that further samples from these groups be included in subsequent testing to confirm the pattern observed to date.

Table 45. Summary statistics for the CUB045 grill sous-vide samples for each sensory variable split by breed type.



	GSV			
	Beef (N=6)	Holstein (N=12)	Holstein x Jersey (N=6)	Jersey (N=6)
cmq4				
Mean (SD)	73.3 (5.35)	72.6 (7.30)	73.6 (8.00)	75.5 (5.98)
Median [Min, Max]	72.1 [67.8, 82.1]	74.0 [61.1, 84.3]	72.5 [63.3, 85.6]	74.4 [69.2, 82.9]
c_tender				
Mean (SD)	77.4 (8.94)	79.5 (5.34)	78.0 (7.42)	79.8 (6.43)
Median [Min, Max]	79.1 [63.0, 89.0]	79.6 [70.2, 86.3]	77.8 [66.2, 87.5]	77.5 [73.5, 87.8]
c_juicy				
Mean (SD)	66.9 (11.6)	63.8 (11.3)	62.4 (13.1)	66.2 (6.03)
Median [Min, Max]	64.5 [50.0, 82.5]	64.4 [46.5, 83.3]	57.9 [50.7, 85.0]	66.5 [55.8, 73.2]
c_flav				
Mean (SD)	73.2 (6.94)	70.3 (8.49)	71.8 (8.24)	74.9 (5.06)
Median [Min, Max]	74.2 [63.2, 81.5]	71.9 [52.2, 82.8]	70.5 [62.2, 85.7]	73.9 [68.5, 81.2]
c_oall_like				
Mean (SD)	73.6 (4.52)	72.4 (9.27)	74.8 (7.77)	75.6 (6.28)
Median [Min, Max]	72.7 [67.7, 81.0]	75.4 [51.3, 83.3]	74.7 [66.0, 84.7]	73.5 [69.0, 83.3]

The higher number of CUB081 results relative to CUB045 (Table 44) reflects the testing of 18 CUB045 samples in connection with GSV (grilled, sous-vide) picks with the CUB081 tested in other grill picks. There was a significant difference to the number of samples collected relative to those tested due to budget constraints and test priority. Table 46 displays summary statistics for the GSV values obtained from dairy beef samples. Comparison to standard GRL values is not displayed due to the very low numbers and inclusion of samples from other non-related MSA groups used in the cook evaluation.

Table 47 displays summary statistics for cohort 2 feedlot samples related to muscle and breed type whereas Table 48 displays results from a linear mixed model for all cohort 2 feedlot steers.

Figure 20. Box plots of CMQ4 consumer values for cuts from all sources in grill sensory picks that contained 5 or greater cohort 2 sensory samples

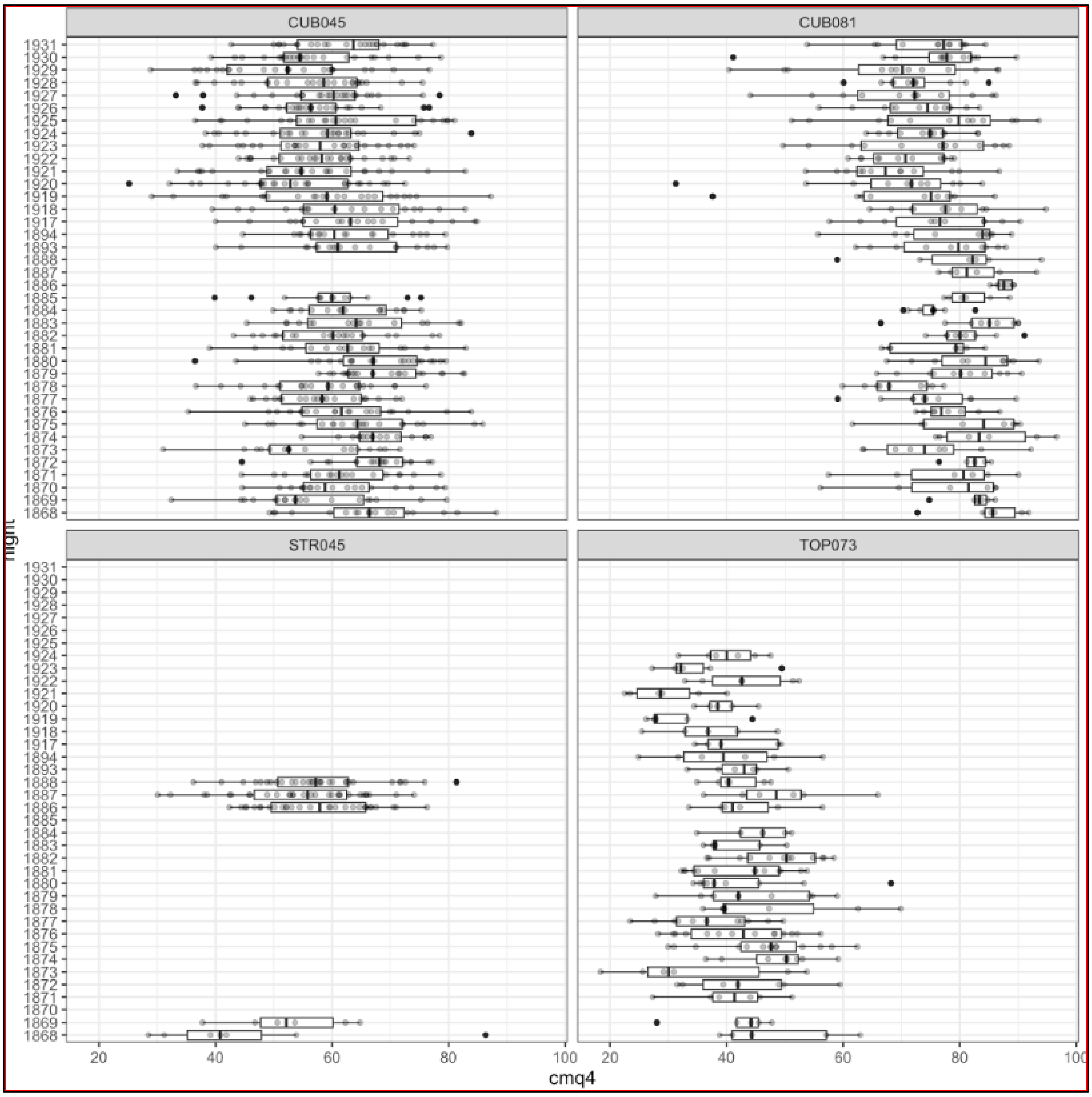


Table 46. Summary statistics for the CUB045, CUB081 TOP073 grill samples for each sensory variable split by breed type

	CUB045				CUB081				TOP073			
	Beef (N=35)	**Holstein (N=51)**	**Holstein x Jersey (N=45)**	**Jersey (N=18)**	**Beef (N=43)**	**Holstein (N=56)**	**Holstein x Jersey (N=51)**	**Jersey (N=22)**	**Beef (N=18)**	**Holstein (N=20)**	**Holstein x Jersey (N=22)**	**Jersey (N=7)**
cmq4												
Mean (SD)	61.3 (11.2)	57.3 (11.5)	62.9 (12.3)	62.0 (12.9)	77.0 (8.16)	73.3 (9.63)	78.5 (10.2)	81.2 (7.67)	39.7 (7.63)	41.6 (9.49)	43.9 (9.81)	47.1 (7.78)
Median [Min, Max]	63.7 [36.0, 82.5]	59.6 [33.5, 76.4]	63.4 [37.0, 85.9]	62.7 [38.3, 81.8]	78.3 [55.7, 89.2]	74.9 [49.7, 88.4]	79.0 [49.9, 94.0]	80.1 [67.7, 96.6]	39.6 [24.8, 53.3]	41.5 [23.4, 59.5]	43.6 [27.8, 66.0]	50.4 [35.6, 56.4]
c_tender												
Mean (SD)	62.6 (13.3)	57.9 (14.6)	64.7 (15.9)	63.7 (17.7)	78.8 (10.5)	74.7 (11.0)	81.0 (10.4)	85.1 (6.96)	31.7 (12.3)	34.7 (11.2)	37.1 (12.1)	39.2 (11.6)
Median [Min, Max]	63.7 [38.3, 85.0]	63.5 [28.3, 79.7]	67.0 [25.8, 92.3]	70.8 [31.7, 84.2]	79.7 [50.5, 95.5]	77.5 [46.7, 93.3]	81.7 [43.2, 94.7]	86.8 [70.3, 97.0]	32.4 [6.67, 53.3]	34.3 [16.0, 56.3]	34.9 [17.3, 64.3]	37.2 [26.0, 54.0]
c_juicy												
Mean (SD)	58.5 (12.4)	53.7 (15.1)	61.2 (15.0)	58.3 (14.2)	80.5 (7.27)	75.1 (10.7)	81.2 (8.28)	82.1 (7.75)	39.5 (9.08)	42.3 (13.4)	46.8 (12.2)	47.4 (4.90)
Median [Min, Max]	58.8 [28.8, 81.7]	55.0 [18.0, 74.8]	61.2 [30.7, 86.0]	56.8 [34.2, 79.8]	80.3 [66.0, 96.0]	76.7 [37.2, 92.2]	81.8 [59.5, 96.0]	83.2 [65.0, 99.0]	37.7 [27.5, 62.2]	41.2 [12.7, 71.3]	47.3 [29.0, 70.7]	48.3 [38.8, 53.3]
c_flav												
Mean (SD)	61.4 (10.2)	58.7 (10.0)	63.2 (11.1)	62.7 (11.1)	76.4 (8.42)	72.8 (8.86)	77.4 (11.0)	78.6 (9.65)	45.1 (6.84)	49.0 (8.81)	48.8 (9.88)	52.6 (7.26)
Median [Min, Max]	62.2 [35.5, 80.2]	60.3 [30.3, 76.7]	63.7 [33.8, 82.0]	63.8 [43.3, 81.7]	76.0 [57.5, 93.2]	73.0 [53.5, 91.7]	80.0 [48.3, 95.8]	77.7 [64.3, 93.9]	45.7 [29.8, 56.2]	50.9 [30.5, 63.0]	48.8 [27.7, 69.8]	53.3 [39.8, 62.5]
c_oall_like												
Mean (SD)	61.6 (11.5)	57.4 (11.8)	63.5 (12.4)	62.5 (12.6)	77.3 (8.58)	73.3 (11.2)	78.9 (11.1)	81.4 (7.82)	41.3 (8.63)	42.1 (10.1)	44.6 (10.7)	48.7 (6.93)
Median [Min, Max]	61.5 [31.7, 82.0]	60.3 [34.3, 77.7]	64.2 [39.8, 88.0]	62.3 [39.3, 83.2]	79.2 [56.2, 90.0]	75.5 [42.2, 92.8]	81.2 [48.5, 94.8]	79.2 [69.8, 98.1]	42.8 [25.0, 58.0]	42.4 [21.8, 61.2]	43.3 [28.2, 64.3]	51.5 [38.8, 56.8]

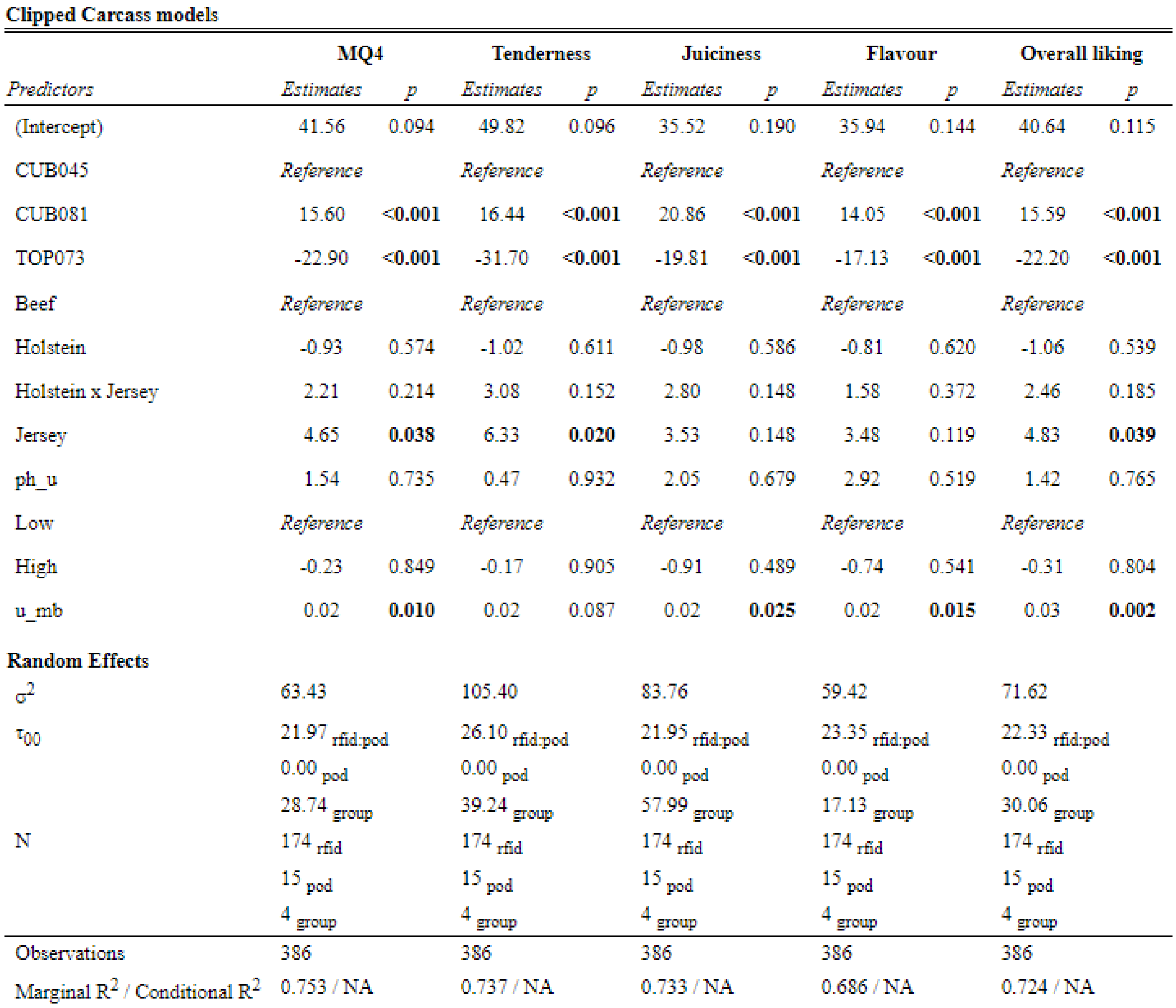
Table 47. Linear mixed model for all cohort 2 feedlot steers (grill samples).

Clipped models

	MQ4		**Tenderness**		**Juiciness**		**Flavour**		**Overall liking**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	58.52	**<0.001**	59.26	**<0.001**	54.80	**<0.001**	59.97	**<0.001**	58.90	**<0.001**
CUB045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
CUB081	15.60	**<0.001**	16.45	**<0.001**	20.87	**<0.001**	14.05	**<0.001**	15.60	**<0.001**
TOP073	-22.86	**<0.001**	-31.66	**<0.001**	-19.77	**<0.001**	-17.10	**<0.001**	-22.16	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Holstein	-1.36	0.384	-1.46	0.432	-1.31	0.438	-1.03	0.505	-1.65	0.314
Holstein x Jersey	1.91	0.202	2.68	0.133	2.64	0.104	1.61	0.282	1.99	0.206
Jersey	4.77	**0.015**	6.23	**0.008**	3.78	0.074	3.95	**0.042**	4.85	**0.018**
Low	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
High	-0.28	0.819	-0.22	0.880	-0.96	0.473	-0.78	0.529	-0.38	0.767
Random Effects										
σ^2	63.38		105.31		83.67		59.35		71.56	
τ_{00}	$23.54_{\text{rfid:pod}}$		$26.64_{\text{rfid:pod}}$		$23.28_{\text{rfid:pod}}$		$24.84_{\text{rfid:pod}}$		$24.93_{\text{rfid:pod}}$	
	0.00_{pod}		0.00_{pod}		0.00_{pod}		0.00_{pod}		0.00_{pod}	
	32.18_{group}		41.35_{group}		64.04_{group}		20.67_{group}		33.93_{group}	
ICC	0.47		0.39		0.51					
N	174_{rfid}		174_{rfid}		174_{rfid}		174_{rfid}		174_{rfid}	
	15_{pod}		15_{pod}		15_{pod}		15_{pod}		15_{pod}	
	4_{group}		4_{group}		4_{group}		4_{group}		4_{group}	
Observations	386		386		386		386		386	
Marginal R^2 / Conditional R^2	0.620 / 0.798		0.632 / 0.777		0.575 / 0.792		0.687 / NA		0.725 / NA	

Table 48 presents comparative data for only the high growth path and Table 49 displays results with the Jersey steers removed to determine impact of these subgroups on over MQ4 scoring.

Table 48. Linear mixed model for high growth animals only accounting for carcase characteristics (grill samples).

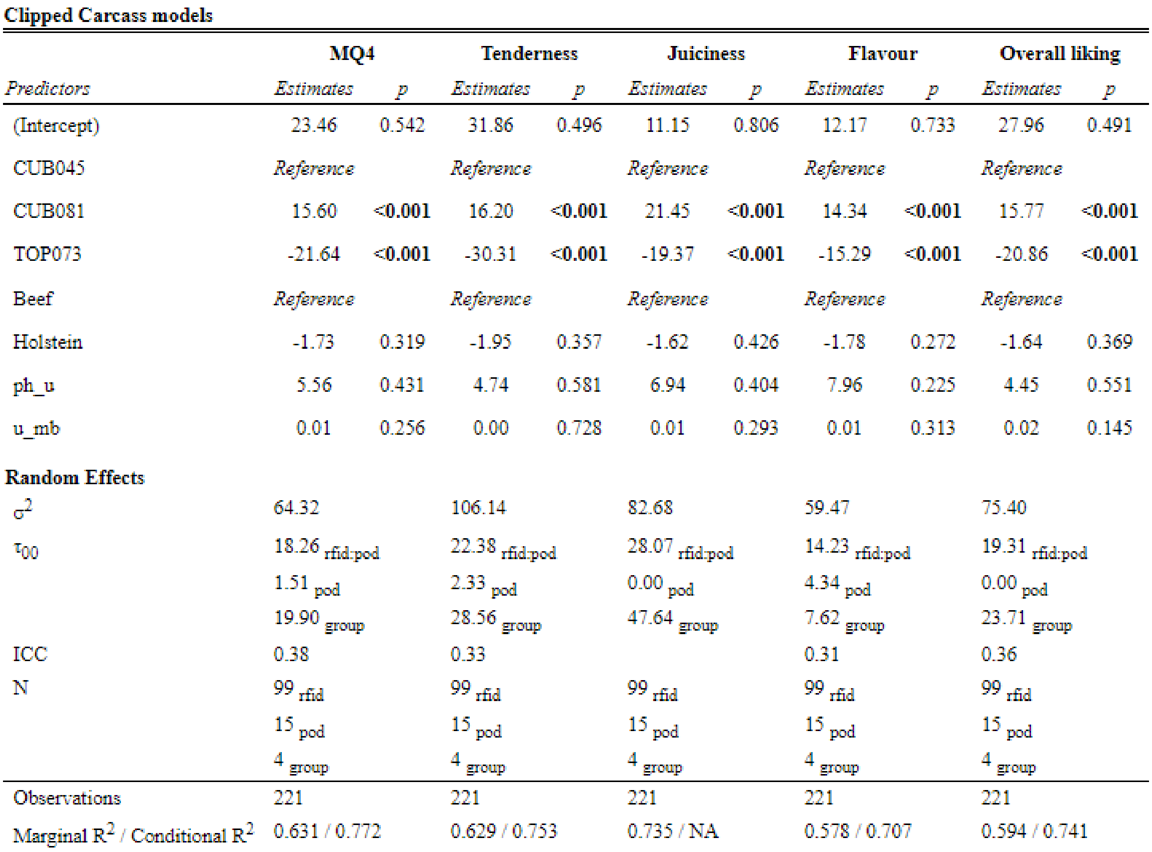


Clipped Carcass models

	MQ4		**Tenderness**		**Juiciness**		**Flavour**		**Overall liking**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	41.56	0.094	49.82	0.096	35.52	0.190	35.94	0.144	40.64	0.115
CUB045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
CUB081	15.60	**<0.001**	16.44	**<0.001**	20.86	**<0.001**	14.05	**<0.001**	15.59	**<0.001**
TOP073	-22.90	**<0.001**	-31.70	**<0.001**	-19.81	**<0.001**	-17.13	**<0.001**	-22.20	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Holstein	-0.93	0.574	-1.02	0.611	-0.98	0.586	-0.81	0.620	-1.06	0.539
Holstein x Jersey	2.21	0.214	3.08	0.152	2.80	0.148	1.58	0.372	2.46	0.185
Jersey	4.65	**0.038**	6.33	**0.020**	3.53	0.148	3.48	0.119	4.83	**0.039**
ph_u	1.54	0.735	0.47	0.932	2.05	0.679	2.92	0.519	1.42	0.765
Low	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
High	-0.23	0.849	-0.17	0.905	-0.91	0.489	-0.74	0.541	-0.31	0.804
u_mb	0.02	**0.010**	0.02	0.087	0.02	**0.025**	0.02	**0.015**	0.03	**0.002**
Random Effects										
σ^2	63.43		105.40		83.76		59.42		71.62	
τ_{00}	21.97 $_{\text{rfid:pod}}$		26.10 $_{\text{rfid:pod}}$		21.95 $_{\text{rfid:pod}}$		23.35 $_{\text{rfid:pod}}$		22.33 $_{\text{rfid:pod}}$	
	0.00 $_{\text{pod}}$		0.00 $_{\text{pod}}$		0.00 $_{\text{pod}}$		0.00 $_{\text{pod}}$		0.00 $_{\text{pod}}$	
	28.74 $_{\text{group}}$		39.24 $_{\text{group}}$		57.99 $_{\text{group}}$		17.13 $_{\text{group}}$		30.06 $_{\text{group}}$	
N	174 $_{\text{rfid}}$		174 $_{\text{rfid}}$		174 $_{\text{rfid}}$		174 $_{\text{rfid}}$		174 $_{\text{rfid}}$	
	15 $_{\text{pod}}$		15 $_{\text{pod}}$		15 $_{\text{pod}}$		15 $_{\text{pod}}$		15 $_{\text{pod}}$	
	4 $_{\text{group}}$		4 $_{\text{group}}$		4 $_{\text{group}}$		4 $_{\text{group}}$		4 $_{\text{group}}$	
Observations	386		386		386		386		386	
Marginal R^2 / Conditional R^2	0.753 / NA		0.737 / NA		0.733 / NA		0.686 / NA		0.724 / NA	

In Table 48 the positive trend for pHu across the sensory traits, as in the veal cohort, is noted but into significant.

Table 49. Linear mixed model of Cohort 2 feedlot steers without Jersey breed data.



Clipped Carcass models

	MQ4		**Tenderness**		**Juiciness**		**Flavour**		**Overall liking**	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	23.46	0.542	31.86	0.496	11.15	0.806	12.17	0.733	27.96	0.491
CUB045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
CUB081	15.60	**<0.001**	16.20	**<0.001**	21.45	**<0.001**	14.34	**<0.001**	15.77	**<0.001**
TOP073	-21.64	**<0.001**	-30.31	**<0.001**	-19.37	**<0.001**	-15.29	**<0.001**	-20.86	**<0.001**
Beef	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Holstein	-1.73	0.319	-1.95	0.357	-1.62	0.426	-1.78	0.272	-1.64	0.369
ph_u	5.56	0.431	4.74	0.581	6.94	0.404	7.96	0.225	4.45	0.551
u_mb	0.01	0.256	0.00	0.728	0.01	0.293	0.01	0.313	0.02	0.145
Random Effects										
σ^2	64.32		106.14		82.68		59.47		75.40	
τ_{00}	18.26 $_{rfid:pod}$ 1.51 $_{pod}$ 19.90 $_{group}$		22.38 $_{rfid:pod}$ 2.33 $_{pod}$ 28.56 $_{group}$		28.07 $_{rfid:pod}$ 0.00 $_{pod}$ 47.64 $_{group}$		14.23 $_{rfid:pod}$ 4.34 $_{pod}$ 7.62 $_{group}$		19.31 $_{rfid:pod}$ 0.00 $_{pod}$ 23.71 $_{group}$	
ICC	0.38		0.33				0.31		0.36	
N	99 $_{rfid}$ 15 $_{pod}$ 4 $_{group}$		99 $_{rfid}$ 15 $_{pod}$ 4 $_{group}$		99 $_{rfid}$ 15 $_{pod}$ 4 $_{group}$		99 $_{rfid}$ 15 $_{pod}$ 4 $_{group}$		99 $_{rfid}$ 15 $_{pod}$ 4 $_{group}$	
Observations	221		221		221		221		221	
Marginal R^2 / Conditional R^2	0.631 / 0.772		0.629 / 0.753		0.735 / NA		0.578 / 0.707		0.594 / 0.741	

When Jersey values were removed (Table 49), a positive but not significant correlation with pHu was observed. It is noted that marbling was no longer a significant predictor when the Jerseys are removed and by this analysis suggesting that there was no significant relationship between breed and MSA marbling in the original model. This is reflected in Fig. 20 which displays the relationship between CMQ4 and MSA marbling score within breed.

Figure 21. Relationship between CMQ4 and MSA marbling (u_mb) by breed types for cohort 2 feedlot steers

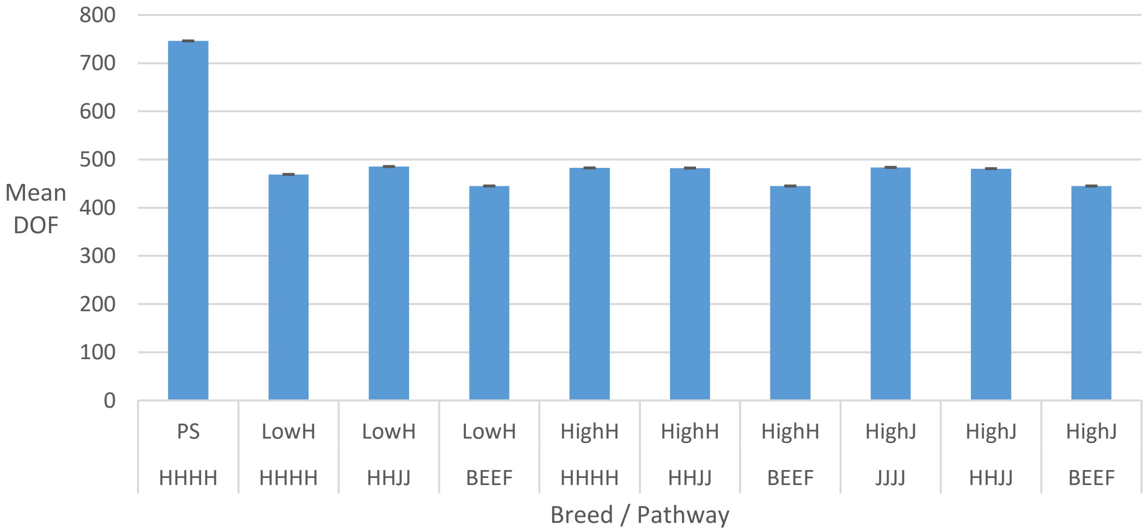
4.1.18. Grass finished steers

Table 50 provides the summary statistics for the 8 grass finished pods from cohorts 1 and 2. Comparisons to other groups are made as observations, rather than statistically tested outcomes to provide an industry context for these steers. The ADG (1.05 ± 0.28 kg/d) at the backgrounder phase (292 ± 43.9kg) was consistent with the other HG Holstein pods, both veal and feedlot, indicating that the random selection process for group allocation provided similar outcomes. The ADG in the finisher phase (0.91 ± 0.19 kg/d) was similar to the gain in the backgrounder phase and below the target of 1.2 kg/d, possibly reflecting the drought conditions for cohort 1. The final weight at slaughter was 656 ± 67.1kg with a carcase weight of 336 ± 34.2kg. The steers were noted as being of considerable body length at slaughter and the weights are approximately 30kg more than the HG Beef and Holsteins from the feedlot. As might be expected, the P8 (6.22 ± 2.24mm) and rib fat (4.54 ± 1.64mm) were lesser than the LG or HG feedlot steers. Hump heights (61.9mm) were similar to the Holstein feedlot finished steers that were 3 to 4 months younger (Fig. 21). The EMA was similar (75.5 ± 5.1), and the ossification (144.5 ± 16.8) about 5% greater than feedlot finished Holsteins. The ultimate pH (5.60 ± 0.05) and colour (3.33 ± 0.86) were similar to the feedlot finished steers. The marbling was approximately 45 score lower than for feedlot finished cattle in cohort 2 (Table 40), but approximately 20 score below cohort 1 (Table 28). Overall, there did not appear to be substantial differences in the steers finished on pasture to the feedlot steers in carcase characteristics, but there were some striking differences in weight and carcase weight that might reflect finish methods, age at slaughter (Cohort 2 shown in Fig. 21), and differences in carcase trim methods between abattoirs (Table 50).

Table 50. Cohort 1 and 2, estimated means ± SD for the grass finished Holstein pods. (N = 80)

Outcome	**Holstein Grass Finished**
Average daily gain on farms (kg/d)	1.05 ± 0.28
Backgrounder farm exit (kg)	292 ± 43.9
Average daily gain on finisher farms (kg/d)	0.91 ± 0.19
Final weight at farm exit (kg)	656 ± 67.1
Carcase weight (kg)	336 ± 34.2
Hump height (mm)	61.9 ± 12.5
Eye muscle area (cm^2)	75.5 ± 5.1
P8 fat depth (mm)	6.22 ± 2.24
Rib fat (mm)	4.54 ± 1.64
Marble (Score 1 to 1190)	353.3 ± 56.6
Fat colour score (0-9)	1.75 ± 0.86
Ossification (Score 100 to 590)	144.5 ± 16.8
Ultimate pH	5.60 ± 0.05
Colour (Score 1 to 6)	3.33 ± 0.86
Meat Standards Australia Index	59.8 ± 2.08

Figure 22. Cohort 2 - Mean days on feed (DOF) by breed and pathway.



BEEF – any European breed including Angus; HHHH, Holstein; HHJJ, Holstein Jersey F1; JJJJ, Jersey. PS, pasture finished. Growth pathways: HighH, High Holstein; LowH, Low Holstein; HighJ, High Jersey.

4.1.19. Sensory analysis of Grass finished steers

The grass-fed steers from cohort 1 were sourced from 3 backgrounders who maintained growth by use of supplementary feed, with amounts fed reflecting different seasonal conditions and pasture availability. All were processed at a single abattoir (Greenhams, Moe) on the same day with MSA personnel recording pH and temperature decline and grading data.

As shown in Table 51, cube roll and Topside cuts were collected from all cattle and fabricated into consumer grill samples. In addition, roast and a new schnitzel cooking method samples were prepared from the topside TOP073 (*M.semimembranosus*) muscle. Ageing at 7 and 21 days was evaluated for the grill and roast samples, with the paired topside roast, grill and schnitzel data to be amalgamated with other collection groups to examine muscle x cook performance.

Table 51. Consumer samples evaluated from Cohort 1 grass fed steers by muscle, days ageing and cooking method within backgrounder (group).

Cook Method	**GRILL**		**ROAST**		**SCHNITZEL**	**Total**
Days Aged	**7**	**21**	**7**	**21**	**7**	
Cut and Group						
CUB045	82	40				122
567.1	35	17				52
567.2	30	15				45
567.3	17	8				25
CUB081	21	22				43
567.1	8	10				18
567.2	8	8				16
567.3	5	4				9
TOP073	41	43	6	6	38	134
567.1	17	18	3	3	15	56
567.2	15	16	2	2	14	49
567.3	9	9	1	1	9	29
Total	**144**	**105**	**6**	**6**	**38**	**299**

Summary statistics for sensory traits within muscle are shown for the cohort 2 grass finished steers in Table 52.

Table 52. Summary statistics for the CUB045, CUB081 and TOP073 grill samples for each sensory variable split by days aged on grassfed cohort 1 animals.

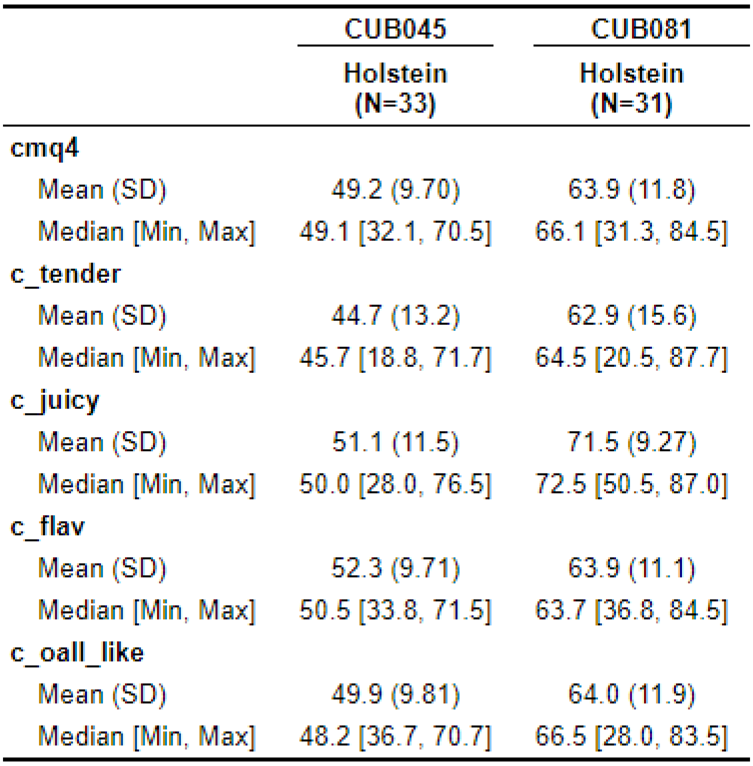
	CUB045		CUB081		TOP073	
	7 (N=40)	**21 (N=40)**	**7 (N=21)**	**21 (N=22)**	**7 (N=41)**	**21 (N=43)**
cmq4						
Mean (SD)	63.0 (10.0)	63.9 (9.91)	76.5 (8.92)	80.4 (8.73)	43.9 (10.1)	44.7 (9.43)
Median [Min, Max]	63.4 [44.5, 82.2]	64.9 [39.0, 83.0]	79.3 [57.5, 88.6]	81.3 [63.7, 91.8]	44.2 [23.4, 69.8]	44.8 [25.6, 68.2]
c_tender						
Mean (SD)	63.1 (11.4)	64.1 (10.9)	78.1 (10.1)	82.7 (7.74)	38.7 (11.8)	40.4 (11.2)
Median [Min, Max]	63.3 [44.7, 85.7]	64.4 [33.0, 85.8]	79.0 [54.8, 95.5]	84.3 [69.8, 95.3]	36.3 [16.2, 64.0]	40.5 [23.7, 66.5]
c_juicy						
Mean (SD)	61.5 (12.9)	63.6 (11.3)	79.4 (8.71)	83.8 (6.04)	42.3 (11.3)	44.6 (13.2)
Median [Min, Max]	62.7 [33.2, 84.7]	64.3 [37.0, 85.5]	80.0 [48.7, 90.8]	84.0 [73.5, 93.2]	43.0 [20.3, 66.3]	48.0 [21.8, 72.8]
c_oall_like						
Mean (SD)	64.4 (10.9)	64.7 (10.3)	76.9 (9.42)	81.0 (9.87)	44.2 (10.9)	45.3 (10.2)
Median [Min, Max]	65.4 [42.8, 84.5]	64.8 [38.0, 85.2]	79.2 [57.0, 90.3]	83.1 [62.3, 92.3]	45.2 [23.3, 75.0]	45.2 [25.2, 72.2]

The cohort 2 steers were also backgrounded and finished on 4 different properties and harvested at Teys Wagga on 2 dates, with one property on 12AUG2021 and the other three on 18Nov2021. Sample counts and average MQ4 values by muscle and days aged are displayed in Table 53 with summary statistics shown in Table 54. It is noted that despite a more normal season, or perhaps a reduction in supplementary concentrate, the sensory scores are less than the cohort 1 pasture finished result (circa 14 MQ4 points, Table 51). It is also observed that the cohort 2 pasture steers were of similar birth date, sources and backgrounders to those in the lower performing cohort 2 feedlot groups (573.1 and 573.2) that had similar consumer MQ4 outcomes.

Table 53. Count and average MQ4 values by muscle within cohort 2 pasture groups

Group ID	**CUB045**					**CUB081**			
	n	**7**	***n***	**21**	**Average**	***n***	**7**	***n***	**21**
580.1	*10*	50.5	*10*	57.5	54.0	*10*	68.7		
588.1	*8*	44.0	*8*	54.7	49.4	*8*	57.0		
588.2	*8*	48.4	*8*	50.7	49.5	*8*	63.4		
588.3	*10*	47.8	*10*	60.2	54.0	*10*	60.0		

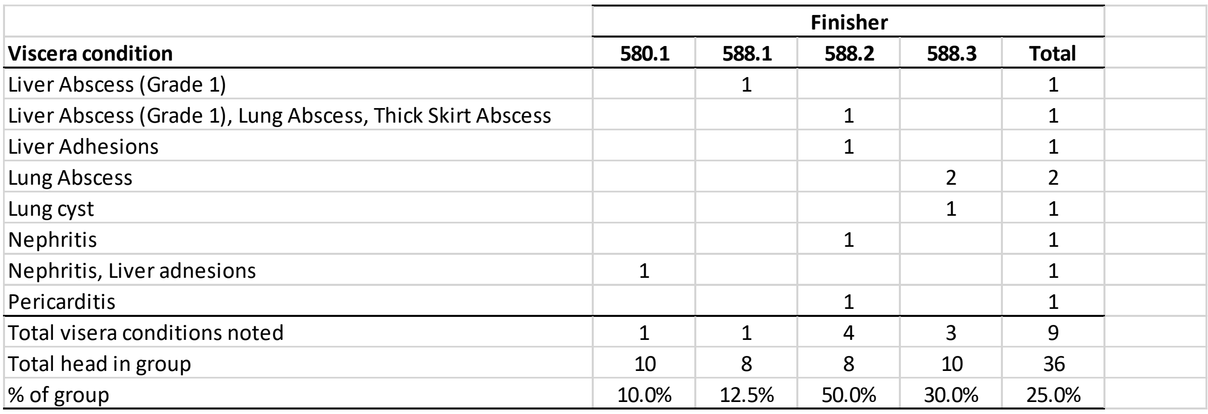
Table 54. Summary statistics for the CUB045 and CUB081 grill samples for each sensory variable on grassfed cohort 2 animals.



	CUB045	CUB081
	Holstein (N=33)	**Holstein (N=31)**
cmq4		
Mean (SD)	49.2 (9.70)	63.9 (11.8)
Median [Min, Max]	49.1 [32.1, 70.5]	66.1 [31.3, 84.5]
c_tender		
Mean (SD)	44.7 (13.2)	62.9 (15.6)
Median [Min, Max]	45.7 [18.8, 71.7]	64.5 [20.5, 87.7]
c_juicy		
Mean (SD)	51.1 (11.5)	71.5 (9.27)
Median [Min, Max]	50.0 [28.0, 76.5]	72.5 [50.5, 87.0]
c_flav		
Mean (SD)	52.3 (9.71)	63.9 (11.1)
Median [Min, Max]	50.5 [33.8, 71.5]	63.7 [36.8, 84.5]
c_oall_like		
Mean (SD)	49.9 (9.81)	64.0 (11.9)
Median [Min, Max]	48.2 [36.7, 70.7]	66.5 [28.0, 83.5]

No viscera data was provided for the cohort 1 pasture fed groups but it was supplied for each cohort 2 groups with results displayed in Table 55. All the pasture steers were Holsteins.

Table 55. Viscera conditions for cohort 2 finisher groups.



	Finisher				
Viscera condition	**580.1**	**588.1**	**588.2**	**588.3**	**Total**
Liver Abscess (Grade 1)		1			1
Liver Abscess (Grade 1), Lung Abscess, Thick Skirt Abscess			1		1
Liver Adhesions			1		1
Lung Abscess				2	2
Lung cyst				1	1
Nephritis			1		1
Nephritis, Liver adnesions	1				1
Pericarditis			1		1
Total visera conditions noted	1	1	4	3	9
Total head in group	10	8	8	10	36
% of group	10.0%	12.5%	50.0%	30.0%	25.0%

The percentage of viscera conditions reported (Table 55) varies considerably across the finishers and overall is not dissimilar to that observed for the feedlot groups (Tables 29 for cohort 1 and Table 41 for cohort 2).

4.2. Comparison of two high carbohydrate diets, 'Spanish (SDT)' and 'Australian (ADT)' for high production performance in intensively housed dairy steers

One explanation for the traditionally low proportion of dairy breed steers that are raised to slaughter at 300kg HSCW or greater is the processor experience, for Holstein types, these often being large framed, often greater than 2 years old and lean, or alternatively more aged with adequate fat cover but excessive carcase weight. Very few Jersey bullocks have traditionally been processed with those handled typically having low carcase weight and meat yield with a reputation for very yellow fat and dark meat colour although often having substantial marbling. These expectations have been reflected in low manufacturing beef pricing and a lack of financial incentive for dairy farmers or fatteners to engage.

Observation of alternative systems in the USA feedlot industry and in European intensive systems indicated that higher quality beef cuts could be produced from at least Holstein and Holstein cross cattle with these systems utilising steers in contrast to bull beef systems that had been employed in New Zealand and southern Australia. In Europe young dairy and dairy cross bulls are commonly fed for slaughter at 16 months of age or less with a large-scale Spanish program observed with more extreme performance and typical final weights of 500kg or greater liveweight at 12 months of age. Dairy steers are also widely fed in the USA but generally to carcase weights of 500kg or greater with growth rate and muscling enhanced by extensive use of both hormonal growth implants and beta-agonists. While most of the USA dairy population is Holstein it was noted that one high profile program utilises Jersey crossed to selected Limousin genetics.

The European system was judged to be more attractive in an Australian context due to the potential finish at a young age and relatively lighter 300kg carcase weight, and without use of growth promotions.

The project included an arrangement with INZAR, a Spanish livestock nutrition company, to as near as possible replicate their accelerated growth program (SDT) and to concurrently evaluate a high performance Australian (ADT) dietary regime utilising more typical Australian feedlot practice where rumen modifiers that are not allowed for use in the EU were utilised. Beta-agonists are not registered for use in Australian beef cattle and, together with HGP, were excluded from both the SDT and ADT treatments.

4.2.1. Disease rates and survival analysis

Unfortunately transport of the more distant calves coincided with severe cold and wet weather creating a health challenge on arrival and requiring active veterinary intervention. A total of 86% of the calves on the Australian Diet Treatment (ADT) had scours during the study and 84% of those on the Spanish Diet Treatment (SDT) (Table 56). The incidences of scours were primarily within the first 14 days of the study. Scouring incidences across the diets and pens were relatively consistent, with an outlier of 1.33% occurring in pen 9 of the SDT diet (Table 57). It was noted that industry sources reported similar performance issues thought to be related to particular batches of the milk replacer that was utilised. The scour score severity was numerically higher in the SDT group (P = 0.141) than the ADT group. Infections of the eye, horns and navel were the second most prominent health disorder. Scouring was rarely identified after 22 days of age, with only two calves presenting with scours later in the feeding period, likely as a clinical presentation of salmonella. The lack of scouring following the initial period on feed may be indicative of the adaptation of the rumen to the diet and increased tolerance to a more acidotic rumen environment. Increased scouring is a common ailment in young calves during feed transitions, typically with a highest prevalence between 1 to 21 days of age. It can also be associated with infectious diseases of the intestine (von Buenau, Jaekel et al. 2005, Meganck, Hoflack et al. 2014), grouping of unfamiliar calves on induction to a new location, and on the introduction of solid feed (Klein-Jöbstl, Iwersen et al. 2014).

Survival

During the study 4 calves died from the SDT group (d 14 peritonitis, d 17 peritonitis/enteritis/pneumonia, d 18 abomasal torsion, and d 78 euthanised due to spiral fracture injury of the femur), 2 calves died from the ADT group (d 10 suspected toxigenic *E. coli* infection, and d 354 unknown), and 2 calves were removed from the study from the SDT group (d 67 positive for pestivirus and d 73 torsed abomasum). Therefore, a total of 35 calves from the ADT and 32 from the SDT groups completed the study.

Table 56. First incidence of disease presentation and percentage of total animals affected per treatment group in calves throughout the study but diseases were primarily within the first 3 weeks of the study. Data is inclusive of diagnoses from calves removed from the study following enrolment.

Primary diagnosis	**Treatment group**[1]	
	ADT (n=37)	SDT (n=38)
Scours	32 (86%)	32 (84%)
Infection	17 (46%)	13 (34%)
Respiratory	9 (24%)	9 (24%)
Bloat	7 (19%)	1 (3%)
Salmonella	0 (0%)	1 (3%)

[1] ADT = Australian diet treatment; SDT = Spanish diet treatment.

Table 57. Total number (includes multiple incidences per calf) and percentage of scouring events and mean (± SEM) severity by pen. Inclusive of scouring events from calves removed from the study following enrolment. Scoring: 1 = extremely liquid faeces, with bubbles and some grain content; 5 = stool samples with formed mounds.

Treatment group[1]	Pen	Number of cases	Percentage of total incidences (%)	Mean scour score (1-5)
ADT	2	8	10.67	1.39 ± 0.18
	4	6	8.00	1.14 ± 0.12
	6	8	10.67	1.5
	8	9	12.00	1.5 ± 0.22
	10	4	5.33	1.42 ± 0.24
	12	5	6.67	1.63 ± 0.31
	Total	40	53.34	1.35 ± 0.07
SDT	1	8	10.67	1.53 ± 0.11
	3	7	9.33	1.17 ± 0.06
	5	8	10.67	1.5 ± 0.22
	7	6	8.00	1.38 ± 0.24
	9	1	1.33	1.64 ± 0.21
	11	5	6.67	2
	Total	35	46.67	1.51 ± 0.08

[1] ADT = Australian diet treatment; SDT = Spanish diet treatment.

4.2.2. Growth rates of ‘Spanish’ diet and ‘Australian’ diet Holstein-Friesian steers on an accelerated growth diet

For the finishing phase of the trial, all steers were transported from the calf rearing facility at Camden, NSW to the Charles Sturt Ruminant Research Facility on the Wagga Wagga campus. Steers were weighed and drafted into their original pen cohorts and moved to standard, open feedlot pens for the duration of the feeding trial. ADG was observed to be significantly different between the two treatment groups, although this outcome was influenced by time as a factor as there was a significant period during the middle of the trial when steers on the ADT showed reduced growth compared to their SDT counterparts. This was related to pelleting of the feed and the resultant change in presentation reducing appetite for the ADT diet. Once this was rectified (see Table 58, Fig. 23), intake returned to normal and liveweight gain compensated. It is therefore important to view this statistical result in the context of the experimental conditions during the trial. This is notable as the intake / pen / day showed a significant increase for ADT pens compared to their SDT counterparts (Table 58).

Table 58. Mean (± SEM) for entry body weight, finishing weight, ADG over the finishing period and daily intake per pen over the finishing period and significance of group, time, and their interaction

	Dietary treatment[1]		**Significance (*P*-value)**		
	SDT N = 32	**ADT N = 36***	**Group (G)**	**Time (T)**	**G×T**
Mean entry weight (kg)[2]	44.7 ± 16.5	44.0 ± 15.0			
Mean daily gain (kg)	1.16 ± 0.31	1.19 ± 0.29	0.492	<0.001	<0.001
Mean finishing weight (kg)[2]	304.92 ± 4.31	293.66 ± 4.30	0.052	<0.001	<0.001
Mean daily intake per pen (kg/d/pen)	37.57 ± 1.95	40.06 ± 1.94	0.380	<0.001	<0.001

[1] ADT = Australian diet treatment; SDT = Spanish diet treatment.

[2] This model includes the covariables "Pen" p = 0.025 and "Age days" p <0.001

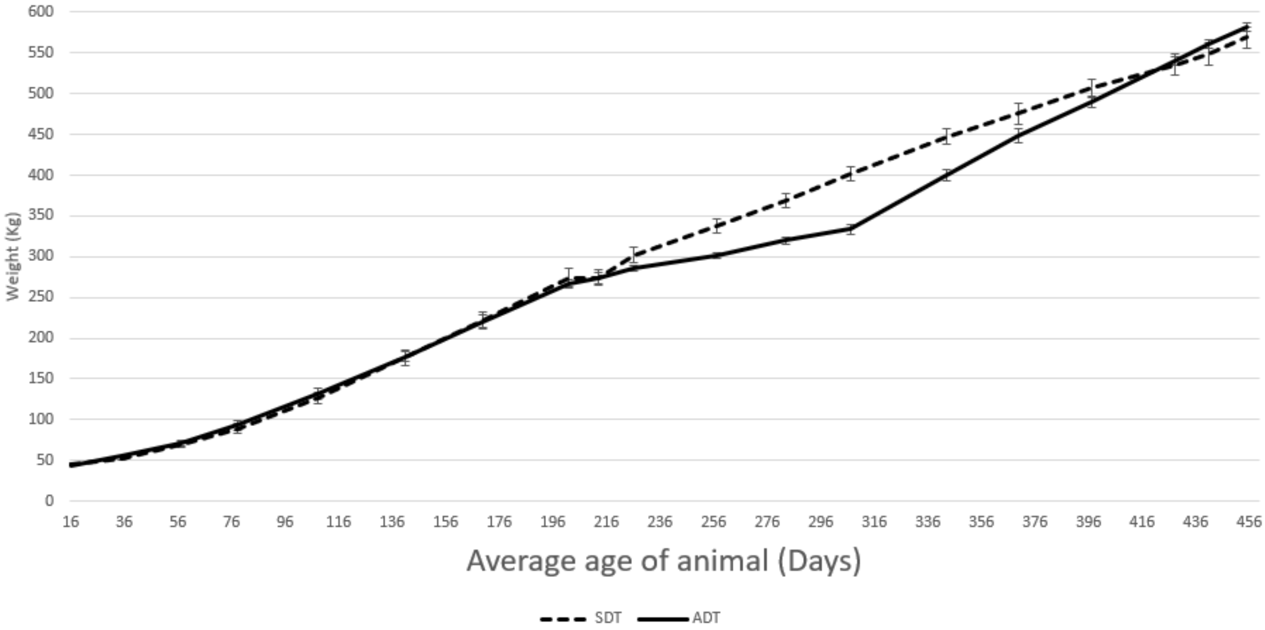
*Includes ADT animal that died at 354 days old.

When time was removed as a factor and only final liveweight was considered, finishing weight was not significantly different at date of slaughter between the two treatment groups (SDT: 570 ± 7.01kg; ADT 583.08 ± 6.69kg, Fig. 24, Table 59). Both groups finished the trial meeting mean target weights of >550kg liveweight at 14 months of age demonstrating the value of accelerated rearing strategies. While this performance is impressive it was below the targeted finish at 12 to 13 months of age and may have been impacted by the health issues in the early milk feeding phase.

4.2.3. Impact of diet on growth rates of Spanish versus Australian diet Holstein-Friesian steers

There were several differences between the Australian and Spanish diet treatments. The Australian Diet Treatment (ADT) included three rumen modifiers in the diet formulation, which were not included in the SDT diet. Flavomycin was added to aid in the reduction of the shedding and infection rates of *Salmonella spp*., *Clostridium*, and *E. coli,* in addition to increased growth rates and reduction of feed costs (International Animal Health Products 2018). Celmanax was included to reduce the incidence, severity and duration of scouring events in calves (Arm & Hammer 2020) (Arm & Hammer 2015, Lucey, Lean et al. 2021). Fermenten was incorporated to improve microbial protein production (Lean, Webster et al. 2005). These additional modifiers did not appear to provide ADT calves with an advantage over SDT calves in terms of production performance and scouring incidences within the first 8 months, however, may have influenced incidences of salmonella (ADT = 1, SDT = 5). Additional benefits may have been observed in the finishing phase due to additional inclusions in the diet as ADT steers yielded higher BW and ADG in the interval before slaughter, although this may also reflect compensatory growth after transition from the pelleted to crumble feed preparation.

Figure 23. Comparison of live weight gain over time for Holstein-Friesian steers fed a 'Spanish' diet treatment (SDT) and 'Australian' diet treatment animals. ADT n = 35; SDT n = 32. Movement from Camden to Wagga Wagga occurred at 1976 days. ADT transition from pelletised ADT ration to crumbled ADT ration occurred at 312 days. Finishing weight was not significantly different between treatment groups.



4.2.4. Carcase traits of 'Spanish' diet and 'Australian' diet Holstein-Friesian steers

At slaughter, all SDT and most ADT animals graded MSA. Two ADT animals were excluded from grading due to high pH values (pH > 5.70). Most carcase characteristics showed no statistical difference between the two treatment groups when pen was considered as a variable (Table 59). This was to accommodate differences in age between early and late filled pens. The only differences noted were in P8 fat depth, and rib fat, both of which were significantly increased in the ADT group (Table 59). The only notable difference between carcases was a numerical increase in prevalence of liver lesions in the SDT group, with 10/32 animals showing liver defects compared to 6/35 in the ADT group (Relative Risk 1.82 95% CI 0.75 to 4.45; P = 0.18). This finding may be consistent with the inclusion of the rumen modifiers to control acidosis risk in the ADT formulation but requires more investigation as both groups have a higher than desirable incidence of abscess. Only when pen was considered a covariable was the difference between treatment significant (Table 59).

Table 59. Statistical analysis of carcase characteristics of 'Spanish' compared to 'Australian' diet treatments at slaughter. P = <0.05

	Dietary treatment		Significance	
Value	**Spanish N = 32**	**Australian N = 35**	**Age (days)**	**Group effect**
Liveweight pre slaughter (kg)[1]	570.07 ± 7.01	583.08 ± 6.69	0.095	0.181
Carcase weight (kg)	284.39 ± 4.20	293.16 ± 4.03	0.292	0.136
Dressing percentage	49.61 ± 0.29	50.52 ± 0.28	0.490	0.263
Hump height (mm)	60.93 ± 1.81	60.23 ± 1.77	0.792	0.783
Eye muscle area (cm^2)	73.57 ± 1.56	71.25 ± 1.11	0.452	0.153
P8 fat depth (mm)	8.19 ± 0.31	9.71 ± 0.29	0.435	**<0.001**
Rib fat (mm)	6.08 ± 0.44	7.67 ± 0.42	0.457	**0.010**
Marble (Score 1 to 1190)	420.53 ± 14.37	423.81 ± 13.89	0.971	0.871
Fat colour score (0-9)	0.25 ± 0.17	0.72 ± 0.69	0.971	0.440
Ossification (Score 100 to 590)	146.93 ± 5.02	133.39 ± 4.80	0.030	0.054
Ultimate pH	5.62 ± 0.19	5.62 ± 0.20	0.300	0.861
Colour (Score 1 to 6)	3.00 ± 0.15	3.08 ± 0.15	0.119	0.694
MSA index (Score 30 to 80)	62.13 ± 0.44	63.09 ± 0.43	0.279	0.125

[1] This model also included the covariable pen p<0.001.

4.2.5. Sensory analysis of 'Spanish' diet and 'Australian' diet Holstein-Friesian steers

Consumer sensory testing was undertaken for samples collected from both SDT and ADT Holstein cattle at slaughter with sample numbers displayed in Table 60.

Table 60. Consumer samples evaluated by muscle within treatment group

Muscle	**586.1 (ADT)**			**586.2 (SDT)**			**Grand Total**
	7	**21**	**Total**	**7**	**21**	**Total**	
CUB045	34	34	68	30	28	58	126
CUB081	35		35	32		32	67
TOP073	35		35	32		32	67
Total	**104**	**34**	**138**	**94**	**28**	**122**	**260**

Average eating quality MQ4 scores for tested samples are shown in Table 61 and in Fig.24. A further 8 samples remain in frozen storage as detailed in the appendix.

Table 61. Average MQ4 values for muscles and days aged within treatment group.

Muscle	586.1 (ADT)			586.2 (SDT)			Overall Average
	7	21	Average	7	21	Total	
CUB045	64.3	63.9	64.1	62.7	67.4	65.0	64.5
CUB081	77.7		77.7	78.8		78.8	78.2
TOP073	37.0		37.0	38.0		38.0	37.5
Average	**59.6**	**63.9**	**60.7**	**59.8**	**67.4**	**61.5**	**61.1**

Diet was not observed to exert a difference in eating quality for any cut examined (Table 61, Fig. 24). When product was aged for either 7 (CUB045, CUB081, TOP073) or 21 days (CUB045 only) ageing, no significant difference in eating quality was observed (Table 61) whilst both CUB081 showed significantly better, and TOP073 significantly reduced eating quality compared to control primals (Table 62).

Figure 24. Sensory analysis of MQ4 for SDT (Spanish) and ADT (Control) grill samples.

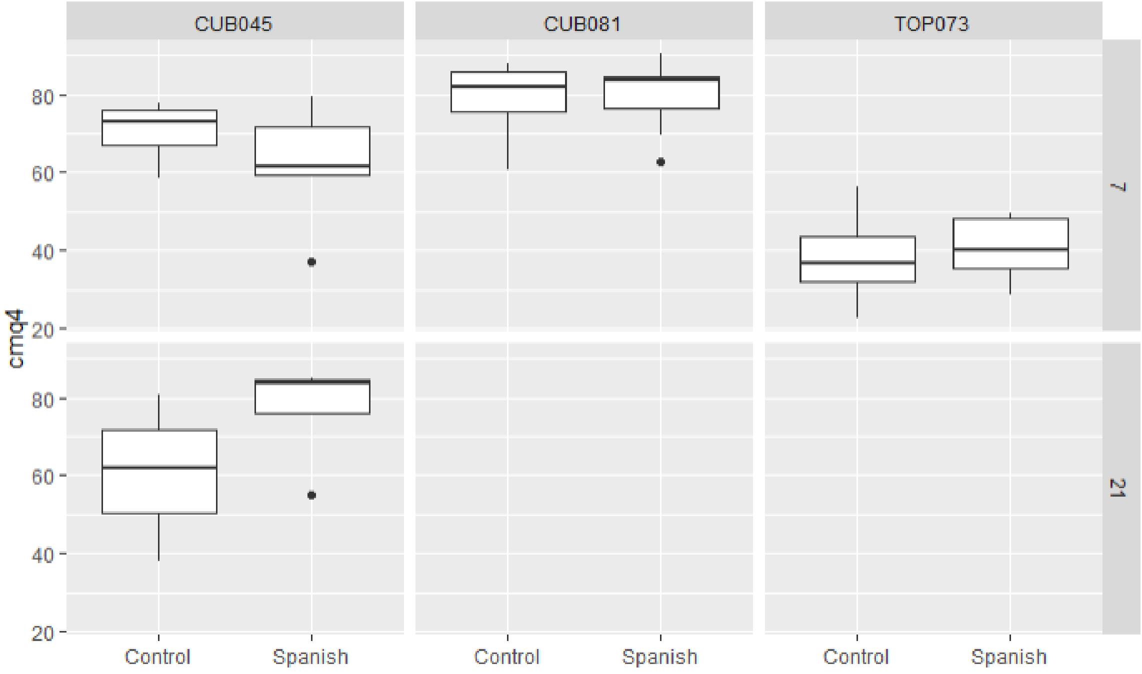
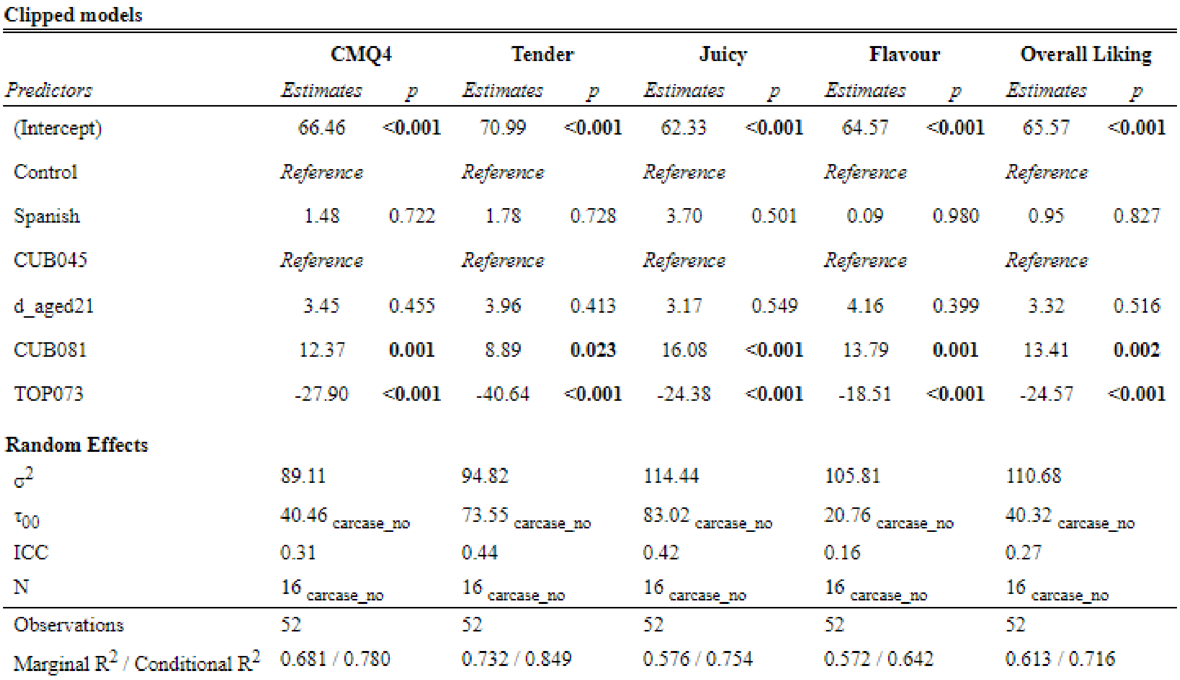


Table 62. Summary statistics of MEQ4 grill samples for each sensory variable on for SDT (Spanish) and ADT (Control) fed Holstein steers.



Clipped models

	CMQ4		Tender		Juicy		Flavour		Overall Liking	
Predictors	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*	*Estimates*	*p*
(Intercept)	66.46	**<0.001**	70.99	**<0.001**	62.33	**<0.001**	64.57	**<0.001**	65.57	**<0.001**
Control	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
Spanish	1.48	0.722	1.78	0.728	3.70	0.501	0.09	0.980	0.95	0.827
CUB045	*Reference*		*Reference*		*Reference*		*Reference*		*Reference*	
d_aged21	3.45	0.455	3.96	0.413	3.17	0.549	4.16	0.399	3.32	0.516
CUB081	12.37	**0.001**	8.89	**0.023**	16.08	**<0.001**	13.79	**0.001**	13.41	**0.002**
TOP073	-27.90	**<0.001**	-40.64	**<0.001**	-24.38	**<0.001**	-18.51	**<0.001**	-24.57	**<0.001**
Random Effects										
σ^2	89.11		94.82		114.44		105.81		110.68	
τ_{00}	40.46 carcase_no		73.55 carcase_no		83.02 carcase_no		20.76 carcase_no		40.32 carcase_no	
ICC	0.31		0.44		0.42		0.16		0.27	
N	16 carcase_no		16 carcase_no		16 carcase_no		16 carcase_no		16 carcase_no	
Observations	52		52		52		52		52	
Marginal R^2 / Conditional R^2	0.681 / 0.780		0.732 / 0.849		0.576 / 0.754		0.572 / 0.642		0.613 / 0.716	

4.3. Outcomes of meat eating quality (MEQ) evaluation and prospective MSA model application.

Overall, the dairy beef project encompassed a complex series of animal and growth strategies. Principal components were:

1. Purchase of Holstein, Jersey, Holstein x Jersey and beef calves in cohort 1. Purchasing and backgrounding was dispersed across 3 regions, Gippsland, Western District and Riverina with purchases from multiple farms within each region and assembly for backgrounding within each region.
2. Nutritional management strategies during backgrounding to produce high and low growth targets.
3. Harvesting on a common date and at a single abattoir of a random selection from each backgrounding location, in turn including a controlled mix of breed categories, for slaughter of 249 head from the project backgrounders at veal weights (<150 kg Hot Standard Carcase Weight, HSCW).
4. Further collection and fabrication of 11 samples per body during the same kill day and location of 25 heifer and 25 bull veal as requested by MLA/MSA to ensure linkage between sex in the veal category.
5. Further balanced selection for backgrounder x breed within the 249 project veal carcases with differing numbers of cuts collected from each. A maximum number of muscle samples (23) were fabricated from 18 head, A lesser but significant number of

muscles (11) were fabricated from 54 head and 2 samples from the remaining 143 project carcases.

6. Collection of cuts and fabrication of 9 consumer samples from each of the externally purchased 25 heifer and 25 bull veal bodies.
7. Allocation to grill, roast, Texas BBQ, slow cook and schnitzel cooking methods with linkages across and within cuts where appropriate to ensure potential veal x cooking method cut interactions could be determined.
8. Variable cut ageing to examine ageing x muscle interaction within veal carcases.
9. Transfer of cohort 1 calves from the backgrounders to Charlton Feedlot for commercial feeding to a notional 300kg HSCW at slaughter.
10. Retention of some cohort 1 animals on grass feeding, with supplement as required, through to slaughter weights of a nominal 300kg HSCW.
11. Collection of selected cuts and consumer sample fabrication from all non-veal cohort 1 cattle. The feedlot cattle were processed at one abattoir on two dates whereas the grass finished steers were processed on a single date at a second abattoir.
12. Assembly and backgrounding of a second cohort again across breeds and regions with differential growth paths but without a veal pathway.
13. Feeding of cohort 2 cattle post backgrounding at Associated and Tullimba feedlots with 4 slaughter dates, 3 at one abattoir and 1 at a second, at a notional 300kg HSCW and fabrication of consumer samples.
14. Pasture finishing of cohort 2 Holstein cattle at 4 finishing properties.
15. Slaughter of the grass finished component of cohort 2 and fabrication of consumer samples on 2 slaughter dates.
16. Purchase of Holstein calves and intensive feeding from birth to a notional slaughter weight of 300kg HSCW utilising two programs, one utilising specific premixes sourced in Spain and rations constructed to approximate those used in the Spanish program, and a second program incorporating Australian intensive feeding methodology. The Australian program utilised loose meal and later pelleted, then crumbled, rations and included the use of an ionophore and Flavomycin antibiotic to control rumen function under a high starch dietary challenge whereas the Spanish ration was produced as a hammermilled meal contained yeasts and a buffer and met EU regulations in not including ionophores or antibiotics.

These extensive production pathways resulted in the fabrication of 4370 non-link consumer samples. The first veal group (536.1) of 18 head were selected as a controlled subset of breed within backgrounder and selected within carcases that met existing MSA minimum standards for rib fat of 3mm or greater, even external fat distribution and meeting the pH window requirements of pH 6 occurring between 12 and 35°C. In practice this was difficult for veal calves which being far younger and lighter generally have very low rib fat and are highly susceptible to cold shortening during chilling. An important MSA consideration is the potential need to revise chilling requirements and rib fat minimums for a prospective veal pathway.

The remaining veal carcases were all outside the MSA minimum rib fat and/or pH temp window with only two primary cuts collected from each, one from the loin (backstrap – a combination of cube roll (CUB045) and striploin (STR045) under the MSA terminology for the *M. longissimus dorsi et* *lumborum* muscle. A lesser number of muscles were collected from the non-veal groups to provide comparison to existing beef breed data.

The number of samples fabricated within cuts from each of the project groups are displayed by cooking method in Tables 63-65.

Table 63. Summary of grill consumer samples fabricated by group and muscle.

	GROUPS COLLECTED																			
	536.1	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**558.1**	**558.2**	**558.3**	**558.4**	**567.1**	**567.2**	**567.3**	**571.1**	**572.1**	**573.1**	**573.2**	**580.1**	**586.1**	**Total**
GRILL SAMPLES																				
BLD096	18	16		6	8															**48**
CHK078	12	9		3	4															**28**
CTR085	27																			**27**
CUB045	18	12	106	12	10	72	28	77	58	6	36	32	18	69	144	118	20	22	134	**992**
CUB081	18					36	14	38	29	3	18	16	9	68	142	118	19	10	67	**605**
EYE075	15	14		3	7															**39**
KNU066	22	3																		**25**
KNU099	22	3																		**25**
OUT005	29	23	82	20	12		14	22	28	2										**232**
OYS036	22																			**22**
RMP005	18																			**18**
RMP131	35	12		6	6															**59**
RMP231	18																			**18**
STR045	36	24	98	21	20															**199**
TDR062	18	12		6	6															**42**
TOP073	29	24	80	15	20	72	14	18	30	4	39	34	18	68					67	**532**
Total Grill	357	152	366	92	93	180	70	155	145	15	93	82	45	205	286	236	39	32	268	**2911**
GRILL SousVide Samples																				
CUB045														30						**30**

The Grill Sous-Vide samples were paired to standard grill samples and tested in conjunction with a range of beef samples to examine the potential value of this cooking method.

Table 64. Summary of roast consumer samples fabricated by group and muscle.

	GROUPS COLLECTED																			
	536.1	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**558.1**	**558.2**	**558.3**	**558.4**	**567.1**	**567.2**	**567.3**	**571.1**	**572.1**	**573.1**	**573.2**	**580.1**	**586.1**	**Total**
ROAST SAMPLES																				
BLD096	18																			**18**
CHK078	12	8		4	4															**28**
CUB045	18	12	98	15	14															**157**
EYE075	12	7		5	4															**28**
KNU066		12		6	6															**24**
KNU099		12		6	6															**24**
OUT005	22	16	65	12	9															**124**
RMP131		12		6	6															**24**
STR045	36	24	106	18	16															**200**
TDR062	18	12		6	6															**42**
TOP073	24	16	67	10	16	72					36	32	18							**291**
Total Roast	**160**	**131**	**336**	**88**	**87**	**72**					**36**	**32**	**18**							960

A lesser number of muscles from the veal collection were large enough to enable a grill to roast within body comparison as displayed in Tables 64. Similarly, selection of muscles for slow cook, schnitzel and Texas BBQ was also restrained with numbers shown in Table 65.

Table 65. Summary of slow cook, schnitzel and Texas BBQ consumer samples fabricated by group and muscle.

	GROUPS COLLECTED																			
	536.1	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**558.1**	**558.2**	**558.3**	**558.4**	**567.1**	**567.2**	**567.3**	**571.1**	**572.1**	**573.1**	**573.2**	**580.1**	**586.1**	**Total**
SLOW COOK SAMPLES																				
BRI056	18																			**18**
CHK078	12	7		5	4															**28**
FQSHIN	18																			**18**
HQSHIN	19																			**19**
Total Slow Cook	**67**	**7**		**5**	**4**															**83**

	GROUPS COLLECTED																			
	536.1	**536.2**	**536.3**	**536.4**	**536.5**	**552.1**	**558.1**	**558.2**	**558.3**	**558.4**	**567.1**	**567.2**	**567.3**	**571.1**	**572.1**	**573.1**	**573.2**	**580.1**	**586.1**	**Total**
SCHNITZEL SAMPLES																				
BLD096		8		6	4															**18**
CUB045																	15			**15**
EYE075	9	3		4	1															**17**
KNU066	14	9		6	6															**35**
KNU099	14	9		6	6															**35**
OUT005	19	8	51	12	7															**97**
OYS036	14																			**14**
TOP073	19	8	55	9	8						15	14	9							**137**
Total Schnitzel	**89**	**45**	**106**	**43**	**32**						**15**	**14**	**9**				**15**			**368**
TEXAS BBQ SAMPLES																				
BRI056	18																			**18**

The slow cook muscles reflected common use in slow cook (stew or casserole) cooking forms and allowed direct comparison within picks to those from a range of beef groups (Table 65). A new MSA schnitzel cooking protocol was developed to establish between muscle effects and linkage to grill, slow cook or roast in view of the extensive commercial use of veal schnitzel. Some linkage was established to the older dairy breed product from project cattle. The Texas BBQ cooking method was only applied to brisket and tested in conjunction with a controlled range of beef cattle categories following previous MSA work that established a substantial eating quality increase relative to slow cook.

An overall summary view of the relative consumer response across the many project cohort treatments and processing dates is presented in Table 66 which displays average observed MQ4 values for grilled samples of the most widely evaluated muscles.

Table 66. Average observed consumer MQ4 values for grilled samples by days aged within most utilised muscles across cohort groups.

	Group ID	CUB045				CUB081				TOP073				OUT005			
Group Description		*n*	7	*n*	21	*n*	7	*n*	21	*n*	7	*n*	21	*n*	7	*n*	21
COHORT 1 - VEAL - Common Kill day Abattoir 1																	
From 18 Calves balanced breed & pod and close MSA compliance	536.1	5	64.0	4	64.2	18	75.5			6	45.2	6	50.7	6	37.6	6	51.1
	536.1 (STR)	9	60.7	9	59.3												
From 48 Calves balanced by breed & pod next best MSA compliance	536.2	3	57.3	2	59.3					5	43.3	4	46.8	4	44.4	3	34.2
	536.2 (STR)	5	57.2	6	56.2												
From 183 Calves remainder of trial group with poor MSA compliance	536.3	26	65.8	27	66.2					16	49.6	16	50.8	4	46.6	18	53.9
	536.3 (STR)	27	55.8	22	61.8												
From 25 heifer calves external to trial group	536.4	4	43.7	4	60.9					2	28.4	3	29.8	2	36.0	4	44.3
	536.4 (STR)	6	54.4	7	54.2												
From 25 bull calves external to trial group	536.5	1	49.7	3	72.6					4	40.4	5	52.9	2	46.0	2	26.0
	536.5 (STR)	3	61.2	5	64.3												
COHORT 1 - FEEDLOT 1 - Abattoir 2 - 2 kill dates																	
Feedlot 1 - 143 DOF - 21 Beef, 7 HH, 8 HJ from 60 in Group - First Kill day	552.1	36	70.6	36	72.4	17	81.7	17	83.2	35	44.0	35	47.8				
Feedlot 1 - 234 DOF - from 16 JJ in group - Second kill day	558.1	14	74.6	14	77.1	7	85.2	6	81.7	6	62.9	6	58.4	7	47.3	7	44.9
Feedlot 1 - 234 DOF - from 19 HH in group (incl Freeze thaw within animal) - 2nd Kill day	558.2	37	72.3	38	73.1	10	75.5	10	82.5	8	45.6	9	42.8	11	39.0	11	38.9
Feedlot 1 - 234 DOF - from 27 HJ in group - second kill day	558.3	29	67.9	29	69.7	13	80.7	14	78.5	13	48.1	14	51.0	14	44.6	14	45.3
Feedlot 1 - 234 DOF - from 4 beef in group - second kill day	558.4	3	71.4	3	62.3	1	81.6	1	73.6	2	42.5	2	52.4	1	52.3	1	58.6
COHORT 1 - GRASS & SUPPLEMENT - Common Kill day Abattoir 3																	
Backgrounder 1 - from 18 HH	567.1	17	62.5	17	61.9	8	71.8	10	78.3	17	39.3	18	43.7				
Backgrounder 2 - from 17 HH	567.2	15	62.2	15	65.2	8	77.4	8	83.9	15	45.4	16	46.3				
Backgrounder 3 - from 10 HH	567.3	8	65.8	8	65.9	5	82.3	4	78.6	9	50.0	9	44.0				
COHORT 2 - FEEDLOTS 2 & 3 - Abattoirs 2 and 4 with multiple kill dates																	
Feedlot 2 - 110 DOF - HH, LH, HJ pods (paired GSV samples not shown) - Abb 2, 3rd kill day	571.1	51	67.6			68	78.9			68	42.2						
Feedlot 3 - 130 DOF - All pod types - same abattoir as Feedlot 1 - Abb 2, 4th kill day	572.1	58	62.7			63	77.1										
Feedlot 3 - 110 DOF - All pod types - same abattoir as Feedlot 1 - Abb 2, 5th kill day	573.1	38	50.1			38	73.2										
Feedlot 3 - 237 DOF - 9 HH, 9LH Same Rearer & Backgrounder - Abattoir 4 different to others	573.2	12	50.6			12	69.6										
COHORT 2 - GRASS & SUPPLEMENT - All Abattoir 2 - 2 kill dates																	
Backgrounder 1 - From 10 HH - Abb 2 - 6th Kill Day	580.1	10	50.5	10	57.5	10	68.7										
Backgrounder 2 - From 8 HH - Abb 2 - 7th Kill Day	588.1	8	44.0	8	54.7	8	57.0										
Backgrounder 3 - From 10 HH - Abb 2 -7th Kill Day	588.2	8	48.4	8	50.7	8	63.4										
Backgrounder 4 - From 11 HH - Abb 2 - 7th Kill Day	588.3	10	47.8	10	60.2	10	60.0										
HIGH CARBOHYDRATE COHORT - Abattoir 1 common kill day																	
High carbohydrate program - ADT	566.1	34	64.3	34	63.9	35	77.7			35	37.0						
High carbohydrate program - SDT	566.2	30	62.7	28	67.4	32	78.8			32	38.0						

4.3.1. Freeze thaw ageing evaluation

Logistical considerations within individual plants often impact decisions on whether selected cuts will be held chilled or frozen immediately after boning. In general bone in cuts and some of the larger secondary items including insides, outsides and chucks are often frozen 1 day post kill to enable higher value items to be chilled and align production to optimise chiller and freezer capacity. With the expanding proportion of cuts marketed under MSA based brands this could result in reduced revenue due to MSA eligibility being restricted to a minimum of 5 days chilled ageing.

A subset of paired samples from a group of Holstein steer carcases from the dairy project were utilised to gain a preliminary understanding on the potential for ageing after initial freezing, storage and thawing. Given suitable tracking and control systems, quantification of a post thaw ageing rate would provide a basis to examine the opportunity for an MSA pathway of ageing after thawing, prospectively in a customer supply chain or distribution facility.

Paired cube rolls were collected from 18 grain fed Holstein steers at Wagga (Group 558.2). One from each body was frozen on plant in the plate freezer immediately after boning and the other prepared into 7 and 21 day aged MSA grill consumer samples at CSU. These control samples were frozen at 7 and 21 days and held frozen until 24 hours prior to sensory testing.

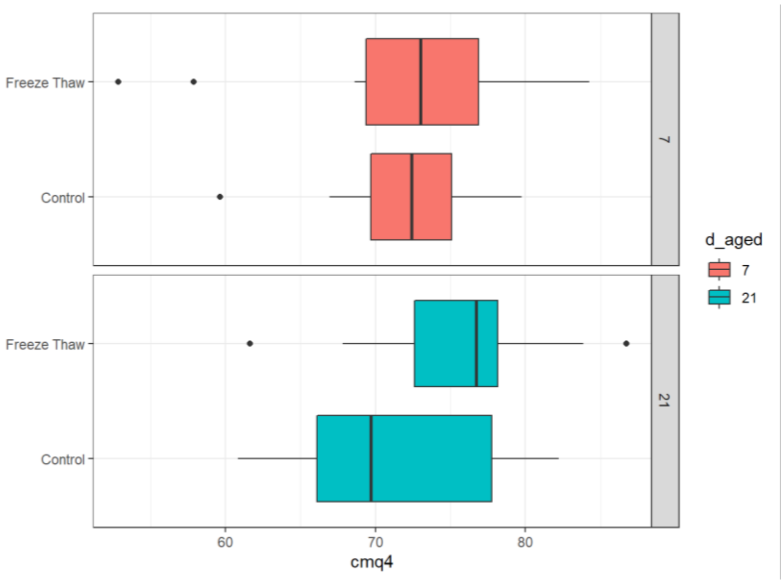
The final 17 paired frozen primals were divided into portions with a band saw 23 days prior to sensory testing, with the 21 days allocated piece thawed and the 7 day piece re vacuum packed until 9 days prior to sensory. After thawing the frozen samples were fabricated to MSA consumer grill samples and tested within the same consumer sessions as their pairs. The adjusted consumer MQ4 means and standard errors are displayed in Table 67.

Table 67. Adjusted Mean MQ4 after 7 and 21 days ageing for control (frozen after ageing) and freeze thaw (frozen 1 day post-mortem and aged after thawing).

Treatment	Days Aged	Mean MQ4	Std Error
Control	7	72.15	1.64
	21	71.32	1.6
Freeze & Thaw	7	72.78	1.6
	21	75.89	1.6

The consumer results are also displayed in Fig. 25 and illustrate a trend towards consumer preference for the frozen and thawed treatment although this finding was not significant. Given the low sample numbers and unusual lack of ageing between 7 and 21 days for the controls, the trend was considered unreliable but did indicate that post thaw ageing could be essentially equivalent to thawing prior to freezing.

Figure 25. Consumer preference analysis of control and freeze/thaw MQ4 samples at 7 and 21 days ageing (d_aged).



There are a number of caveats around that conclusion in addition to the low sample size including the possibility that freezing in full primal form may impact ageing relative to freezing after fabrication into consumer samples. The results were however encouraging and suggest that, subject to replication across further paired cuts, ageing after thawing could be a consideration for future MSA commercialisation. The difficulties regarding supply chain monitoring, control and consistency in international markets, however, creates issues for practically applying a freeze thaw pathway.

5. Conclusions

This is the first and largest study to date to directly evaluate the growth, carcase, and eating performance of dairy steers in comparison to beef animals. The two cohorts finished in the feedlot addressed slightly different hypotheses and some findings differed between the cohorts. The first cohort evaluated responses of steers grown on different growth paths in backgrounding that entered the feedlot and were fed in a single pen, whereas the cattle in cohort 2 were not mixed among high and low growth pods in the two feedlots.

Despite the finish in the feedlot or on pasture, there were considerable similarities in breed responses between the veal and feedlot findings with Jersey calves having lower weights than other breeds. For cohort 1, treatment was effective in increasing the ADG, final weights for veal, and before entry to the feedlot. However, the gains for the HG pods in backgrounding were below the targeted 1.2 kg/d for Holsteins on pasture, possibly reflecting challenges in feeding the steers during the drought. Notwithstanding this, the beef breed steers achieved gains of >1.2 kg/d, indicating that the nutrition was adequate for better ADG and that other factors were also inhibiting better ADG. It is possible that being older, heavier and raised on their dams prepared the beef steers to graze more efficiently than the dairy reared steers.

For cohort 1, differences in weight, final weights before farm exit, either for veal production, or entry to the feedlot were reflected in veal carcase weights, but not for feedlot finished carcases. Holstein pods performed similarly to the Beef pods in the feedlot for ADG, resulting in similar carcase weights. The hypothesis that effects of growth path in backgrounding will not be evident when pods are combined and fed in a single pen at the feedlot, was essentially met for carcase traits which showed no significant treatment effects but was challenged in regard to live animal performance due to compensatory gain of the LG cattle once in the feedlot environment and a significant treatment effect for increased ADG for the LG steers in the feedlot. The compensatory gain in this group, which was reverse in trend compared to growth pathway, was a finding of significance. The impact of compensatory gain during backgrounding on subsequent in-feedlot performance required further investigation.

Veal carcases had little fat cover, often failed to have an ultimate pH <5.7, and had high meat colour scores. Within these pods, it was notable that the Jersey carcases had very high pH, dark meat colour and little fat. However, for the LG and HG veal pods, the Beef steers had the highest fat colour scores and all groups had acceptable fat colour scores. The Jersey steers had the lowest fat colour score in the HG pod in the veal carcases. The low carcase weight and rib fat combination created conditions that indicate substantial cold shortening in some muscles and may relate to the reduced sensory scores observed with the LD (backstrap) within mid MSA 3* range on average but substantially below the 4* level of the cohort 1 feedlot pods.

The carcase characteristics of all pods that finished in the feedlot were consistent with MSA graded quality but spanned a substantial sensory range beyond what might be expected from the grading model inputs. While the cohort 1 feedlot steers performed at a high-quality level, and consistent with MSA V2.0 model grill residuals, with CUB045 having high 4* MSA sensory scores these were lower in cohort 2 and substantially lower for the later groups fed at Tullimba in which the CUB045 result was in the lower 3* range with residuals indicating consumer response 8 to 10 MQ4 points below model estimates. This is of concern and at this point unexplained.

For cohort 2, the beef breeds were mixed into the pods at a similar age to the dairy breeds. This differed from cohort 1 in which the beef cattle spent variable and greater time on their dams. It is notable that the weight gains in backgrounding were lower for the beef cattle in cohort 2, while those of the dairy breeds were similar to cohort 1. Cohort 2 included 4 offtake groups with feedlot average entry weight ranging from 213kg to 392kg and days on feed from 110 to 267, providing a considerable range of potential feeding combinations. The feedlot ADGs were numerically greater for cohort 2 and the exit weights from the feedlot numerically lower. However, the MSA Index scores and carcase characteristics were very similar for the two cohorts. Notably, however, the gains in weight achieved in backgrounding for the higher growth path steers were retained in the feedlot for cohort 2, indicating that benefits of early life nutrition can be retained notwithstanding that there was no additional gain over the low growth path steers. The pasture cohorts were all Holstein steers with analysis restricted to descriptive statistics due to low numbers and further dispersion over 3 finishers for cohort 1 and 4 for cohort 2. Sensory results were typically in the mid MSA 3* range and numerically below the feedlot contemporaries.

The difference in breed pHu is of interest and worthy of further evaluation and may be related to breed differences in metabolites and growth hormone physiology between beef and dairy cattle. Alternatively, the lower fat thickness relative to HSCW may result in faster muscle temperature decline in the dairy and a related slower pH decline rate. This finding warrants further investigation, particularly as breed-related differences in muscle physiology and development may be underlying many of the differential characteristics in meat eating quality identified in this study. Given that all cattle in the two kill dates were grain fed on ad lib high energy rations for 198 (Group 552.1) or 234 (Group 558.1 - 558.4) days it would be expected that all would have high muscle glycogen levels. Further due to their dairy background they had quiet temperament and were managed as a single pen group within a large commercial feedlot utilising standard transport protocols that normally result in very low levels of pH non-compliance. Is the relationship a genuine breed related difference reflecting genetic or metabolic/physiological mechanisms, is it related to differences in chill rate in turn influenced by HSCW and fat differences or does it reflect a slower rate of decline with an associated question as to whether the bodies were at a genuine ultimate reading when MSA graded? Each of these alternatives could influence commercial recommendations for optimum pH and temperature management and specific dairy breed processing practice.

The comparatively low numbers of Jersey steers that were compliant with MSA grading requirements in this study had a significant impact on their commercial value. This was primarily related to pH and colour by this analysis. Interestingly, there was no significant difference in breed types for rib fat compliance. Growth pathway did not impact rib fat or pH compliance between the two growth pathway groups suggesting that either compensatory growth occurred for all LG animals sufficient to meet MSA requirements or that growth pathway exerted little impact on carcase outcomes across the board, despite exerting some impact economically.

5.1. Novel diet performs well against an equivalent Australian formulation

To investigate a new alternative growth pathway for Holstein non-replacement steers, a novel 'Spanish' diet (SDT) formulation was trialled compared to an equivalent Australian formulation. The difference in process between this growth analysis and those growth pathways (high / low / feedlot finished) previously discussed is that the novel diets are formulated to be fed from birth to slaughter under intensive feeding conditions. Steers within this trial were never placed on pasture and were fed in an intensive system from milk rearing through to feedlot finishing. This novel approach is new to Australia and warranted testing under Australian conditions.

This is the first study assessing the growth impacts in Australia of a diet developed for European markets (INZAR Nutrición Animal, Zaragoza, Spain) for high growth of dairy steers from cow-calf separation to slaughter. After 8-months, steers in the Spanish Diet Treatment group yielded similar bodyweights and ADG to those in the Australian Diet group. This was consistent with previous studies that investigated high starch versus low starch calf diet studies (Hill, Bateman et al. 2012, Aragona, Suarez-Mena et al. 2020) during the first 6 months. The SDT treatment ADG remained similar to steers raised in a conventional US feed-lotting system (1.1 kg/d) reported by Bjorklund, Heins et al. (2014). These results were achieved against early life challenges of animal health interventions and milk replacer concerns which may have impacted later performance.

In addition, the hypothesis that the high starch SDT system would yield Holstein steers with higher weight gains was not supported as both the SDT and ADT diets produced high rates of gain and performed equivalently when carcase characteristics were considered. It should be noted however that the SDT did not include any rumen modifiers whereas these were utilised in the Australian formulation. Only P8 fat depth and rib fat were significantly increased in the ADT group. The study demonstrated that Holstein-Friesian steers grown out from cow-calf separation to slaughter, grown using a high-quality, high quality starch feed product, can produce an MSA graded carcase within a shortened finishing period.

A further commercial industry challenge, and potentially an opportunity, is the likely need to further develop specialist young calf rearing businesses that can professionally raise calves from 5 days of age or less to the post weaning period to provide a viable outlet for calves at the earliest possible age to enable allocation of scare resources to raising the heifer calves. A critical requirement for success in these ventures will be rigorous protocols for disease prevention at the birth farm that will include management of dry cow therapies, calving environments and colostrum quality. For the rearer initial calf transport conditions, rearing facility environment and milk or milk replacer quality and management are also critical factors, as noted within the project.

In this study, the extent to which the challenging climatic factors during transport and possible milk replacer issues impacted immediate and later health indicators is unknown but likely to exceed normal industry experience. Future extensive feeding of dairy calves for beef production is likely to require the expansion of specialist rearers. The success of these ventures will be heavily dependent on health outcomes, in turn directly impacted by dairy dry cow programs, calving conditions, colostrum quality and intake and by transport conditions and milk replacer and dry feed palatability, quality and intake.

5.2. Meat eating quality of dairy beef

Ultimately, of key interest relative to development of a viable and profitable dairy beef rearing and finishing pathway is the integration of the meat quality characteristics in a score that reflects eating quality. MSA consumer evaluation is used to develop the MSA eating quality prediction models with individual samples from specified muscles (with many common cuts including multiple muscles) evaluated within multiple cooking methods, ageing periods and compared under multiple breeds, production systems and interventions including HGP use, alternative carcase suspension systems and retail packaging. Each sample is evaluated by 10 consumers and the results utilised to calculate an MQ4 score for each sample and related satisfaction (grade) cut-off values (see section 3.5). The developed model predicts individual muscle by cooking method outcomes (311 combinations in the V2.0 research version) for every carcase graded with each reflecting the model inputs and adjusted for days aged post-mortem and for retail packaging method.

To provide a simplified guide of MSA grade potential, the MSA Index score is a standard weighted average of predicted MQ4 scores for 39 muscles each cooked by a designated standard methods aged 5 days and from an Achilles tendon hung carcase (McGilchrist, Polkinghorne et al. 2019). The index is a valuable tool for producers to evaluate their breeding and management strategies as it is standard across processing establishments and not influenced by post slaughter practices. It should however be recognised that it does not provide individual cut results or relativities as the weighted sum of the 39 cuts utilised can achieve common values with different combinations of high and low cut scores.

Project results are presented at the muscle MQ4 level throughout this report and will be utilised in review of the MSA predictions. These new data are valuable in providing new data on veal weight carcases and extensive controlled data relating to beef and dairy breeds raised under different management systems. The veal results indicate that further analysis and abattoir process development may be needed to provide an efficient commercial veal grading outcome although the base structure of the existing V2.0 model appears suitable.

The heavier, circa 300kg HSCW, carcase data also documents some typical variation in grading model inputs with dairy consistently leaner than beef cattle at similar carcase weight but with similar other inputs including marbling and ossification. The project also supports the need to further evaluate pH measurement, the timing of pH decline to pHu and the need to involve further muscles beyond the LD. It is hypothesised that muscle metabolism may differ between beef and dairy, reflecting the known difference in nutrient partitioning toward milk and muscle output. Muscle MQ4 results indicate that beef from dairy breeds is at least equal to that from beef breeds.

While the cohort 1 and first two cohort 2 feedlot groups demonstrated reasonable alignment with the V2.0 prediction the later 2, associated with a second feedlot intake period, produced substantially lower MQ4 outcomes than the prediction. This result is concerning and requires consideration as it is currently not explained.

The differences in consumer result were not reflected by the MSA Index, as might be expected given it is derived from the MQ4 muscle estimates, with all feedlot and intensive fed groups having index scores in the high 50s to mid 60s. The grass-fed steers groups performed well on evaluation of the MSA Index, although the interval to slaughter was considerably longer than for the feedlot finished steers.

5.3. Considerations relating to grading veal

While a large proportion of the veal cuts scored well above MSA minimum levels there are several issues that need to be considered for successful development and commercial implementation of an MSA Veal prediction model for grading encompassing both commercial and scientific aspects. Most apply generically to optimal processing of veal calves rather than specifically to dairy beef which was found to be of equal to superior eating quality to the beef bred calves. Some principal considerations are:

1. An MSA veal grading model of similar structure to the current MSA V2.0 beef model is likely to be feasible given the residual values for predicted versus observed values. There are several caveats around this however due to the inclusion of samples outside MSA V2.0 limits for rib fat and ultimate pH as well as meat colour, which is a common commercial screening variable not used in MSA predictions or part of the MSA program. Also SNZ and TBQ cooking methods were not contained in the MSA V2.0 model. There is a trend for high connective tissue secondary cuts to score closer to the primary higher quality cuts as grills whereas roast values are uniformly over predicted.

2. The high level of failure to meet existing MSA minimum criteria for rib fat, temperature at pH6 and ultimate pH. Some improvement could be expected with increased weight and accompanying rib fat depth and potentially muscle glycogen levels. While the project cattle were lighter than the 150 kg veal maximum it is considered unlikely that the majority would have achieved a 3mm rib fat minimum with a further 20 kg of carcase weight. It is also noted that similar failure levels were recorded in the external calves purchased.

3. A veal specific processing specification including modified chilling to avoid cold shortening by holding temperature above 12°C until pH6 is achieved could reduce the need for the 3mm rib fat minimum. This requires validation in conjunction with examination of electrical stimulation settings and a review of potential interaction with electrical stunning.

4. While the Jersey breed calves achieved satisfactory eating quality, they remained a production concern due to their light weights and reduced growth at every production stage. This directly relates to processor concerns of low carcase weight, small ribeye area and low yield.

5. Current commercial activity promoting the use of specific beef sire lines suitable for use on Jersey females could significantly improve commercial outcomes if the cross had improved growth and muscling. The same might also be relevant, but less critical, to the Holstein cross Jersey cattle as carcase weight, yield and muscling are directly related to processing economics.

6. This extensive study of veal weight calves has demonstrated that current meat science knowledge is lacking in sufficient practical understanding to actively manipulate pH, muscle and temperature relationships across carcase muscles. Further these relationships are likely to interact with the development of flavour precursors, knowledge of which could provide the ability to actively manipulate flavour outcomes. A structured study of pH, temperature, electrical inputs and flavour chemistry is recommended across major muscles as a base for effective commercial application.

7. Schnitzel (SNZ) and Texas BBQ (TBQ) cooking methods to be added to the MSA and prospective Veal prediction models. This may require additional data and, if so, it is recommended that they be included as additional comparative cooking methods in cuts being collected for other MSA research.

8. Additional bull calf cuts to be consumer tested prior to adding a bull sex to any veal prediction model. While at the young age tested male hormone levels were expected to be similar to steers with a likely equal eating quality, results indicated a strong negative bull relationship to high pH (83.3% of the bulls failing MSA criteria). These calves were not from project groups but from two external sources. It cannot be established whether the result is typical of the broad bull veal calf population.

5.4. Key findings

Key findings of the project were:

- Holstein steers performed equivalently for the measures in this study to Beef breeds when grown and finished in a feedlot after backgrounding on high and low growth diets.
- There was little difference between the two growth pathways examined – high and low – with the exception for Holstein steers where the high growth pathway performed better than the low growth pathway, suggesting that optimal growth performance for Jersey and Jersey X steers may need further research.
- Holstein x Jersey and full Jersey steers showed reduced performance compared to Holstein counterparts, returning both lower carcase values and HSCWs despite similar days on feed.
- All feedlot-finished dairy steers showed increased levels of liver abscess compared to beef counterparts.
- Holstein x Jersey and Jersey carcases showed lowest percentages of carcases grading to MSA compliance despite indications of at least equal and possibly higher eating quality. This needs to be considered in light of the curvilinear relationship of pH and eating quality above pH 5.7, and no further investigation around further factors impacting eating quality, such as shelf life, being the reason for minimum MSA requirements for pH (>5.71).
- The Jersey cattle provided at best moderate growth performance during backgrounding and feedlotting reflecting their genetic potential which also resulted in carcases of low weight and often failing to grade due to low rib fat and high pHu.
- The study shows the current commercial challenge of developing satisfactory beef pathways for Jersey cattle, despite high eating quality performance, and indicates the need to consider an alternative MSA model for dairy beef or potential crossbreeding systems to maximise positive MEQ traits related to Jersey breed. As the Holstein cross cattle achieved improved outcomes other options of selected beef breed sires may have potential.
- Two novel diets – an ionophore free SDT diet, and a locally formulated antibiotic and ionophore-containing equivalent, when fed using intensive protocols from 7 days, can produce a high value carcase at 460 days of age although a higher rate of liver abscess was noted in the ionophore free diet (SDT).

- Meat eating quality was high in dairy breed steers, meeting or exceeding beef breed counterparts. Similarly, some eating quality results for dairy breeds were from carcases above pH 5.7. The curvilinear relationship between tenderness and pH may explain some of this finding, and does not consider other impacts of high pH such as shelf life.
- Current MSA grading models, developed from beef data, provided reasonable eating quality estimates for some feedlot dairy cattle groups but have not been developed for veal carcases. While the model structure was found to be applicable to veal, development of amended processing systems in conjunction with a review of MSA rib fat screening criteria is recommended to avoid cold shortening and improve eligibility, with further evaluation of sensory prediction from this base. While consumer MQ4 results were acceptable, and sometimes high, for Jersey F1 and full Jersey carcases, these results were complicated by a high proportion of high pHu and dark meat colour that would exclude them from MSA grading and commercial industry specification.
- The project results support the need for detailed study of individual muscle pH development and interactions with eating quality, storage, and sensory outcomes. These studies may add commercial value to currently ungraded cuts through optimal processing and possibly value adding, or expansion of allowed cuts as part of the MSA standards.
- These studies may also require examination of potential differences in muscle metabolism between dairy and beef breed carcases after correction for fat cover related to carcase mass and resultant chilling rates throughout major muscles.
- Ageing after thawing may be an option for some primals and could allow alternative management of ageing in industry settings. However, and pending further research, the practical considerations for commercial implications come with some difficulties, particularly in international markets.

5.5. Benefits to industry

Benefits to industry from the project outcomes include:

- A financial and quality-driven pathway can be developed for dairy breed steers using both intensive and pasture fed systems.
- Dairy breed steers can produce a carcase of good eating quality, with Holstein animals meeting MSA grading requirements. This presents a viable value proposition for Holstein-bred beef steers to fill quality yield gaps in Australian beef markets.
- Expansion of dairy beef production directly addresses social licence concerns regarding euthanasia of young day-old calves in conjunction with increased efficiency through creation of additional high value beef.

5.6. Future research and recommendations

This project produced substantial animal, carcase and sensory data across a wide range of potential commercial pathways to veal and heavy carcase production utilising pasture, feedlot and intensive systems with further comparison of low and high growth strategies during backgrounding for the veal and feedlot groups. These data need to be analysed to better inform MSA prediction modelling of dairy breed cattle.

Due to budget constraints a considerable number of project consumer samples remain in frozen storage as detailed in the appendix with those tested prioritised to provide an overall evaluation that could be expanded by evaluating further stored samples where analysis indicated this could add value through greater numbers. This is recommended for the later cohort 2 groups (573.1 and 573.2) which had a relatively small proportion of samples tested, with results to date substantially below MSA V2.0 predicted values.

Matters requiring further evaluation are:

1. The failure of veal carcases to meet existing MSA screening criteria relating to rib fat and pHu together with evidence of extensive cold shortening.
2. To alleviate the veal issues, it is recommended that a study be conducted to evaluate alternative processing criteria including a step chill designed to hold veal carcases above 12°C until pH6 is reached to potentially prevent cold shortening and enable a reduction in minimum rib fat for lightweight carcases.
3. That further evaluation of electrical stunning and electrical stimulation be conducted in conjunction with chill studies.
4. That extension of the MSA prediction model to veal to incorporate results from the work suggested above and further evaluation of MEQ characteristics related to Jersey breed.
5. While sensory results for cohort 1 and the initial cohort 2 groups were predicted by the MSA V2.0 model within acceptable limits the later cohort 2 feedlot and pasture groups performed substantially below model predictions. The cause of this has not been identified and requires further investigation.
6. The pattern of substantial pHu failure during grading for dairy breeds and associated high meat colour.
7. Further evaluation of potential biological mechanisms that may impact the rate of pH decline including possible metabolic pathway differences between beef and dairy cattle is recommended in combination with the mechanical effects related to fat cover, carcase mass and chilling rate. (Is the pH decline for dairy carcases a function of pH declining slower due to colder muscle temperature, in turn due to lower fat cover, or is it related to more fundamental biology?).
8. The proportion of carcases where pHu has not been reached when graded and the degree to which it may decline further. With data this could result in recommendations or a requirement to hold bodies beyond a set level for re-appraisal.
9. A detailed study of pH decline and ultimate values in muscles other than the *M.longissimus dorsi* to establish if relationships are constant or erratic across the carcase coupled with sensory evaluation across the pH range but critically in bands between pH 5.5 and 6.5. This work would inform whether the entire carcase should be downgraded due to the grading site pHu being >5.7 and also inform potential approaches to more profitably utilise high pH

meat given the lack of association with eating quality in this and other studies. Any further work would also need to include factors such as shelf life, as the minimum requirement for pHu >5.71 as part of the MSA standards is due to these additional factors, not the relationship with MQ4.

10. It would be useful and important to determine if co-locality or impacts of significant bushfire activity during the rearing and finishing phases for Cohort 2 might have impacted MEQ scores. Comparison of location with biochemical analysis, such as gas chromatography/mass spectrometry (GC-MS/MS) could begin to elucidate the underlying differences between cohort 1 and 2.
11. Addition of SNZ and TBQ cooking methods to the MSA prediction model once data is judged sufficient.

Future research recommendations include:

- Extension materials for the project findings should be used to increase uptake of dairy steer beef production in southern Australian systems.
- Extension materials should include strong animal health criteria relating to disease prevention in newborn calves including recommendations for dry cow vaccination, calving and calf pickup conditions, the use of tested colostrum and transport from farm to rearer.
- Examination of growth pathways suitable for northern systems should be investigated to provide avenues for profitable dairy steer beef production in northern Australia.
- Further research should be commissioned into optimal calf rearing strategies to reduce incidence of scours in intensive rearing systems and to promote liver health across the lifetime on feed. In particular, early life studies of liver health area required.
- There is a need to increase understanding of rumen development on differing rearing diets utilising metagenomic methods.
- An MSA grading system adaption to more accurately predict dairy beef, and specifically veal weight calves should be pursued and must include development of optimal processing post slaughter in conjunction with screening criteria. While Jersey beef achieved at least equal eating quality, and potentially higher, it was associated with commercial issues of unacceptable carcase characteristics, high pHu and dark meat colour. Alternative production systems utilising beef cross breeding should be evaluated to ensure producer return on investment for dairy beef products with evidenced high eating quality.
- Further research is required on the impact of pH to inform optimal processing to achieve superior consumer value. Such work must evaluate individual muscle relationships and include related consideration of slaughter systems and post slaughter chilling and potential variation due to metabolic differences between beef and dairy genetics or across muscles.
- The detailed study of individual muscle and pH should include flavour chemistry evaluation due to the expectation that pH by muscle combinations will impact flavour precursors. Greater understanding of these individual muscle relationships is expected to improve utilisation of currently discounted meat and to offer significant commercial opportunity for value adding.
- A comparative beef and dairy yield comparison should be conducted with measurement of liveweight, dressed weight and muscle mass post boning.

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7. Appendix

7.1. Remaining consumer samples in frozen storage

7.1.1 Veal cohort

Table 69. Veal sensory samples in frozen storage

	Available						Picked						Posted														Grand Total
	536.3				536	Total	536	536	536	536	537	Total	536.1				536.3			536.4			536.5			Total	
CUT	GRL	RST	SNZ	Total	GRL	Available	RST	RST	RST	RST	RST	Picked	GRL	GRL	RST	Total	GRL	RST	Total	GRL	RST	Total	GRL	RST	Total	Posted	
BLD096							12					12		4		4							2		2	6	18
CHK078							8	4		1	2	15			2	2					3	3		2	2	7	22
CTR085																											
CUB045							12	5	65	11	11	104			4	4		10	10		4	4		3	3	21	125
EYE075							8	2		2	2	14	3	5	3	8					3	3	3	2	5	19	33
KNU066								3		1	3	7	4	3	6	9					5	5		3	3	21	28
KNU099								3		1	3	7	4	3	6	9					5	5		3	3	21	28
OUT005	1		30	31		**31**	15	7	39	6	6	73	5	8	5	13	12	14	26	4	4	8	3	2	5	57	161
OYS036													4													4	4
RMP005																											
RMP131								4		2	4	10			5	5					4	4		2	2	11	21
STR045		1		1		**1**	24	14	67	10	9	124			5	5		13	13		5	5		6	6	29	154
TDR062							12	5		3	4	24			4	4					3	3		2	2	9	33
TOP073			35	35	1	**36**	16	7	41	5	11	80	5	7	6	13	12	18	30	4	3	7	8	3	11	66	182
Grand Total	**1**	**1**	**65**	**67**	**1**	**68**	**107**	**54**	**212**	**42**	**55**	**470**	**25**	**30**	**46**	**76**	**24**	**55**	**79**	**8**	**39**	**47**	**16**	**28**	**44**	**271**	**809**

7.1.2 Cohort 1 Feedlot

Table 70. Cohort 1 feedlot samples in frozen storage

Muscle x Cook	Available			Picked	Posted					Grand Total
	558.2	558.3	Total	552.1	552.1	558.1	558.3	558.4	Total	
CUB045										
GRL										
CUB081	**1**		**1**		**2**	**1**	**2**	**1**	**6**	**7**
GRL	1		1		2	1	2	1	6	7
TOP073		**1**	**1**	**50**	**14**	**2**	**2**		**18**	**69**
GRL		1	1		2	2	2		6	7
RST				50	12				12	62
Grand Total	**1**	**1**	**2**	**50**	**16**	**3**	**4**	**1**	**24**	**76**

7.1.3 Cohort 1 Pasture

Table 71. Cohort 1 pasture pathway samples in frozen storage

Cook and Muscle	567.1			567.2			567.3			Grand Total
	7	21	Total	7	21	Total	7	21	Total	
GRL	**5**	**1**	**6**	**4**	**1**	**5**	**1**	**1**	**2**	**13**
CUB045	1	1	2	1	1	2	1	1	2	6
TOP073	4		4	3		3				7
RST	**15**	**15**	**30**	**14**	**14**	**28**	**8**	**8**	**16**	**74**
TOP073	15	15	30	14	14	28	8	8	16	74
Grand Total	**20**	**16**	**36**	**18**	**15**	**33**	**9**	**9**	**18**	**87**

7.1.4 Cohort 2 Feedlot

Table 72. Cohort 2 feedlot samples in frozen storage

	Available						
Muscle	**571.1 GRL**	**572.1 GRL**	**573.1 GRL**	**573.2 GRL**	**GRL Total**	**573.2 SNZ**	**All Total**
CUB045	19	58	84	3	**164**	15	179
CUB081		54	84	3	**141**		141
Grand Total	**19**	**112**	**168**	**6**	**305**	**15**	**320**

7.1.5 Cohort 3 "Spanish" high carbohydrate

Table 73. Cohort 3 "Spanish" high carbohydrate samples in frozen storage

Muscle	**586.1**			**586.2**			**Grand Total**
	7	**21**	**Total**	**7**	**21**	**Total**	
CUB045	1	1	2	2	4	6	8
Grand Total	**1**	**1**	**2**	**2**	**4**	**6**	**8**