Final report

MSA Beef Model Expansion: Sensory Evaluation of Entire Males

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Abstract

The project was conducted as a component of MSA research activity aimed at enabling all Australian cattle to be MSA graded. Young bulls are currently a small proportion of beef production in Australia and are excluded from MSA grading due to not being evaluated previously, but represent a significant percentage of beef production in other countries.

If successfully meeting MSA grade criteria, young bull production systems could be attractive due to reported higher growth rates and feed conversion efficiency. Further they may provide a safeguard against potential pressures to eliminate HGP use or welfare concerns regarding castration or euthanising of dairy calves at birth.

The project collected 36 cuts from 18 young supplementary fed dairy bulls from a commercial supply chain and fabricated 1,796 sensory samples for consumer testing. Grill, roast, stir fry, slow cook, sous-vide and Texas BBQ cooking methods were utilised in conjunction with varied ageing periods from 10 to 73 days. The samples were MSA sensory tested in conjunction with other projects to provide linkage to existing MSA data. The project objectives were met in full and exceeded in several areas providing additional valuable modelling data to be utilised in updating the MSA V2.0 prediction model.

Executive summary

The project was conducted as a component of MSA research activity aimed at enabling all Australian cattle to be MSA graded. Young bulls are currently a small proportion of beef production in Australia and are excluded from MSA grading due to not being evaluated or sensory tested previously but represent a far greater percentage of beef production in many countries including in New Zealand and Europe. Current Australian production predominantly utilises young bull meat in manufacturing beef or Muslim export markets where it is regarded as more desirable.

If eligible for MSA grading, and successfully meeting grade criteria, young bull production systems could be attractive due to reported higher growth rates and feed conversion efficiency. Further they may provide a safeguard against potential pressures to eliminate HGP use or welfare concerns regarding castration in addition to providing a commercial incentive to raise dairy bred bull calves, many of which are currently euthanised at birth or sold as bobby veal.

The project collected 18 cuts from each side of 18 young supplementary fed dairy bulls from a commercial supply chain and fabricated 100 sensory samples from 39 muscles within each body for a total of 1,796 sensory samples, each to be tested by 10 consumers. Grill, roast, stir fry, slow cook and Texas BBQ cooking methods were utilised in conjunction with varied ageing periods from 10 to 73 days. The samples were MSA sensory tested in conjunction with other projects to provide detailed linkage to existing MSA data enabling high quality statistical modelling.

The project data augmented existing MSA data to build knowledge on a number of muscles for which prior data was insufficient to enable inclusion in the MSA model. The project also increased within animal comparisons of sous-vide and casserole slow cooking methods and between casserole and Texas BBQ cooking of briskets. Further value was delivered by greatly extending ageing data in steps from 10 to 73 days across a wide range of cuts. The unusually large number of tested muscles, muscles by cook and muscles by ageing days and linkage within sensory sessions to several other diverse MSA projects ranging from long fed Wagyu, veal, cull cow and grass and grain fed dairy steer to long distance road and rail transported *bos-indicus* steers delivered extremely valuable data for use in prediction modelling the full range of Australian cattle.

The project objectives were met in full and exceeded in several areas providing additional valuable modelling data to be utilised in updating the MSA V2.0 prediction model. Inclusion of bulls within the MSA model would create further commercial opportunity and the ability to harvest premium quality cuts into higher priced retail or wholesale cut programs including branded offerings. Development of a superior priced market related to MSA grade and based on eating quality rather than sex cipher certification could encourage more professional management of bull production and price equivalence for equal eating quality to steer or heifer product without differentiation. This could reduce reliance on manufacturing pricing and encourage increased higher quality and value production.

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1. Background

Young bulls represent a very small proportion of current Australian beef production and are excluded from MSA grading due to insufficient sensory data. Only one prior project, conducted by James Cook University with MSA support, has evaluated Australian bulls, with these being high *bos-indicus* content animals from a northern Australian production system. Only two cuts were collected with both grilled. Limited supplementary data is available from collaborative studies that utilised MSA protocols in France, Poland, Northern Ireland and Wales with the European production systems very different to Australian.

A primary aim of this project was to extend young bull data to encompass young dairy breed animals from southern Australia and generate extensive sensory data for a wide range of muscles, cooking methods and ageing periods to provide sufficient data linkage to enable analysis and potential inclusion of bulls within the MSA prediction model. This objective aligned with MSA objectives to enable all Australian cattle to be eligible for grading.

In contrast to Australia, young bulls form a significant portion of beef production in many countries. As displayed in Table 1 bulls account for 28% of EU beef production (Anon, 2021), exceeding 50% in 5 member states including Poland, one of the largest producers and exporters.

Table 1. Bull meat as % of beef production within the European Union

Country	% Bull	Country	% Bull	Country	% Bull
Slovakia	**57.7%**	Germany	38.2%	Estonia	22.9%
Poland	**52.7%**	Lithuania	36.7%	Latvia	20.9%
Slovenia	**52.5%**	Luxembourg	35.7%	Hungary	19.8%
Finland	**51.1%**	Greece	34.7%	France	18.8%
Malta	**50.0%**	Cyprus	33.3%	Belgium	18.8%
Croatia	44.7%	Italy	32.2%	Denmark	15.6%
Czechia	42.1%	Spain	30.3%	Romania	15.2%
Sweden	41.7%	Portugal	30.0%	Ireland	9.2%
Austria	38.4%	Bulgaria	23.3%	Netherlands	2.7%
EU Average 27.8% bull					

Within Europe bull production systems vary widely. Polish production includes a large proportion slaughtered close to 30 months of age whereas young, less than 12-month-old, bulls are common in Spain and Portugal and typical young bull systems in Ireland and the UK mostly slaughter under15 months. Feeding regimes also vary considerably with a mix of grazing on pasture through summer and roughage with concentrate during winter housing common in Poland while very intensive milk and high concentrate rations are commonplace in Spain and Portugal with many young dairy calves imported for specialist feeding. Irish and UK systems are often fully housed for young bulls which are fed significant concentrates with silage while there are large scale intensive housed systems in Italy.

Dairy bull production is also common in New Zealand with intensively managed pasture-based systems accounting for up to 32% of table and from 68 to 100% of manufacturing product with seasonal variation (Geenty and Morris, 2017). The New Zealand systems are based on purchase of weaned dairy calves, typically around 100kg live weight for turnoff from 15-18 months or on purchase of older stores turned off at 18-22 months or 18 months to 2 years of age (Geenty and Morris, 2017) The categories reflect seasonal calving patterns, the intensity of grazing management and a choice between sale for table or manufacturing beef, with some supply chains integrated with supply contracts from major hamburger restaurant chains.

Variations of the New Zealand approach have been utilised by some processors in Australia to supply specific Muslim markets including Malaysia or for manufacturing beef under contract to hamburger chains. The sale of dairy bulls as bobby calves is more common with a proportion also euthanised at birth. Both outcomes create significant industry welfare issues and represent the loss of a potentially large quantity of beef if they were raised to heavier slaughter weights. A further potential welfare related issue is castration regulation with the cost or difficulty of utilising pain relief a possible incentive for bull production within suitable commercial supply chains. Young bull production may also provide an alternative to HGP implanting to address public concerns, customer specifications or importing country regulations.

Inclusion of bulls within the MSA model would create further commercial opportunity and the ability to harvest premium quality cuts into higher priced retail or wholesale cut programs including branded offerings. Development of a superior priced market related to MSA grade and based on eating quality rather than sex cipher certification, could encourage more professional management of bull production and price equivalence for equal eating quality to steer or heifer product without differentiation. This could reduce reliance on manufacturing pricing and encourage increased higher quality and value production.

2. Objectives

The contract purpose and description were described as “This project will determine the impact of the ‘bull or entire male’ effect on the eating quality of beef to facilitate the development of an MSA pathway thus allowing all cattle types in Australia to be eligible for MSA grading. The study will aid in quantifying the eating quality difference between the current MSA model predictions, based on steers and bull or entire male beef.

The project will sensory evaluate 34 primals collected from each of the selected 18 head against 2,400 untrained consumers using five cooking methods. Extended ageing to 50 days, and further testing of the newly established BBQ smoking protocol will be included in the project to continue to populate new predictions in the MSA model”.

This was expanded to objectives listed as “Such a comprehensive cut collection across the carcases in conjunction with cooking methods, will provide definitive data on the potential impact of a ‘bull or entire male’ effect on the eating quality of beef.

At a more detailed level the following objectives will be achieved:

- Comparison of bull effect to the current MSA model predication.
- Development of a MSA pathway for young bulls to address the MSA 2020 goal of all cattle eligible for grading.
- Utilise cuts collected to continue to refine accuracy of predictions of extended ageing and new BBQ smoking protocol for secondary cuts”.

The stated purpose and objectives were met in full and exceeded in several areas providing additional valuable modelling data linked to other MSA projects through sensory testing within common consumer groups.

3. Methodology

3.1 Experimental design overview

The trial objectives are broadly described above and essentially specified testing of a wide range of cut x cook x muscle combinations derived from a commercial young bull supply chain. Interest from the Central Agri group who processed young dairy bulls from a specialist supplier on a weekly basis provided the opportunity and subsequent methodology to meet the scientific protocol within the plant was developed in consultation.

Subsequent to collection MSA sensory sample fabrication was conducted to MSA protocols at both Charles Sturt University (CSU) and the University of New England (UNE). Sensory testing was also to MSA protocol and conducted in diverse country and capital city locations. Particular care was taken to test the bull samples in conjunction with a range of muscles from different cattle types and with multiple ageing periods and cooking styles with evaluation by different consumer populations to create extensive linkage and ensure strong statistical connection during subsequent review of the MSA V2.0 prediction model.

3.1.1 Cattle and slaughter

It was agreed with the plant that 18 carcases would be selected from a group of 50 scheduled for slaughter on 30th April 2019. The cattle were young, approximately 8.5 to 9 months old, Holstein bulls sourced from a large Northern Victorian/Riverina calf rearer. Technically the bulls were grass fed as they were not despatched from an accredited feedlot but in practice, they were fed milk from birth, rising to 6 litres /day by despatch to slaughter in conjunction with a commercial finisher pellet and hay through paddock-based feeders. While housed in small paddocks actual pasture intake would have been minimal. The cattle were trucked to the abattoir at Trafalgar Victoria on April 29th and killed first on the 30th commencing at 06:29 and finishing at 08:16.

The abattoir utilises electric stun which enables Halal certification, an important requirement for access to the Malaysian and other export Halal beef markets. As no previous MSA collections were from electrically stunned cattle this was of scientific interest in relation to subsequent pH and temperature decline and potential ultimate eating quality interaction. The kill was observed by research staff on the kill floor who also recorded knock time and application of an electronic immobiliser during shackling.

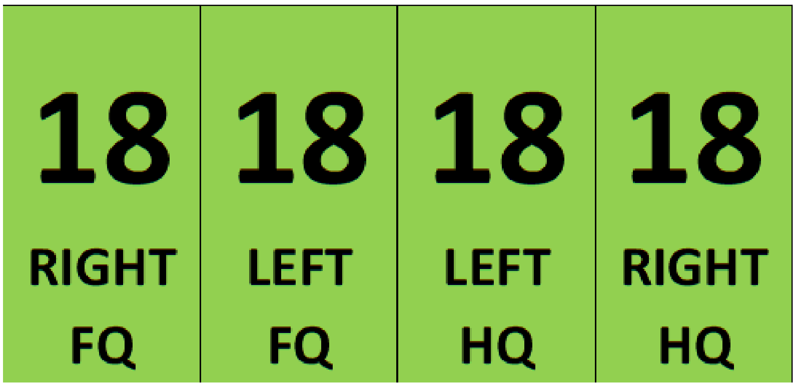
Immediately on entry to the carcase chiller MSA staff commenced recording pH and temperature readings from the posterior end of the *M.longissimus dorsi* (striploin) muscle. The initial readings were taken at the usual 1-hour intervals but, following observation that the pH decline was unusually slow, extended to 1.5 to 2 hours for later readings. Readings were continued beyond the standard 5 with a sixth reading on most bodies and seventh, some 9 hours post stun, on those where pH remained above 6.0 at the sixth. At 5pm only 4 carcases had reached pH 5.7 with 35 then at or below pH 6.0 and 15 remaining above 6.0. The minimum temperature was 13.7˚C and average 15.3˚C for the 35 at or below pH 6.0, indicating compliance with the MSA “abattoir window” which mandates that pH 6.0 be attained between 35˚C and 12˚C. The remaining 15 bodies with pH above 6.0 had an average temperature of 11.9˚C and maximum of 13.8˚C at the 7th reading indicating they would fall out of MSA specification.

3.1.2 Body selection for MSA cut collection

All 50 carcases were assessed by MSA graders on May 1st, some 28 hours post kill. No carcases had the MSA 3mm minimum rib fat but the ultimate pH readings were mostly below 5.71 meeting MSA criteria. Given the observed slow temperature and pH decline rate it was concluded that cold shortening was unlikely on these carcases and selection of 18 compliant for temperature at pH 6.0 and ultimate pH below 5.71 was made on the basis of other MSA criteria including ossification, marbling and carcase weight.

A large coloured and laminated ticket with a body number (1 to 18 and linked to actual plant body number), side and quarter was attached to each quarter using 150mm stainless steel skewers to ensure identification during quartering, marshalling and boning. Example Quarter Tickets for one carcase are shown in Fig. 1.

Figure 1. Example of Quarter Tickets utilised for ID from selection to boning



3.1.3 Boning and cut collection

To ensure accurate tracking and identification of the large number of cuts to be collected from each body the plant proposed a procedure to bone each quarter utilising a single boner in a fixed table position. Boning of the selected quarters was programmed after a run of commercial bodies, commencing after a break to ensure all tables and downstream packing stations were clear of product. This approach worked well and is recommended for any subsequent work in this facility.

The cuts agreed for collection from each side of the 18 carcases are displayed in Table 2.

Table 2. Cuts selected for collection from both sides of 18 carcases

HAM	PRIMAL	NOTES
2270	Chuck-Square Cut	Rhomboideus to be retained. Intercostals and subscapularis removed
2244	Cube Roll	Quartering rib to suit plant practice
2650	Rib Meat Square	M.Latissimus dorsi only
2430	Intercostals	
2353	Brisket Point End, Deckle Off	Leave fat between pectoral muscles. Remove cutaneous trunci
2342	Brisket Navel End	Intercostals removed
2310	Chuck Tender	
2302	Bolar Blade	
2303	Oyster Blade	
1682	Shin & armbone shin FQ	Retain humerus, ulna and radius and related muscles as single piece
2160	Tenderloin, side strap off	
2140	Striploin, larder trim	Remove ligament and multifidi dorsi. 25mm from eye.
2090	Rump	Retain all tail
2070	Knuckle	
2000	Topside	
2020	Silverside	Retain heel muscle
2200	Thin Flank	Remove M.cutaneus trunci
1683	HQ Shank	

An initial fore and hind quarter were boned to confirm cutting lines and procedure with other boners/slicers observing. Research personnel were then stationed adjacent to each boning/slicing station and retrieved the large Quarter Ticket and pin from the quarter during boning. All cuts from the quarter were transferred to a plastic tub as boned and the Quarter Ticket placed on top. The tubs, containing only cuts from the one quarter, were then transferred to the packing station.

A senior MSA researcher was stationed at the packing/bagging station prior to the vac packer to confirm and transfer ID to each individual cut. She was equipped with pre-sorted sets of 50 x 50mm coloured and laminated Primal Tickets for all cuts from each quarter. An example of the Primal Tickets is displayed in Fig. 2. In the example 1L indicates the left FQ from body 1 with 61012 a unique number for the primal cut which is designated to be a cube roll.

Figure 2. Example of primal labels used for cut ID from boning to fabrication to consumer samples.

61012 **1L** **CUBE ROLL**	**61014** **1L** **OYSTER BLADE**	**61015** **1L** **BLADE**
61016 **1L** **CHUCK TENDER**	**61022** **1L** **CHUCK**	**61026** **1L** **PE BRISKET**

Each Primal Label was placed on top of the relevant cut with both then bagged and vacuum packed. After checking for leakers the cuts were cartoned and moved to the cuts chiller for storage on marked pallets. The Primal Number was utilised as the primary identifier in subsequent sample fabrication.

The product was released from storage after a 24-hour chill by mid-afternoon on May 2nd. Research personnel collected the product in a rented refrigerated truck with VMA accreditation and drove to Wagga overnight.

3.1.4 Sensory sample fabrication

To enable the large number of samples to be processed within the earliest (10 day) ageing period sensory fabrication was conducted at Charles Sturt University (CSU) and University of New England (UNE). The tenderloins, striploins and cube rolls were offloaded at CSU on the morning of May 3rd and the remaining cuts plus further sensory samples driven to UNE arriving on the evening of May 4th. Sample fabrication was completed at both sites by May 8th.

The experimental design was developed using MSA CutUpDeveloper (CUD) software after extensive discussion with MSA research managers to agree muscle, cook and ageing priorities coupled with statistical advice on desired data to complement that available for a model update. Table 3 shows the muscle and cook combinations designated for fabrication and Table 4 displays the number of ageing comparisons, also within MSA muscle code.

Table 3. Muscle and cook combinations fabricated for sensory testing

			COOKING METHOD							
Primal	**Muscle**	**MSA Code**	**GRL**	**RST**	**SC2**	**SFR**	**SVD**	**TBQ**		**Total**
Chuck	M.rhomboideus	CHK068			35					**35**
	M.semispinalis capitis	CHK074	18		18					**36**
	M.serratus ventralis cervicis	CHK078	9	9	89					**107**
Chuck Tender	M.supraspinatus	CTR085	12	11	12					**35**
Blade	M.triceps brachii caput laterale	BLD095			17	1				**18**
	M.triceps brachii caput longum	BLD096	18	14	18		16			**66**
	M.triceps brachii caput mediale	BLD097			18	18				**36**
	M.transversus abdominis	BRI092			18					**18**
Oyster Blade	M.infraspinatus	OYS036	18	16	18		17			**69**
Cube Roll	M.longissimus dorsi	CUB045	56	16						**72**
	M.spinalis dorsi	CUB081	19	16						**35**
Intercostals	M.intercostales externus and internus	INT037			18		13			**31**
Rib Meat Square	M.latissimus dorsi	RIB041			34					**34**
Point End Brisket	M.pectoralis profundus	PEB056			18			24		**42**
	M.pectoralis superficialis	PEB057			18			12		**30**
Navel End Brisket	M.serratus ventralis thoracis	NEB079			17			12		**29**
	M.transversus abdominis	NEB092						12		**12**
FQ Shin	M.biceps brachii	FQS004			17	18				**35**
	M.brachialis	FQS006			16	16				**32**
	Several	FQSHIN			17		15			**32**
Striploin	M.longissimus dorsi	STR045	94	14						**108**
Rump	M.biceps femoris (syn. gluteobiceps)	RMP005	18	17						**35**
	M.tensor fasciae latae	RMP087		18	18					**36**
	M.gluteus medius	RMP131	18	17						**35**
	M.gluteus medius	RMP231	18	17						**35**
Tenderloin	M.iliacus	TDR034	18	18						**36**
	M.psoas major	TDR062	18	18						**36**
Silverside	M.semitendinosus	EYE075	18	17	18	18				**71**
	M.biceps femoris (syn. gluteobiceps)	OUT005	36	36	36					**108**
	M.gastrocnemius	OUT029			18	18				**36**
Knuckle	M.rectus femoris	KNU066	13	11	12					**36**
	M.vastus lateralis	KNU099	18	16	18		18			**70**
Thin Flank	M.obliquus externus abdominis	TFL051			15	12				**27**
	M.obliquus internus abdominis	TFL052			20	15				**35**
	M.rectus abdominis	TFL064			18	18				**36**
Topside	M.adductor femoris	TOP001	18		18					**36**
	M.gracilis	TOP033			18	18				**36**
	M.semimembranosus	TOP073	36	36	36					**108**
HQ Shin	M.peronaeus tertius	HQS059			19	17				**36**
	Several	HQSHIN			18		18			**36**
		Total	**473**	**317**	**680**	**169**	**97**	**60**		**1796**

Table 4. Number of ageing treatments by MSA muscle code

	Days Aged				
MSA Code	**10**	**31**	**52**	**73**	**Total**
CHK068	10	9	7	9	**35**
CHK074	10	10	8	8	**36**
CHK078	83	8	8	8	**107**
CTR085	10	8	7	10	**35**
BLD095	5	5	4	4	**18**
BLD096	16	18	18	14	**66**
BLD097	10	10	8	8	**36**
BRI092	5	5	4	4	**18**
OYS036	20	19	15	15	**69**
CUB045	18	18	18	18	**72**
CUB081	10	9	8	8	**35**
INT037	9	11	7	4	**31**
RIB041	10	7	8	9	**34**
PEB056	13	11	8	10	**42**
PEB057	9	8	6	7	**30**
NEB079	9	7	6	7	**29**
NEB092	4	3	2	3	**12**
FQS004	9	10	8	8	**35**
FQS006	8	10	8	6	**32**
FQSHIN	10	10	8	4	**32**
STR045	54	18	18	18	**108**
RMP005	8	12	9	6	**35**
RMP087	10	10	8	8	**36**
RMP131	12	8	8	7	**35**
RMP231	8	8	8	11	**35**
TDR034	10	10	8	8	**36**
TDR062	8	8	10	10	**36**
EYE075	20	20	16	15	**71**
OUT005	27	28	27	26	**108**
OUT029	10	10	8	8	**36**
KNU066	9	9	9	9	**36**
KNU099	20	19	15	16	**70**
TFL051	8	8	5	6	**27**
TFL052	10	10	8	7	**35**
TFL064	10	10	8	8	**36**
TOP001	10	10	8	8	**36**
TOP033	10	10	8	8	**36**
TOP073	27	28	27	26	**108**
HQS059	10	10	8	8	**36**
HQSHIN	10	10	8	8	**36**
Total	**569**	**452**	**390**	**385**	**1796**

Sample fabrication procedures adhered to MSA protocols with files produced by the CUD software used to instruct fabrication and ageing (freeze down dates). The CutUpSheet was printed on A4 paper and bound whereas and CutUpLabels were printed on Avery 7160 Label stock and also bound. Each “book” was bound with acetate covers to assist in keeping them dry in a production environment.

The production flow commenced with a primal cut being removed from its vacuum packaging and the enclosed Primal Ticket being placed on a plastic tray adjacent to the primal. Experienced butchers then fully denuded the cut removing all covering fat and, where the cut comprised multiple muscles, separated the individual muscles. Silverskin was removed from the individual muscles which were placed on the tray with the Primal Ticket. Muscles were arranged in a standard orientation with a designated position, such as head, placed to the right etc. Each butcher opened only one primal bag at a time to ensure ID was maintained.

The tray was then transferred to a research member responsible for oversighting sample fabrication and recording subsequent fabrication to consumer sample(s). The recorder noted the Primal Number on the ticket and referenced this in the pre-printed CutUpSheet book. An example portion of a CutUpSheet page is displayed in Fig. 3.

Figure 3. Example portion of CutUpSheet used to control sample fabrication and ID

Seq	EQS	Primal	Cut	Cook	Age	Pos	Kill	Obj	Check
AUS117717	W0Z6	61011	TDR034	GRL	52	C	Tue 30 Apr 19		
AUS118186	K4U3	61011	TDR062	RST	73	C	Tue 30 Apr 19	y	
AUS117718	T8B4	61012	CUB081	GRL	31	C	Tue 30 Apr 19		
AUS117719	E9N9	61012	CUB045	GRL	10	A	Tue 30 Apr 19	y	
AUS117720	L1T2	61012	CUB045	GRL	31	P	Tue 30 Apr 19		
AUS117721	K3Q8	61013	STR045	GRL	52	A	Tue 30 Apr 19		
AUS117722	P7L2	61013	STR045	GRL	73	C	Tue 30 Apr 19	y	
AUS118150	U8U3	61013	STR045	LNK	10	P	Tue 30 Apr 19	y	

Referencing Fig. 3 Primal Number 61011 was a tenderloin with two muscles to be collected as designated by the MSA codes TDR034 (Butt tender or *M.illiacus*) and TDR062 (*M.psoas major*). This TDR034 was designated as a grill (GRL) sample and the TDR062 as a roast (RST), both of which were to be prepared from the centre (C) portion of each muscle. The “y” against the TDR062 indicates that an objective laboratory sample was also required.

Primal Number 61012 was a cube roll comprising 2 muscles, the CUB081 (Spinalis *or M.spinalis dorsi*) and the larger CUB045 (Rib Eye or *M.longissimus dorsi et thoracis*). Both muscles from this primal were to be prepared as GRL with 2 samples from the CUB045, one from the anterior (A) and the second from the posterior (P) end.

For each tray the recorder then referenced the CuUpLabels book locating the Primal Number and all labels related to that primal. A portion of the related CutUpLabels book is shown in Fig. 4.

Figure 4. Example portion of CutUpLabels

61011	AUS117717 W0Z6 61011 GRL C TDR034 2106	OBJECTIVE 61011 - TDR062 K4U3 1207
AUS118186 K4U3 61011 RST C TDR062 1207	61012	OBJECTIVE 61012 - CUB045 E9N9 1005
AUS117719 E9N9 61012 GRL A CUB045 1005	AUS117720 L1T2 61012 GRL P CUB045 3105	AUS117718 T8B4 61012 GRL C CUB081 3105

Referencing Fig. 4 it can be seen that there are 3 labels following the 61011 Primal number, each also including the 61011 identification. The first notes a GRL sample to be prepared from the "C" position of the TDR034 (Butt tender). The 2 following labels for the TDR062 dictate an objective and RST sample. The following primal 61012 again has an objective label and 2 GRL samples for the CUB045 (rib eye) and a GRL label for the CUB081 (spinalis).

The 4 numerals at the lower right of each label signify a freeze down date (DD/MM) that corresponds to the days of ageing displayed in the CutUpSheet.

The labels were each lightly affixed to the edge of the tray aligned with the nominated position and cut orientation. A horizontal line was placed in the Check column of the CutUpSheet as the labels were cross checked against the CutUpSheet detail. The tray with muscles and labels was then transferred to a cutting station adjacent to the recorder and manned by a butcher/slicer with the labels providing an instruction as to which samples were required from each position within each muscle.

Sample fabrication was in accordance with MSA protocols. In brief GRL samples were prepared by firstly orienting the cut on a cutting jig in the orientation of the tray labels. The right-hand end was faced to establish a flat surface at right angles to the grain direction and progressive 25mm slices taken with the 25mm established by cutting jig settings whereby the knife was passed down two locating stainless steel posts set 25mm from an adjustable flat face.

An example of the cutting jig and a RMP231 muscle oriented to achieve a 90-degree cutting line relative to grain direction is shown in Fig. 5.

Figure 5. RMP231 muscle oriented for facing and slicing across the grain direction

The 25mm slices were then fabricated to produce 5 individual small approximately 75 x 40mm steaks with trimmed portions retained for the objective sample where designated. Further slices were utilised for progressive samples as designated for following muscle positions. Each set of 5 steaks and any objective samples were placed on the tray adjacent to the labels. For GRL samples each of the 5 steaks were wrapped in freezer wrap before placing the set of 5 in 250 x 300mm vacuum pouches with the label transferred from the tray edge to the pouch. This comprised a consumer GRL sample.

Fig. 6 illustrates a series of trays with denuded muscles on trays with labels applied, two cutup jigs and subsequent sensory GRL samples being wrapped and packed.

Figure 6. Example of CutUp procedure from denuded muscle to sensory sample

From this point primary sample ID became the unique Sequence number and paired unique 4 digit alphanumeric “EQSRef” code as each primal label often related to multiple sensory samples. As an example, in Fig. 3 and Fig. 4 the first sample from Primal 61011 carries a sequence number of AUS117717 and a paired EQSRef of W0Z6. These ID were carried through to consumer testing and are the sample identification utilised in the AUSBlue database which also carries linkage back through Primal number, Side and Carcase number to animal ID.

RST samples were prepared from designated muscle positions by fabricating a block as near as possible to 75mm x 75mm x 150mm oriented along the grain direction. SC2 and SVD (sous-vide) samples were prepared as sets of 22 cubes of nominal 22mm x 22mm x 22 mm or equivalent mass. SFR samples were prepared as a block of 20mm thickness x 110mm x 75mm cut with the grain parallel to the 75mm face.

In all cases the RST or SFR “blocks” and SC2/SVD cubes were placed in vacuum pouches with the Labels transferred from the tray. As for GRL the Sequence and EQSRef codes provided the unique ID carried forward through sensory testing to sample data in AUSBlue. TBQ (Texas BBQ) cuts were retained as cuts for cooking prior to consumer sample preparation.

All samples were then vacuum packed, sorted by freeze down date within cook type and frozen on the designated date to achieve the specified days of ageing. The completed CutUpSheets were then checked and corrected to note any samples missed or changes in position or cooking method. A routine within the CUD software was then enacted to transfer the final sample details to the AUSBlue database and assign an “Available” status.

3.1.5 Allocation of sensory samples to consumer groups and picking

In accordance with MSA protocols all sensory testing was delivered by testing sets of 42 samples of a common cooking method, referred to as a “Pick”, within subsets of 60 consumers. Of the 42 samples in each pick 6 were “Links” being common presumed mid quality samples served to all consumers as their first sample. The remaining 36 samples in a pick were assigned as 6 products, each containing 6 samples. The products were selected to deliver a wide anticipated quality range with each consumer served one sample from each product to ensure they received product from poor to higher eating quality.

For the bull samples allocation to product was related to a mix of muscle and ageing period. A proportion of picks also incorporated samples from other MSA projects including veal, grass and grain fed dairy steers, road and rail transport *bos-indicus* content steers, cull cow and Wagyu studies. This ensured both product range and linkage via multiple consumer groups to cuts from other cattle types and muscles prepared for cooking by multiple methods to guard against confounding and ensuring that eventual statistical evaluation could robustly relate scores to prediction modelling.

Following manual pick planning to meet the desired quality range, muscle or cook comparisons and multiple project linkages, AUSBlue software routines were used to select samples and assign them to product groups within picks. The software firstly generated a “Pick Sheet” that listed the Sequence and EQSRef codes for the selected 42 samples. Multiple Pick Sheets were combined and sorted by Sequence to produce a Pick List. This was used to select samples from frozen storage, confirm they were found and sort into Picks. The process used was to have one research team member with the Pick List and others removing samples from storage (in Styrofoam boxes) and then transferring them to the individual picks. The process utilised a cross check where a sample Sequence code was called and then referenced by the person with the Pick List who called back the EQSRef code if present on the list. Once the cross check was confirmed the relevant Pick number was called and the sample placed in the appropriate Styrofoam Pick box. At completion each Pick Box was again cross checked to confirm the required 42 samples were present and the still frozen samples returned to the frozen storage.

<u>This method of cross calling the Sequence No and EQSRef is highly recommended to avoid errors in any sample sorting routine and is a mandatory check within several MSA protocol routines.</u>

On confirmation that all samples were found, or after substitution for any that were missing, a "Posting" routine was run within the CUD software. The process allocated each sample to a specific 10 consumers in a specific serving order. Every consumer was first allocated a Link sample with the following 6 allocated according to a 6 X 6 Latin square to ensure that each product was served equally in serving orders 2 to 7 and equally before and after each other product. The software utilised 5 Latin squares per pick with each sample having one of their 5 portions, halved after cooking to serve two consumers, allocated to a different serving order and once within each of the 5 Latin squares. Specific cook type related routines were triggered within the software to produce subsequent files and labels for sensory questionnaires and plates. Further detail is available in Anon (2008).

Different procedures were followed for each cooking method following Picking in accordance with MSA protocols. The RST and TBQ picks required no further management prior to delivery to the sensory venue whereas the SC2 and SVD protocols required cooking prior to transfer for sensory testing. The SFR Picks required slicing of blocks and cooking prior to transfer and the GRL samples required a step described as "Posting". Each is briefly described in following sections as are the final consumer serving practices.

3.1.6 Posting of GRL (grill) samples

To achieve a distribution of the 5 individual steaks within each grill sample to selected consumers a "Posting" procedure was followed in accordance with MSA protocol. Posting files produced by the CUD software included 21 "Round Sheets", each pre-printed with 10 Sequence and EQSRef pairs located in a 3 - 4 – 3 layout together with the Pick number, consumer session (1, 2 or 3, each being a sensory sitting of 20 consumers) and Round number (1 to 7 being the order of cooking and serving) printed on each corner. Each Round sheet was placed in a plastic sheet protector to prevent moisture on the paper sheets and then placed within a 250 x 350mm vacuum bag lightly clipped to a clipboard.

The 42 frozen samples for a Pick were arranged on a stainless-steel table in an EQSRef ordered array of 6 x 6 with the Link samples sorted off. Each sample bag was checked to ensure it contained 5 steaks and then the 5 broken apart (made possible by individual steak freezer wrapping at CutUp) and the bags cut open. One research team member, the caller, was then positioned with the clip board and bag at one end of the table, adjacent to a vac packer, and called the first, and furthest corner, of the 10 EQSRef numbers on the Round Sheet. A second team member then located the sample bag with that EQSRef on its label and called back the paired Sequence number. Once the cross check was confirmed one steak was removed from the sample bag and passed to the caller who placed it over the printed Sequence and EQSRef codes. This was repeated until all 10 samples were "posted" after which the Round Sheet was transferred to the vacuum packer, the clipboard retrieved and the completed Round Sheet vacuumed to hold the 10 samples in place. This procedure was repeated for the 21 Round Sheets which were placed in 2 foam boxes in a specific order with those to be cooked last, XXXX-3-7, at the bottom and that to be cooked first, XXXX-1-1 on top. Three bags of "Starters", steaks prepared from scrap material and 25mm thick were used to divide the round sheet stacks within the boxes. After a check for leakers the boxes were lidded and returned to freezer storage until sensory testing.

3.1.7 Preparation and cooking of SFR (stir fry) samples

The 42 SFR blocks within each pick were moved to a table and placed adjacent a balance, microwave and slicer. A cutting board was placed near the slicer and a new set of sample bag labels and bags located further along the table and in proximity to a vacuum packer.

Each sample was weighed and conditioned by microwaving for approximately 30 seconds (varied to suit sample mass) to achieve a just pliable but still frozen state in which the slices would curl as sliced but be able to be flattened without breaking. The bag was then opened and placed on the output side of the slicer to retain ID. Ten or more 10mm slices were sliced from the block with the grain direction parallel to the 75mm sliced face and running the length of the slice. Each slice was then halved and trimmed as required to produce a final 22 10mm x 10mm stir fry strips. The strips were then placed in a fresh vacuum pouch and labelled with a new label, cross checked as being identical to the original. The cut sample pouches were then returned to freezer storage until removed for cooking within 48 hours of the sensory session.

The frozen sample bags were thawed overnight at 2˚C prior to cooking. To commence the cooking procedure one research team member firstly opened each sample and transferred the strips to a wire mesh strainer held within a saucepan to allow drainage. The label was cut from the bag and placed under the bar across a 1/9 bain-marie lid which was placed with the sample in the strainer. This was repeated for all samples at a rate that allowed continuous cooking by the cook(s). The saucepan, strainer and sample were then placed next to the cook(s).

A protocol specified glaze mix of 125ml of honey, 125ml of Kikkoman soy and 125gm of arrowroot powder was prepared prior to cooking and placed convenient to the cook(s) with a 20ml ladle. A further container of olive oil and 20ml ladle was also located at the cooking station.

The cooking protocol utilised a 4-burner gas stove and 3 mild steel woks for each of the two cooks (the procedure can utilise a single or multiple cook station(s)). The cook(s) utilised 3 burners and woks in a rotation with one being washed and returned post cooking and placed on one burner at low heat ready for use. A count up timer and related timing sheet was used to control cooking operations. The timing sheet, a portion of which is displayed in Fig. 7, designated a time, each even minute, to commence the cooking procedure.

Figure 7. First and start of second cycle of Stir Fry cooking control chart (timing in mm:ss)

ACTION	Samples 1 to 12
Empty Wok with oil to burner #1	**00:00**
Burner #**2** to **simmer**	NA
Stir oil - wok on burner #**1**	00:20
Add Meat to wok on burner #**1**	00:30
Remove Wok from burner #2 (Finished)	**NA**
Turn burner #**2** to **FULL HEAT**	01:30
Transfer Wok from burner #**1** to #**2**	01:40
Add glaze to Wok on burner #**2**	01:50
Empty Wok with oil to burner #1	**02:00**
Burner #**2** to **simmer**	02:15
Stir oil - wok on burner #**1**	02:20
Add Meat to wok on burner #**1**	02:30
Remove Wok from burner #2 (Finished)	**03:00**
Turn burner #**2** to **FULL HEAT**	03:30
Transfer Wok from burner #**1** to #**2**	03:40
Add glaze to Wok on burner #**2**	03:50

Referencing Fig. 7 to commence cooking an empty wok with 20mm of olive oil was moved to burner 1 which was set to simmer. The oil was stirred in the wok at 00:20 and meat added from the strainer at 00:30 seconds and continually stirred while cooking. The lid with ID was placed beside the cook to retain ID. At 1:30 the second burner was turned to full heat and the wok on burner 1 transferred to burner 2 at 1:40 with 20ml of glaze added at 1:50. A second wok was then placed on burner 1 at 02:00 (the next even minute) with the process above repeated. Burner 2 (with the first sample) was turned to simmer at 2:15 and the wok removed at 3:00 giving a total of 2:30 cooking time during which the meat was continually stirred.

The cooked sample, wok and lid were then transferred to a bench area where the sample was placed in a 600ml plastic container. A new sample ID label was affixed to the lid after cross checking the original and the lid pressed to seal. The containers were then cooled to room temperature before transferring to chilled storage where temperature was reduced to 0 to 1˚C. Cooling in the sealed container generated a partial vacuum and cook chill system to maintain shelf life and food safety.

The chilled containers were transferred in foam boxes to the sensory venue for re-heating and serving.

3.1.8 Cooking of SC2 (slow cook) samples

The SC2 protocol dictated browning of cubes prior to a 2-hour slow cook in a mild broth. Five bain-maries each equipped with 9 x 1/9th steamer pans and lids were set up in the cooking area, filled with water covering the lower 10mm of the pans and brought to a rolling boil.

A broth was made up with 1,400 gm of sliced carrots, 1,400 gm of sliced onion, 450 gm of sliced celery and 70 gm of salt added to 15 litres of water and heated in an electric urn for 45 minutes after reaching a rolling boil. The broth was then strained and 300 ml of liquid measured into 42 of the 1/9th bain-marie pots with each returned to the bain-maries and maintained at a rolling boil.

A sample preparation area was located adjacent to a sink. The frozen sample bags were thawed overnight at 2˚C prior to cooking. To start the cook process one research team member firstly opened each sample and transferred the cubes to a wire mesh strainer held within a saucepan to allow drainage. The label was cut from the bag and placed under the bar across a 1/9 bain-marie lid which was placed with the sample in the strainer. This was repeated for all samples at a rate that allowed continuous cooking by the cook. The saucepan, strainer and sample were then placed next to the cook.

Two electric hot plates were located close to the bain-maries and a dosing gun set to deliver 20ml of olive oil was positioned adjacent to the cook tops. Three heavy stainless-steel frypans were utilised in a rotation with one placed on the first hotplate to pre-heat with 20ml of olive oil added. Cooking was controlled by a count-up timer with the warmed pan moved to the second hotplate on the even minute and a sample added from the strainer, with the lid and sample ID placed next to the cook top to retain ID. The cubes were continually stirred around the saucepan to achieve even browning for 90 seconds, being removed on the next odd minute and 30 seconds. A hot bain-marie pot was brought from a bain-marie to the cook area just prior to sample removal and the cubes transferred to the pot and the lid with sample ID placed on top. The pot, lid and ID were then placed back in the bain-marie in a sequential order and the time recorded.

The next warmed frypan was then moved to the cooking hot plate and sample added at the next even minute to repeat the cycle. The previous frypan was washed prior to being returned to the spare hot plate and the strainers and saucepan also washed and recycled.

Each 1/9th bain-marie pot was removed after 2 hours of cooking and transferred to a bench area where the sample and broth was placed in a 600ml plastic container. A new sample ID label was affixed to the lid after cross checking the original and the lid pressed to seal. The containers were then cooled to room temperature before transferring to chilled storage where temperature was reduced to 0 to 1˚C. Cooling in the sealed container generated a partial vacuum and cook chill system to maintain shelf life and food safety.

The chilled containers were transferred in foam boxes to the sensory venue for re-heating and serving.

3.1.9 Cooking of SVD (sous-vide) samples

The sous-vide protocol did not include browning with samples cooked within their original sample bag. The frozen sample bags were thawed overnight at 2˚C prior to cooking. In common with the SC2 protocol the same broth was prepared and strained to provide 300ml of liquid per sample but, for sous-vide, added to the cubes after cooking. As many picks combined SC2 and SVD paired samples to be served together for comparison the standard 15 litre batch was sufficient.

A laboratory waterbath or the standard bain-maries with an immersion circulator placed in a corner were used for cooking sous-vide. The water was heated to 62.5˚C prior to sample addition. Sample bags were suspended from an oven rack placed on the bain marie top and secured by bulldog clips each with a cord linked to a duplicate laminated external ID label. A foam box lid was placed over the rack to reduce temperature loss. Samples were cooked for 3 hours after the water returned to 62.5˚C after lowering the bags into the chamber, with all bags fully immersed.

On removal each sous-vide sample bag was emptied into a wire mesh strainer and drained with the cooked hot cubes then transferred to individual 600ml airtight containers and 300ml hot broth added prior to sealing. Duplicate ID labels were checked against the laminated labels on the bulldog clips then affixed to the container lids. The containers were then cooled to room temperature before transferring to chilled storage where temperature was reduced to 0 to 1˚C. Cooling in the sealed container generated a partial vacuum and cook chill system to maintain shelf life and food safety.

The chilled containers were transferred in foam boxes to the sensory venue for re-heating and serving.

3.1.10 Consumer recruitment and set up for sensory testing

Consumers were recruited from community groups who participated to raise funds for their particular interest. Groups include sporting, school and church groups together with CWA, Lions, Rotary and other organisations. Participants were screened to be regular beef eaters 18 years or older who ate beef at least once per fortnight and preferred it cooked to medium doneness. The use of groups has been found to generate a wide range of demographics with this further ensured by testing across multiple locations ranging from Melbourne, Brisbane and Sydney to regional centres such as Armidale and Wagga and smaller regional communities. Each group was paid $1,000 for successfully recruiting 60 consumers with the funds used for group activities rather than paying the individuals. Each "pick" utilised 60 consumers who each evaluated 7 samples of a total 42 each of which was evaluated by different sets of10 consumers. The 42 samples were allocated to 7 products with every consumer receiving one sample from each to ensure sensory range.

The recruitment and consumer testing effort were achieved predominantly within the COVID-19 pandemic period adding considerable challenges to remain compliant at all times. Locations were often reallocated to comply with regional lock downs. Consumers were recorded and checked in maintaining social distancing and masks as required at the time and location of testing together with hand sanitising. Seating arrangements were adjusted from the conventional 4 consumers per table to 1 or 2 per table in order to maintain a 2-metre distance between consumers and between serving staff and consumers. Rather than serving plates directly to consumers and leaning across them to check markings on their questionnaires a procedure was developed where the sample plate was placed on a tray and slid to the consumer. On completion of a sample the empty plate and questionnaire was placed back on the tray and slid to the server who replaced the plate with the next sample, collected the used plate and checked the questionnaire was marked before returning the tray.

3.1.11 Cooking and serving of GRL (grill) samples

The GRL samples were cooked at the sensory venue on heavy duty 3 phase Silex S-Tronic 165 clam shell grills equipped with cast iron smooth bottom and grooved top plates. These units, specified in MSA protocol, have sufficient capacity to cycle continuously cooking 10 steaks and hold consistent temperature.

Grill testing was conducted as 3 sittings of 20 consumers for each pick. Mostly all 3 sittings were conducted at the same venue at one-hour intervals but on occasion sittings were spread across dates. The frozen Round Sheets, 7 per session (sitting) or 21 in total, were removed from frozen storage and thawed overnight in a chiller at approximately 2˚C the evening prior to testing. They were transported to the test venue in foam boxes then laid out on individual serving trays to rise to room temperature prior to cooking.

A suitable cooking area, generally a kitchen fitted with a large extraction fan, was located at the venue as close as possible to an area suitable for seating 20 consumers in a COVID-19 complaint arrangement. The Silex grill was placed under the exhaust hood and connected to mains power or to a 20KVA portable generator one hour prior to the first serving time to equilibrate plate temperatures. Each grill was calibrated to achieve a medium doneness in a set time which required slightly different plate settings for each. The primary unit used settings of 210˚C for the bottom and 195˚C for the top plate.

After starting the grill each round sheet bag was cut open on 3 sides and folded back. The freezer wrapping was then removed from each of the 10 steaks which were checked for condition. A pack of "starter" scrap steak of similar mass to a standard Round was placed on the tray adjacent to the Silex with Rounds 1 to 7 of the first Session aligned in order on their trays and checked for orientation to ensure the 3-4-3 order was maintained. A cutting board was placed on the opposite side of the Silex and trays containing consumer plates, 4 per tray, stacked adjacent to the cutting board with the first round trays on top.

Immediately the cook was advised that 20 consumers were checked in the grill plates were sprayed lightly with olive oil, two count-up timers were started and the Starter steaks placed on the grill. From this point all cooking activity was conducted in accordance with the Timing Chart specific to the individual grill. The UNE Silex chart is displayed in Fig. 8.

Figure 8. Timing chart used to control grill cooking

COOKING CHART FOR 25ML STEAK ON SILEX						
Top Plate	**195°C**		**Bottom Plate**		**210°C**	
Note: All Starters & Steaks are 25mm thick and cooked with central Wt/Ht setting						
Round No.	*Unload Steaks*	Load Next	*Close Lid*		Cut Up & Serve	
		START	*00:30*			
Starters	*5:00*	6:15	*7:00*			
1	*11:30*	12:45	*13:30*		14:30	
2	*18:00*	19:15	*20:00*		21:00	
3	*24:30*	25:45	*26:30*		27:30	
4	*31:00*	32:15	*33:00*		34:00	
5	*37:30*	38:45	*39:30*		40:30	
6	*44:00*	45:15	*46:00*		47:00	
7	*50:30*				*53:30*	*END*

With reference to Fig. 8 the Silex top plate was lowered at 00:30 seconds and then opened at 5:00 minutes and the starters removed. The grill plates were cleaned down with a wire brush and scraper and sprayed with olive oil prior to loading the first round at 6:15. The steaks were transferred strictly in order from the top left corner of the Round Sheet maintaining the same 3-4-3 orientation on the grill plate. The top plate was lowered at 7:00. The starters were then cut to check doneness and discarded. The empty round sheet was then moved to a position adjacent to the cutting board.

At 11:30 the 10 first round steaks were transferred to the cutting board in the fixed 3-4-3 order and orientation, the grill plates cleaned, sprayed with olive oil and the second round loaded at 12:45 with the top plate lowered at 13:30. At 14:30 the first-round steaks were cut in half maintaining their cutting board position. A server then held the first tray (consumers 1 to 4) adjacent to the cutting board and the halves of the first steak were transferred to paper plates labelled Cons 1 and Cons 2, Rnd 1 and also carrying the sample EQSRef code. This code was called by the server and cross checked by the cook against the empty Round Sheet to ensure ID was accurately maintained and that the plates were in the designated order. The remaining 9 steaks (18 halves) were transferred to following trays serving 20 consumers their first sample completing Round 1. This procedure was repeated until the session was completed with serving of the 7th round. Subsequent sessions repeated that for the first.

3.1.12 Re-heating and serving of SC2 (slow cook), SVD (sous-vide) and SFR (stir fry) samples

Each of the SC2, SVD and SFR cooking methods utilised a common re-heat and serve procedure. The plastic sample containers with the 42 pre-cooked and chilled samples were packed tightly in a foam box for transport to the sensory venue. Five bain-marie units fitted with 9 x 1/9th x 100mm deep pans and lids were utilised and placed adjacent to each other on benches in the kitchen area prior to filling with water to 10mm above the pan bottoms and connecting to 240-volt power. The water was brought to 50˚C and maintained at that temperature throughout the sensory session(s).

Pre-printed Avery 7160 labels carrying the 42 EQSRef numbers (produced from the CUD software) were then affixed to the lids. The 6 Link samples were placed in one bain-marie and the remaining 36 test sample EQSRef codes placed in alphanumeric order across the other 4 to facilitate identification during serving. Once the water approached 50˚C each of the plastic containers was emptied into the matching EQSRef labelled pan. Regular product temperature checks were conducted and the heater element settings adjusted as needed to maintain 50˚C. Serving trays with pre-labelled paper plates were stacked in serving order and placed adjacent to the bain-maries.

Consumers were seated as 3 sessions of 20 with serving commencing once the 20 were seated and a briefing delivered. Each consumer was served either 2 cooked cubes (SC2 and SVD) or two stir fry strips for each of their 7 samples. Serving was controlled by count-up timers with an example portion of a serving sheet displayed in Fig. 9. The serving sheets were produced by the CUD software.

Figure 9. Portion of example serving chart showing timing for SC2 samples

	SC2	Night	1324		
Serve Time	EQSref	Night.Sess	Rnd	Cons	Cons
00:00	X2H7	1324.1	1	1	2
00:20	X2H7	1324.1	1	3	4
00:40	X2H7	1324.1	1	5	6
01:00	X2H7	1324.1	1	7	8
01:20	X2H7	1324.1	1	9	10
01:40	S0P2	1324.1	1	11	12
02:00	S0P2	1324.1	1	13	14
02:20	S0P2	1324.1	1	15	16
02:40	S0P2	1324.1	1	17	18
03:00	S0P2	1324.1	1	19	20
04:00	N4Q5	1324.1	2	1	2
04:20	Y4C9	1324.1	2	3	4
04:40	N5S8	1324.1	2	5	6
05:00	A1Y2	1324.1	2	7	8
05:20	J2P4	1324.1	2	9	10
05:40	M1M0	1324.1	2	11	12
06:00	T8L4	1324.1	2	13	14
06:20	A4P7	1324.1	2	15	16
06:40	D3E0	1324.1	2	17	18
07:00	U8A5	1324.1	2	19	20

Fig. 9 is for a SC2 pick but of identical form to that used for SVD or SFR serving. Fig 9 displays the serving instruction for the first Link round and subsequent first round of test samples. 1324.1 designates that this sheet is for the first round (consumers 1 to 20) of pick 1324. With reference to Fig 9 it is noted that consumers 1 to 10 all received a common Link sample (X2H7), as did consumers 11 to 20 (S0P2) with each consumer pair served at 20 second intervals. For the second round (first of the 6 test sample rotations) it is noted that each consumer pair is served a different EQSRef to align with the underlying Latin Square controlled sequence.

This procedure was repeated for each session until the 7 rounds had been served. In accordance with the underlying software driven design at completion each consumer had been served 7 samples, a Link and then 6 others, one from each of 6 products and each EQSRef code (sample) had been evaluated by 10 consumers.

3.1.13 Cooking and serving of RST (roast) samples

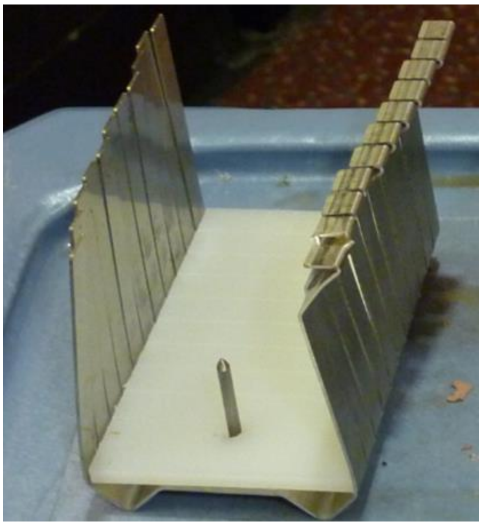
The MSA RST protocol dictates seating and serving of 60 consumers in a single session. Other than requiring a much larger consumer seating area, particularly under COVID-19 compliant requirements serving of consumer samples is common to other methods albeit with radically different cooking and cutting procedures.

The 42 RST samples in a pick were transferred from freezer storage 48 hours prior to cooking and thawed at approximately 2˚C in a chiller. They were then transported to the test venue in foam boxes with the cooking procedure commencing 3 hours prior to the consumer sitting.

Five bain-maries each equipped with 9 x 1/9th x 100mm steamer pans were positioned in an area adjacent to the consumer seating room with sufficient room beside each for a stack of serving trays, each with specific plates bearing designated EQSRef codes and arranged in serving order. Unlike the SC2, SVD and SFR protocol each bain-marie was separately located and manned by a different cutter. Each bain-marie was filled with water to 10mm above the pan bottoms and connected to 240-volt power. The water was brought to 50˚C and maintained at that temperature throughout the sensory session.

Pre-printed Avery 7160 labels carrying the 42 EQSRef numbers (produced from the CUD software) were then affixed to the lids. The 6 Link sample labels were attached to one bain-marie and 9 of the remaining 36 test samples assigned by the CUD software to each of the other 4 bain-marie lids. The allocated EQSRef codes for each set of 9 were placed in alphanumeric order within each bain-marie. A small cutting board and filleting knife was placed adjacent to each bain-marie (cutting station) together with a count up timer and timing sheet relevant to each. A stainless-steel roast keeper as illustrated in Fig. 10 was placed in each pan to warm. The keepers each comprised a folded stainless steel "U" with 1mm slots down the sides at 10mm intervals, a pin centrally mounted at the left-hand end and a small cutting board in the base.

Figure 10. Roast keeper as used to hold roasts for cutting and serving



The raw samples were firstly arranged by size on oven racks which placed the smallest samples to the front of heavier ones to simplify their earlier removal when reaching the specified 65˚C internal temperature. Pre-printed laminated labels of all EQSRef codes were arranged in alphanumeric order and pierced by 50mm trussing pins. The samples were then opened and the matching laminated

EQSRef tag pinned to each sample and cross checked prior to disposing of the bags. Digital thermocouple leads were then inserted in the centre of each sample avoiding obvious fat seams.

The ovens were set 2 hours prior to the consumer sitting achieving 160˚C prior to loading the racks, placed above 25mm deep trays for drainage. The racks were loaded 1:45 prior to serving time and thermocouple leads connected to Digital readouts which were placed along the top of the oven and the door closed with the leads placed under the door seal.

As each roast reached an internal temperature of 65˚C it was checked with a reference thermometer and transferred to a lidded 150mm deep 1/3 gastronome pan to rest prior to further preparation. The time of oven removal was recorded on a “Take Out Sheet” and a further laminated tag attached by a second trussing pin inserted to indicate order of removal (1 to 42) and referenced to the removal time.

After a minimum 10-minute rest period each roast was then removed in take out order from the resting pan and trimmed by removing external browned surfaces and sized to a 65mm x 65mm x 110mm block. A warmed roast keeper was brought to the preparation area and the trimmed roast block inserted within the tines and held securely by the keeper pin. The laminated EQSRef label was pinned to the extreme left of the block which was then taken to the cutting station (bain marie) also shown on the label – for example B35T 2 signifying cutting station 2. This process was repeated until all roasts were cooked, trimmed and transferred after which the oven and kitchen equipment and area was cleaned.

In the serving area the 420 pre-labelled consumer plates were firstly sorted into cutting station stacks and then placed on trays with the earliest served uppermost. Sorted tray stacks were then placed adjacent to the Link and 4 test product cutting stations. One cutter was assigned to each station.

Immediately all consumers were seated and briefed cutting and serving began. The first (Link) round was all served from the Link station with each Link served to 10 consumers in accordance with a timed cutting schedule. Cutting and serving then proceeded at the 4 cutting stations. Each station utilised a timing chart, an example portion of which is shown in Fig. 11, referencing their count up timers. The timers at all 4 stations were started at the same time with the cutting sheets dictating staggered start times from 00, 15, 30 and 45 second intervals past a minute to ensure a smooth flow of plates to the sensory room.

Figure 11. Portion of cutter 2 roast cutting and serving chart

1	*00:00:00*	**N44C**	**2**	1	2
1		**A01N**	**2**	3	4
1	00:01:00	**V93N**	**2**	15	16
1		**U65C**	**2**	29	30
1	00:02:00	**M86W**	**2**	43	44
1		**S31Z**	**2**	57	58
1	00:03:00	**B25R**	**2**	59	60
1	*00:05:00*	**N21P**	**3**	1	2
1		**K61H**	**3**	5	6
1	00:06:00	**A01N**	**3**	15	16
1		**N44C**	**3**	19	20
1	00:07:00	**V93N**	**3**	33	34
1		**U65C**	**3**	47	48
1	00:08:00	**M86W**	**3**	49	50

Fig. 11 displays the cutter 1 serving schedule for Rounds 2 and 3. At 00:00:00 cutter 1 located the pan lid labelled N44C and removed the roast and keeper, placing it on the cutting board, facing the block by running the filleting knife between the first 2 tines adjacent to the block, and then cut a 10mm slice by cutting between the next tines. The keeper and block were then returned to their pan and the lid replaced after cross checking the EQSRef code against the first 2 plate labels with the server who held the first tray close to the cutting station while the cutter cut the slice in half, placing each on the plates for consumer 1 and 2. The procedure was repeated for sample A01N for consumers 3 and 4 which completed a tray, then delivered to the consumer area.

The same process was followed at 00: 00:15 by cutter two, 00:00:30 by cutter 3 and 00:00:45 by cutter 4 serving different EQSRef contained in their bain-maries. At 00:01:00 the cutting sequence returned to cutter one who served V93N to plates for consumers 15 and 16 and then U65C to consumers 29 and 30. The process continued until all 60 consumers had been served 7 samples with each sample tested by 5 different consumer pairs in different rounds as dictated by protocol and delivered by the software generated control sheets and labelling.

3.1.14 Cooking and serving of TBQ (Texas BBQ) samples

Texas BBQ protocols specified use of a Green Mountain Jim Bowie Model Wood Pellet smoker, a number of which were imported by UNE and previously utilised to compare Texas and Australian consumer response to paired beef brisket and rib samples.

In the current bull study, the same protocol was adopted with paired samples evaluated as SC2 to establish within animal comparison. Each brisket was weighed and identified with an ovenproof tag linked to the Primal number prior to cooking. The point and navel end briskets were cooked as full multi-muscle primal cuts after minimal trimming and light seasoning with a 50:50 salt & pepper rub 14 hours prior to placing fat side down in the smoker after it had reached the 250˚F / 121˚C set point. Internal brisket temperature was monitored regularly by the smoker probe which was placed in the smallest brisket within the smoker. When the internal temperature reached 150˚F / 66˚C the brisket was removed and wrapped in heavy duty aluminium foil then returned to the smoker in the same orientation with time recorded. When the internal temperature reached 200˚F / 93˚C the brisket was removed, left in the foil wrapping and placed in an insulated holding box with time recorded. After holding for a minimum of 30 minutes, but generally to 90 minutes pre the planned consumer taste panel start time, the brisket was removed from storage, unwrapped, weighed, and processed. Cooking times varied widely as typical for smoked briskets but were in the order of 4 to 6 hours.

After weighing, processing of the cooked primal commenced with separation and weighing of the two primary muscles within each of the PEB and NEB primals. Muscle identification and orientation was maintained and linked to specified preparation as displayed in the portion of a Brisket Cook Sheet displayed in Fig. 12. The cook sheets always contained 42 individual final consumer sample EQSRef identified codes derived from a lesser number of muscles, primal cuts and carcases. The 42 EQSRef codes in each pick were printed and laminated with the laminated codes cross checked and placed on the final samples as prepared from each muscle.

Figure 12. Portion of a typical brisket cook sheet

Night		1682		COOK RECORD							Date HOT			
Carcase	CUD	Primal No	Cold Wt	Time In	Time Wrap	Time Out	Cut Hot Wt	Muscle	Muscle Wt	Position	SERVE	EQSref	Check	COOK
39	12L	61444						BRI056		P	BQC	E1M4		W
39	12L	61444		Temp	Temp	Temp		BRI056		N	BQS	D5M5		W
39	12L	61444						BRI057		C	BQC	L4A9		W
39	12L	61445	Temp					BRI079		C	BQC	W5G9		W
39	12L	61445						BRI092		C	BQC	S1X2		W
49	14L	61520						BRI056		P	BQC	C4M4		W
49	14L	61520		Temp	Temp	Temp		BRI056		N	BQS	V4B7		W
49	14L	61520						BRI057		C	BQS	H7W1		W
49	14L	61521	Temp					BRI079		C	BQC	E1Y8		W
49	14L	61521						BRI092		C	BQC	M4Q6		W

Referring to Fig. 12 it can be seen that 4 brisket muscles have been designated from the left side of carcase 39 (CUD 12L). Primal 61444, the PEB provided 3 samples, 2 from the BRI056 muscle and 1 from the BRI057. The sample from the point (P) end of the BRI056 was designated to be served in chopped (BQC) form whereas the navel (N) end sample was to be served sliced (BQS). The single BRI057 sample was designated to be served chopped (BQC) for this body but sliced (BQS) from carcase 49. The smaller BRI079 and BRI092 from the NEB, primal 61445, were both to be served in chopped form. Further to the right the unique EQSRef numbers assigned to each final consumer sample are shown together with a W to indicate the cut is to be cooked as a whole primal. BQS (sliced) samples were prepared on a cutting jig set to achieve a 6mm slice across the muscle grain whereas the BQC (chopped) samples were cut as approximately 20 x 20mm cubes.

As for the RST protocol 5 bain-maries each equipped with 9 x 1/9th x 100mm steamer pans were positioned in an area adjacent to the consumer seating room with sufficient room beside each for a stack of serving trays, each with specific plates bearing designated EQSRef codes and arranged in serving order. Each bain-marie was filled with water to 10mm above the pan bottoms and connected to 240-volt power. The water was brought to 50˚C and maintained at that temperature throughout the sensory session.

Pre-printed Avery 7160 labels carrying the 42 EQSRef numbers (produced from the CUD software) were then affixed to the lids. The 6 Link sample labels were attached to one bain-marie and 9 of the remaining 36 test samples assigned by the CUD software to each of the other 4 bain-marie lids. The allocated EQSRef codes for each set of 9 were placed in alphanumeric order within each bain-marie.

Once prepared each sensory sample and its associated laminated EQSRef label was transferred to the bain-marie and pot with the corresponding EQSRef lid label and held prior to serving.

Sample serving order and timing was identical to the RST protocol and controlled by the individual cutter serving sheets. For TBQ however the roast keepers were not used as no further slicing was required, with samples held loose in the pots and transferred to consumer plates with a cross check of ID at the nominated serving times.

3.1.15 Consumer questionnaire completion and data entry

The standard MSA consumer questionnaire was utilised for all cooking methods. Once seated each session was briefed on the testing and scoring procedure before completing a basic two-page demographic questionnaire. A single page score sheet was then utilised for each sample with the EQSRef the only sample identification. Consumers were asked to place a mark across the four 100 mm line scales to indicate their individual ratings of the sample tenderness, juiciness, flavour liking and overall satisfaction. The scales were anchored respectively with Not Tender/Very Tender, Not Juicy/Very Juicy and, for both the flavour and overall scales Dislike Extremely/ Like Extremely. After marking each line, they selected one of four category boxes described as unsatisfactory, good everyday, better than everyday or premium quality. Serving staff checked that each line had been marked and a box selected before the next sample was served and a new page marked.

A final sheet after the 7 samples was then marked to record willingness to pay prices/kg for each category description, again utilising a line scale for each of the 4 category boxes denoting $/Kg ranging from $0 to $80.

The questionnaire formats are attached in the Appendix for reference (Appendix. 8.1).

The completed questionnaires were double entered and each line scale measured in mm from the left-hand end to produce a score between 0 and 100 and a category code of 2 (unsatisfactory) 3, 4 or 5 (premium quality) in line with the category box descriptions, also referred to as 3*, 4* or 5*. The two entry files were then cross checked with any deviation greater than 1mm apart being re-checked to ensure accurate line measurement prior to them being electronically forwarded to research personnel responsible for managing the AUSBlue database.

Software routines within the AUSBlue software checked the forwarded file against the EQSRefs served and the order of serving to each consumer. If correct a routine was then enacted to calculate an MQ4 score for each consumer sample by multiplying the tenderness score x 0.3, the juiciness score by 0.1 and the flavour and overall scores each by 0.3, the results then being summed to create a weighted value between 0 and 100. The weightings used were current MSA weightings. The 10 scores relating to each EQSRef were then sorted and an average of the 10 values calculated for each of the scales and the MQ4 values. Clipped values for each were then computed by removing the lowest and highest two scores with the central 6 values being averaged to produce clipped scores. The average and clipped values for each scale, the MQ4 and the category box were then uploaded to the AUSBlue database and aligned with the EQSref to connect all other animal, grading and processing data. These data were extracted from AUSBlue for subsequent statistical analysis to report the project results and also pooled with all AUSBlue data for further development of the MSA V2.0 prediction model.

The individual consumer data were also stored as sensory files and utilised for calculation of Willingness to Pay values for each category description and retained to allow for individual consumer analysis.

4. Results

The project results, in line with the objectives, relate principally to the generation of extensive within animal data from young bulls related to 39 different muscles, six cooking methods and ageing comparisons between periods from 10 to 73 days. These data will inform further development of the MSA V2.0 prediction model facilitating improved predictive power, allowing inclusion of further muscles with insufficient previous data and providing MSA eligibility for young bulls.

4.1 Sensory testing

A feature of this project was extensive linkage both within animal through multiple muscles and to a wide range of other MSA projects by testing samples from multiple projects within common sensory sessions or picks, a pick representing 36 test samples allocated to 6 products of expected different eating quality and evaluated by 60 consumers. Within a pick each consumer evaluated 7 samples and each sample was evaluated by 10 consumers.

Bull sensory samples were included in 81 sensory picks engaging 4,860 consumers in evaluation, providing extensive linkage for model development.

4.2 Slaughter and MSA grading

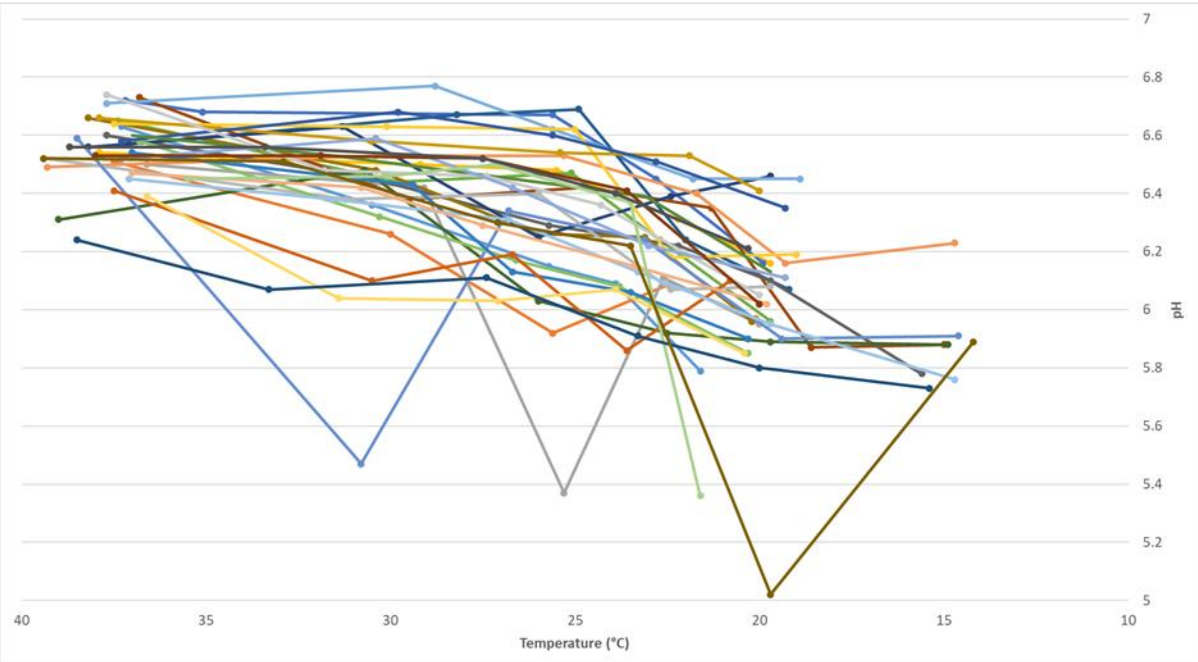
The 18 head were slaughtered at a southern Victorian abattoir on 30th April 2019.

4.2.1 Slaughter and pH decline

The abattoir utilised electric stunning, a process unfamiliar to prior MSA collections and of interest due to its potential influence on pH decline. "Paddling" of limbs is also a condition associated with electric stunning leading to application of an electric immobiliser as required to assist in shackling. This also potentially affected the pH decline rate. Temperature and pH readings were taken on 50 bodies at chiller entry then 1 hour, and later at 1.5-hour intervals, with the individual decline curves presented in Fig. 13. The graph includes a few obvious outlier values that are highly improbable but retained to reflect the original unmodified raw data entry. The 18 head subsequently selected were all compliant with MSA abattoir window and ultimate pH standards.

The data established that both pH and temperature declines were slow relative to typical situations where low voltage stimulation is applied and also considerably slower than that observed with heavy grainfed steers. Given the light average carcase weight of 195 kg and 0 to 1mm rib fat cover this was surprising but not of concern given the relationship of loin temperature and pH at each point. MSA specify an "abattoir window" related to the loin temperature at pH 6.0 with the extremes 35˚C to avoid heat toughening and 12˚C to avoid cold shortening.

Figure 13. Temperature and pH relationships for individual bodies from knock time



From the means summarised in Table 5 it is observed that the mean pH was well in excess of 6.0 at 4 hours post knock with loin temperature averaging 23.4. A mean pH of 6.1 was associated with a 20˚C temperature at 5.5 hours and remained above 13˚C at 7.25 hours at which point mean pH was 5.6.

Table 5. Mean temperature and pH decline values for 50 young dairy bulls

Time from Knock	pH	Temp ˚C
00:28	6.6	37.5
01:30	6.5	31.6
02:43	6.4	31.8
03:57	6.3	23.4
05:26	6.1	20.0
07:17	5.6	13.7

These means refer to 50 bodies, of which 12 remained above pH 6.0 when checked at 8.5 hours indicating they were likely to remain high and be dark cutters, but allowing for these, “window” compliance was close to ideal. A subset of 18 bodies with an ultimate pH below the required MSA maximum of 5.71 at grading was selected for product collection.

As bull sex was confounded with electric stun and low rib fat it is not possible to speculate on causal relationships to the observed pH decline rate.

4.2.2 MSA grading data

All 50 bodies were graded by MSA research personnel commencing at 11:00 the morning after kill. After grading 18 bodies were selected for the research cut collection. Any bodies with erratic pH declines or ultimate pH above 5.7 were rejected so that the selected 18 were MSA compliant for pH. However, none achieved the required minimum 3mm of rib fat. Table 6 displays summary grading data for the 18 selected carcases with Table 7 displaying the individual carcase values.

Table 6. Summary statistics for MSA grading inputs for 18 selected young bull carcases

	Upper Moira (N=18)
Carcase Weight (Kg)	
Mean (SD)	195 (13.4)
Median [Min, Max]	192 [176, 230]
Hump Height	
Mean (SD)	48.3 (5.14)
Median [Min, Max]	50.0 [40.0, 60.0]
Ossification	
Mean (SD)	129 (12.6)
Median [Min, Max]	130 [100, 140]
Eye Muscle Area	
Mean (SD)	56.3 (5.14)
Median [Min, Max]	55.0 [47.0, 66.0]
MSA Marbling	
Mean (SD)	161 (37.5)
Median [Min, Max]	155 [120, 230]
Meat Colour	
1C	6 (33.3%)
2	3 (16.7%)
3	7 (38.9%)
4	2 (11.1%)
Ultimate pH	
Mean (SD)	5.57 (0.0473)
Median [Min, Max]	5.57 [5.45, 5.65]
Rib Fat	
Mean (SD)	0.611 (0.608)
Median [Min, Max]	1.00 [0, 2.00]

Table 7. Individual body MSA grading inputs for 18 selected young bulls

					Marbling				Colour		
Body	**HSCW**	**Hump**	**Uoss**	**Ribfat**	**AUS**	**MSA**	**pH**	**Temp**	**Meat**	**Fat**	**Ema**
2	178	40	130	1	0	130	5.45	6.5	2	0	52
3	196.4	45	140	1	0	200	5.52	7.8	3	1	59
9	175.6	45	100	1	0	160	5.54	6.8	3	2	48
10	227.2	50	140	1	0	200	5.55	6.1	3	1	55
38	200	60	130	0	0	160	5.58	6.3	4	1	55
27	191.6	45	140	1	0	120	5.58	6.7	1C	1	57
11	186	50	120	0	0	230	5.59	6.4	2	3	53
24	187.2	55	140	0	0	130	5.65	6.4	1C	1	63
41	204.8	55	130	1	0	200	5.55	6	3	1	63
15	183.6	45	120	0	0	120	5.57	6	4	0	47
40	187.2	50	130	1	0	140	5.62	6.2	3	1	54
39	188.4	50	140	0	0	140	5.58	6.4	3	2	54
50	188	45	140	1	0	170	5.52	6.1	1C	0	54
20	191.6	45	110	0	0	150	5.57	6.4	1C	1	66
49	190.4	50	110	1	0	120	5.57	6.1	1C	1	62
19	195.2	40	140	0	0	120	5.61	6.2	3	1	58
18	210	50	130	2	0	230	5.54	6.6	2	1	54
36	215.6	50	140	0	0	170	5.64	6.8	1C	1	60
Average	**194.3**	**48.3**	**129**	**0.6**	**0**	**161**	**5.6**	**6.4**		**1.1**	**56.3**

All but the rib fat values and associated fat distribution (data not shown) were MSA compliant. Meat colour was widely distributed relative to the ultimate pH values with no relationship between the two. Carcase weight and marbling values were also low as might be expected from 9-month-old dairy bulls. Hump and ossification (Uoss) values were moderate, and higher than typical for the carcase weight and stated age, which was interpreted as a reflection of bull sex. This was consistent with data from the BeefQ project in Wales where bull sex was associated with far higher ossification values for actual age than were steer and heifer sex (Polkinghorne, 2020). The inclusion of some milk replacer (6 litres/day) in the diet through to kill makes these cattle potentially eligible for an MFV (milk fed vealer) categorisation as while not suckling on the cow the diet may have been broadly comparable. While not displayed in table 7 to conserve space, all carcases were graded as 0%TBC, HGP Free and Bull.

4.3 Sensory Results

4.3.1 Evaluation of muscle and cook combinations for MSA model expansion

A number of muscle and cook combinations were incorporated in this project to expand or create new data sufficient to produce reliable estimates to expand the MSA V2.0 prediction model and add to data for other combinations currently included but with marginal data. Supplementary samples were also collected to further linkage and data where muscle mass permitted.

Two navel end brisket muscles, *M.serratus ventralis thoracis* (NEB079) and *M.transversus abdominis* (NEB092) were tested for the first time as were BLD097, FQS004, FQS006 and HQS059 for stir fry cooking. New controlled comparisons of SC2 (slow cook/casserole) and TBQ (Texas BBQ) cooking methods were obtained using 4 brisket muscles with further needed data comparing SC2 and SVD (sous-vide cubes) and grill and roast comparison of butt tenderloin (TDR034). These data provide an opportunity to add to model predictions in addition to the primary objective of adding substantial data for a large range of muscle x cook x ageing days combinations derived from young dairy bred bull carcases. These provided a widely separated and more comprehensive data reference from the existing AUSBlue data relating to subsets of Northern Australian *bos-indicus* infused cattle and to that shared by international collaborators.

The addition of ageing data beyond 50 days across many muscles and from within animal comparisons also added considerably to extended ageing data assisting in future extension of the existing 50-day maximum prediction for cuts other than tenderloin and to the current 40-day tenderloin limit.

4.3.2 Sensory scores

Table 8 displays raw mean scores for all muscle and cook combinations. These include all ageing treatments and are unadjusted so need to be interpreted with caution. However, as no cook x ageing interaction was found it is believed the scores provide a reasonable general view of relative performance.

Table 8. Mean raw clipped MQ4 values for all tested muscle by cook combinations

	COOKING METHOD						
MSA Code	**GRL**	**RST**	**SC2**	**SFR**	**SVD**	**TBQ**	**Mean**
BLD095			57.2				**57.2**
BLD096	53.3	40.6	60.8		50.9		**53.6**
BLD097			64.9	65.7			**65.4**
BRI092			58.0				**58.0**
CHK068			57.1				**57.1**
CHK074	57.5		73.3				**61.9**
CHK078	51.4	43.6	60.9				**53.6**
CTR085	47.4	41.3	61.1				**53.1**
CUB045	59.3						**59.3**
CUB081	67.5	62.4					**67.2**
EYE075	48.2	51.8	49.7	54.8			**50.5**
FQS004			74.0	58.3			**64.2**
FQS006			71.6	57.8			**62.7**
FQSHIN			63.3		20.1		**41.7**
HQS059			75.9	63.4			**69.3**
HQSHIN			73.1		39.1		**56.1**
INT037			77.1		52.7		**67.2**
KNU066	56.1	50.1	60.9				**57.4**
KNU099	40.9	50.3	57.0		38.6		**44.7**
NEB079			50.5			59.3	**54.2**
NEB092						68.2	**68.2**
OUT005	37.3	25.7	59.2				**42.8**
OUT029			63.9	68.2			**66.3**
OYS036	61.6		80.3		59.9		**67.3**
PEB056			44.6			58.1	**52.3**
PEB057			50.5			70.3	**58.4**
RIB041			62.3				**62.3**
RMP005	61.7	59.2					**61.5**
RMP087		45.7	58.1				**57.1**
RMP131	59.5	68.4					**59.8**
RMP231	58.5	68.1					**58.7**
STR045	49.2						**49.2**
TDR034	62.4	79.7					**63.3**
TDR062	68.4	72.6					**68.8**
TFL051			55.7	58.3			**57.1**
TFL052			65.6	62.4			**63.7**
TFL064			52.6	56.8			**55.4**
TOP001	46.8		43.2				**45.6**
TOP033			62.4	61.0			**61.6**
TOP073	42.9	31.4	44.1				**42.8**
Mean	**52.9**	**50.6**	**58.7**	**60.6**	**46.8**	**62.8**	**55.8**

The following sub sections address results related to individual cooking methods in greater detail.

4.3.3 Grill samples

Fig. 14 displays an overview of individual muscle clipped MQ4 (CMQ4) scores obtained from sensory testing of grilled samples. As shown a considerable score range was found across and within cuts ranging from less than the MSA fail point of 46 CMQ4 to over the 5* lower boundary of 77 CMQ4. It should be noted however that some of the within cut variation may reflect different ageing periods given days ageing ranged from 10 to 73 days post-mortem. No ageing by cook interaction was observed despite significant cut by ageing interaction.

Figure 14. Box plot depiction of clipped MQ4 values of grilled samples by muscle

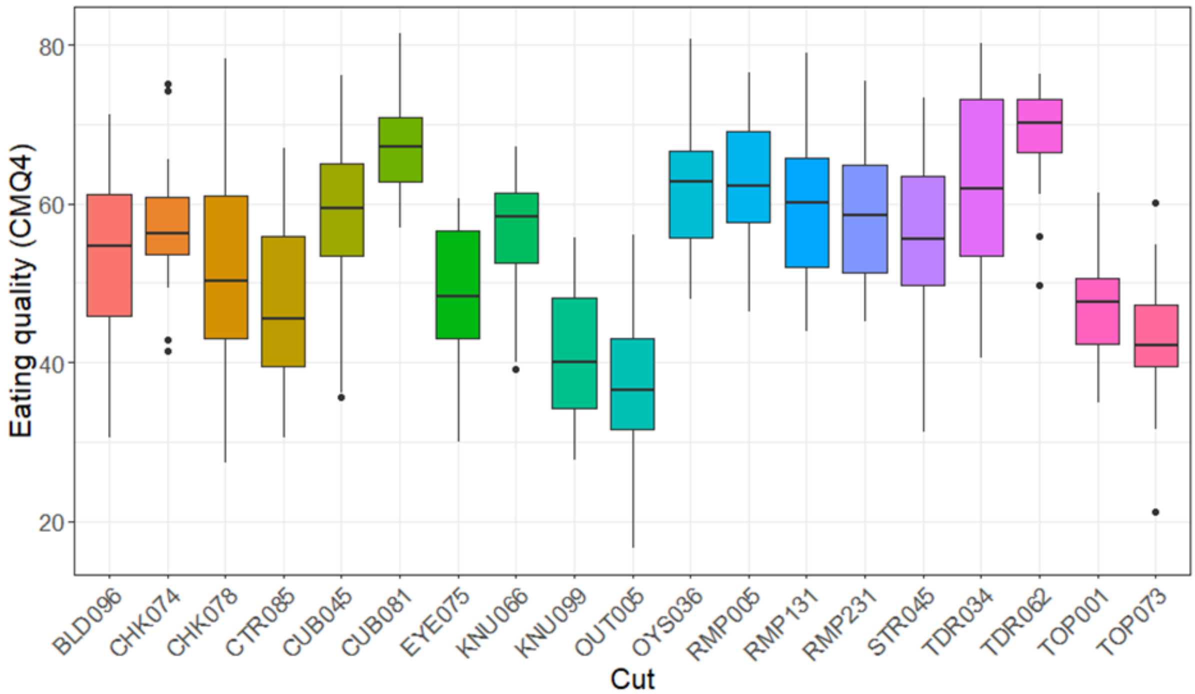


Table 9 provides a summary of the four individual sensory scales in addition to the CMQ4 values. The relationship between the tenderness and flavour scales varied considerably between cuts with tenderness tending to be higher for traditional high quality grilling cuts, similar for intermediate and flavour making a greater contribution to CMQ4 for traditional tougher secondary cuts including CHK078, EYE075, KNU099, OUT005 and TOP073. The mean CMQ4 values were below the MSA 3* minimum for the knuckle cover (KNU099), outside flat (OUT005) and major topside muscle (*M.semimembranosus* TOP073) and only slightly above for the chuck tender (CTR085), eye round (EYE075) and topside *M.adductor* (TOP001) muscle.

In common with existing MSA findings the two principal knuckle muscles differed significantly with the eye portion (KNU066) some 15 points greater than the cover (KNU099). The *M.spinalis dorsi* (CUB081) muscle mean within the cube roll also exceeded the *M.longissimus dorsi et thoracis* (CUB045) by 8 CMQ4 points. Other within cut muscle relationships for the chuck and topside primal also displayed typical mean score relationships.

Table 9. Summary statistics of grilled sample sensory scores

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
BLD096						
Mean (SD)	**(N=18)**	53.3 (10.4)	51.8 (14.2)	55.8 (11.3)	54.5 (8.25)	52.6 (11.5)
Median [Min, Max]		54.7 [30.6, 71.2]	56.9 [22.8, 68.2]	57.4 [35.2, 74.8]	54.8 [36.3, 71.7]	51.5 [25.7, 73.8]
CHK074						
Mean (SD)	**(N=18)**	57.5 (8.83)	56.2 (11.8)	63.0 (9.89)	58.9 (8.10)	56.9 (8.54)
Median [Min, Max]		56.3 [41.5, 75.2]	54.6 [32.7, 79.5]	63.6 [45.2, 84.2]	58.0 [45.2, 73.3]	56.5 [42.3, 73.8]
CHK078						
Mean (SD)	**(N=9)**	51.4 (14.8)	45.6 (18.0)	54.2 (15.5)	54.6 (13.7)	52.6 (14.8)
Median [Min, Max]		50.3 [27.4, 78.3]	46.0 [21.2, 78.5]	56.5 [30.5, 79.3]	52.5 [31.3, 76.8]	50.8 [27.0, 76.0]
CTR085						
Mean (SD)	**(N=12)**	47.4 (11.2)	44.9 (13.1)	49.0 (12.2)	50.0 (11.9)	47.1 (12.2)
Median [Min, Max]		45.6 [30.6, 66.9]	44.4 [28.2, 72.3]	47.6 [29.3, 65.5]	49.8 [32.0, 65.5]	45.3 [29.8, 66.3]
CUB045						
Mean (SD)	**(N=56)**	59.3 (9.22)	60.1 (10.8)	57.9 (10.7)	59.7 (9.26)	59.2 (9.80)
Median [Min, Max]		59.4 [35.6, 76.1]	60.3 [29.5, 77.3]	57.8 [26.5, 79.3]	60.1 [33.2, 78.3]	60.3 [28.5, 78.3]
CUB081						
Mean (SD)	**(N=19)**	67.5 (7.33)	69.6 (7.97)	68.8 (7.48)	66.6 (7.63)	67.0 (7.95)
Median [Min, Max]		67.2 [57.0, 81.5]	69.3 [54.5, 83.2]	72.3 [57.0, 79.3]	65.8 [54.0, 82.2]	65.5 [54.2, 80.3]
EYE075						
Mean (SD)	**(N=18)**	48.2 (8.85)	44.9 (11.6)	49.2 (10.5)	51.3 (9.96)	48.5 (8.41)
Median [Min, Max]		48.2 [30.0, 60.6]	45.0 [22.8, 61.0]	45.9 [33.5, 70.3]	50.9 [30.8, 65.0]	47.0 [30.7, 61.0]
KNU066						
Mean (SD)	**(N=13)**	56.1 (8.70)	57.3 (11.3)	56.1 (10.2)	55.8 (8.49)	57.3 (7.83)
Median [Min, Max]		58.3 [39.1, 67.2]	55.8 [35.7, 71.8]	55.8 [36.3, 71.2]	56.5 [40.7, 70.8]	59.0 [39.0, 68.0]
KNU099						
Mean (SD)	**(N=18)**	40.9 (8.54)	34.8 (10.8)	42.8 (9.37)	43.9 (8.36)	42.0 (9.13)
Median [Min, Max]		40.0 [27.7, 55.7]	35.9 [19.0, 52.7]	43.2 [24.2, 68.2]	40.4 [34.2, 63.7]	39.0 [29.2, 57.8]
OUT005						
Mean (SD)	**(N=36)**	37.3 (9.91)	29.4 (12.2)	42.3 (10.6)	42.9 (9.24)	38.8 (11.3)
Median [Min, Max]		36.6 [16.5, 56.1]	29.5 [4.17, 55.5]	42.4 [17.7, 65.8]	43.4 [23.8, 58.8]	38.3 [18.7, 59.2]
OYS036						
Mean (SD)	**(N=18)**	62.2 (9.04)	64.1 (12.8)	65.5 (6.98)	60.7 (9.12)	63.0 (8.40)
Median [Min, Max]		62.8 [47.9, 80.7]	64.8 [42.8, 88.3]	64.6 [53.0, 77.7]	60.4 [43.7, 82.0]	63.3 [50.5, 81.0]
RMP005						
Mean (SD)	**(N=18)**	61.7 (9.30)	63.5 (10.6)	59.3 (12.9)	62.5 (9.56)	62.5 (9.04)
Median [Min, Max]		62.2 [46.4, 76.6]	65.2 [42.2, 80.2]	61.4 [39.2, 79.3]	62.2 [43.5, 74.8]	62.4 [48.5, 77.2]
RMP131						
Mean (SD)	**(N=18)**	59.3 (9.90)	59.1 (14.0)	58.3 (10.2)	61.3 (9.13)	60.5 (9.56)
Median [Min, Max]		60.1 [43.9, 79.0]	58.9 [31.2, 84.5]	57.5 [41.3, 79.2]	61.7 [49.0, 78.2]	61.0 [42.0, 77.8]
RMP231						
Mean (SD)	**(N=17)**	58.5 (8.99)	60.7 (12.1)	54.0 (9.40)	58.1 (9.14)	58.4 (8.60)
Median [Min, Max]		58.6 [45.1, 75.4]	61.7 [34.7, 81.5]	55.2 [42.7, 73.0]	55.8 [43.5, 75.2]	61.0 [45.3, 74.8]
STR045						
Mean (SD)	**(N=58)**	55.7 (10.2)	56.3 (12.3)	52.0 (10.5)	56.9 (10.5)	55.8 (10.4)
Median [Min, Max]		55.6 [31.2, 73.4]	57.5 [27.7, 77.5]	51.9 [29.5, 73.7]	60.3 [32.0, 72.8]	57.1 [29.8, 74.3]
TDR034						
Mean (SD)	**(N=18)**	62.4 (13.0)	65.8 (13.2)	58.7 (11.8)	62.3 (12.6)	62.3 (13.8)
Median [Min, Max]		61.8 [40.6, 80.2]	66.8 [38.2, 83.0]	56.7 [41.7, 77.8]	63.9 [37.0, 79.0]	62.2 [37.8, 80.3]
TDR062						
Mean (SD)	**(N=18)**	68.4 (7.02)	71.4 (6.31)	63.9 (7.21)	67.9 (8.91)	68.1 (7.91)
Median [Min, Max]		70.1 [49.8, 76.4]	73.6 [55.8, 79.2]	64.9 [45.8, 75.2]	70.3 [42.5, 78.7]	70.1 [46.3, 76.5]
TOP001						
Mean (SD)	**(N=18)**	46.8 (7.19)	43.9 (9.60)	42.3 (10.0)	50.5 (7.45)	48.4 (7.53)
Median [Min, Max]		47.5 [35.0, 61.4]	42.8 [28.7, 59.8]	41.3 [28.0, 61.0]	50.6 [37.0, 63.5]	46.8 [35.3, 62.7]
TOP073						
Mean (SD)	**(N=36)**	42.9 (7.12)	36.6 (10.6)	41.9 (10.5)	48.2 (6.19)	43.1 (6.76)
Median [Min, Max]		42.2 [21.2, 60.2]	35.3 [10.0, 61.2]	41.9 [15.0, 70.7]	47.5 [34.8, 61.3]	43.1 [21.5, 63.8]

4.3.4 Stir fry samples

The stir fry sample CMQ4 distributions for each muscle are displayed in Fig. 15. Only the EYE075 was also tested as a grill with the remaining muscles typically too small or unsuitably shaped for grilling but linked to casserole (SC2) or sous-vide (SV2). All the muscle mean CMQ4 scores exceeded the minimum 46 required to meet the MSA 3* category with few individual failures and the upper portion of the bolar blade (BLD097) and heel muscle (OUT029) averaging over the 64-point MSA 4* threshold. All muscle means were over 54 indicating a mid to upper 3* rating. The EYE075 mean of 54 was substantially above the grill score of 48 CMQ4. The range of scores within and between muscles was reduced relative to the grill results.

Figure 15. Box plot depiction of clipped MQ4 values of stir fried samples by muscle

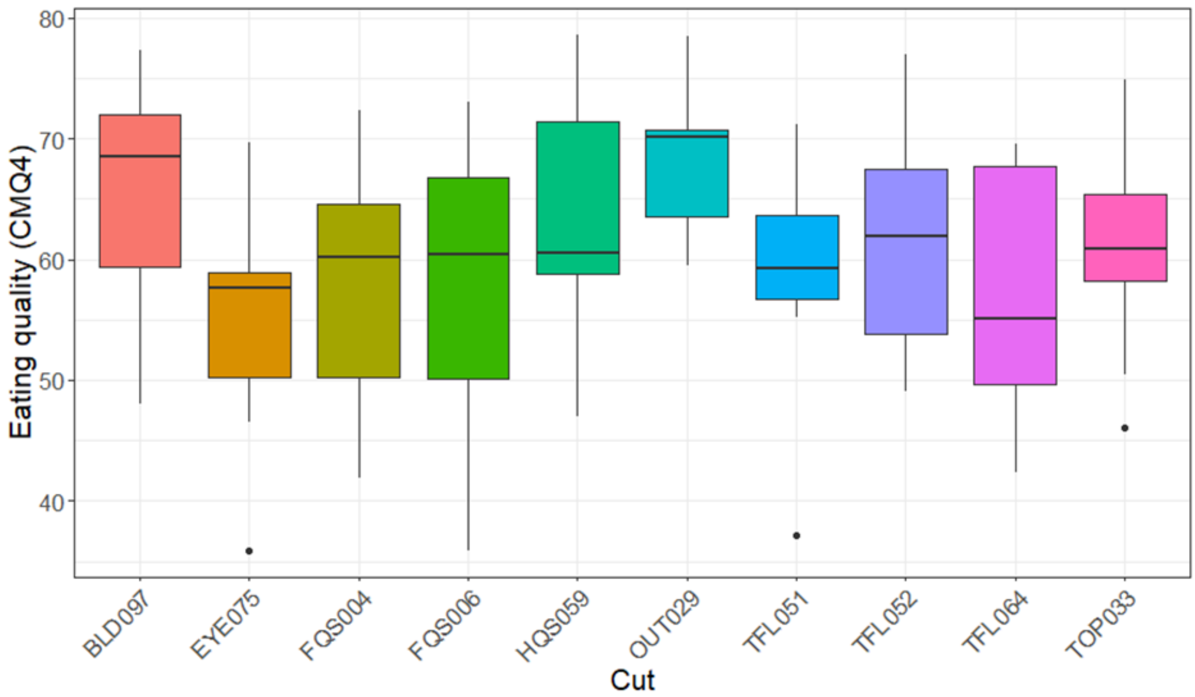


Table 10 displays a statistical summary of the individual sensory scales for each muscle, the weighted combination of each creating the MQ4 statistic. It is observed that the tenderness and flavour scales are more consistently correlated than were the grilled muscle samples.

Table 10. Summary statistics of stir fried sample sensory scores

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
BLD097						
Mean (SD)	**(N=12)**	65.7 (9.59)	66.4 (11.1)	65.8 (11.7)	66.5 (8.37)	65.8 (8.98)
Median [Min, Max]		68.6 [48.1, 77.3]	70.5 [48.8, 79.2]	71.6 [42.7, 76.5]	67.8 [50.3, 79.3]	68.3 [48.2, 76.7]
EYE075						
Mean (SD)	**(N=11)**	54.8 (9.21)	57.4 (11.7)	53.3 (11.0)	54.3 (7.11)	53.8 (9.32)
Median [Min, Max]		57.6 [35.9, 69.7]	55.8 [34.2, 79.3]	55.3 [33.7, 69.8]	55.2 [39.3, 65.0]	55.8 [36.2, 69.5]
FQS004						
Mean (SD)	**(N=10)**	58.3 (10.7)	61.4 (15.1)	63.3 (14.4)	58.6 (8.49)	56.7 (11.1)
Median [Min, Max]		60.2 [42.0, 72.3]	63.3 [31.3, 82.5]	68.0 [37.8, 78.8]	59.0 [43.0, 68.5]	60.1 [40.8, 70.8]
FQS006						
Mean (SD)	**(N=9)**	57.8 (12.7)	58.5 (14.1)	59.5 (11.2)	59.2 (12.9)	56.6 (12.4)
Median [Min, Max]		60.4 [35.9, 73.0]	57.0 [33.0, 76.8]	58.5 [40.0, 72.3]	63.8 [38.7, 74.0]	58.2 [36.3, 71.8]
HQS059						
Mean (SD)	**(N=9)**	63.4 (9.79)	66.3 (14.7)	68.5 (8.59)	60.9 (9.58)	62.7 (8.69)
Median [Min, Max]		60.6 [47.0, 78.6]	67.8 [41.2, 89.5]	70.7 [58.5, 80.0]	61.2 [43.2, 72.8]	60.0 [52.7, 75.8]
OUT029						
Mean (SD)	**(N=9)**	68.2 (6.35)	73.2 (7.09)	64.1 (9.93)	66.3 (6.63)	67.6 (6.53)
Median [Min, Max]		70.2 [59.5, 78.4]	76.8 [60.2, 81.5]	62.8 [51.3, 78.2]	64.5 [56.8, 78.7]	67.2 [58.2, 79.0]
TFL051						
Mean (SD)	**(N=7)**	58.3 (10.8)	61.4 (16.9)	61.0 (12.9)	54.4 (8.01)	58.9 (11.3)
Median [Min, Max]		59.2 [37.1, 71.2]	66.3 [27.5, 75.7]	60.3 [38.0, 80.3]	55.0 [39.5, 66.8]	60.3 [37.8, 73.7]
TFL052						
Mean (SD)	**(N=9)**	62.4 (9.31)	62.0 (16.9)	65.6 (10.0)	63.1 (5.30)	61.8 (9.02)
Median [Min, Max]		62.0 [49.1, 76.9]	69.5 [38.3, 83.2]	68.0 [43.3, 77.5]	61.2 [56.0, 72.7]	61.8 [51.3, 76.0]
TFL064						
Mean (SD)	**(N=12)**	56.8 (9.71)	57.7 (12.0)	59.5 (10.8)	56.2 (9.88)	57.1 (9.16)
Median [Min, Max]		55.1 [42.4, 69.6]	57.6 [40.0, 73.2]	62.3 [38.3, 74.0]	59.3 [39.7, 66.8]	55.6 [41.5, 69.3]
TOP033						
Mean (SD)	**(N=12)**	61.0 (7.84)	63.7 (7.39)	62.2 (6.90)	59.7 (10.5)	60.8 (9.82)
Median [Min, Max]		60.9 [46.1, 74.9]	64.7 [48.5, 74.5]	62.3 [49.7, 74.2]	60.1 [40.0, 75.2]	61.0 [43.8, 77.3]

4.3.5 Texas BBQ samples

Four brisket muscles were evaluated by sensory testing after TBQ (Texas BBQ) cooking which is a low and slow cooking process including smoking, further described in the methodology section. Summary statistics for each muscle are displayed in Table 11.

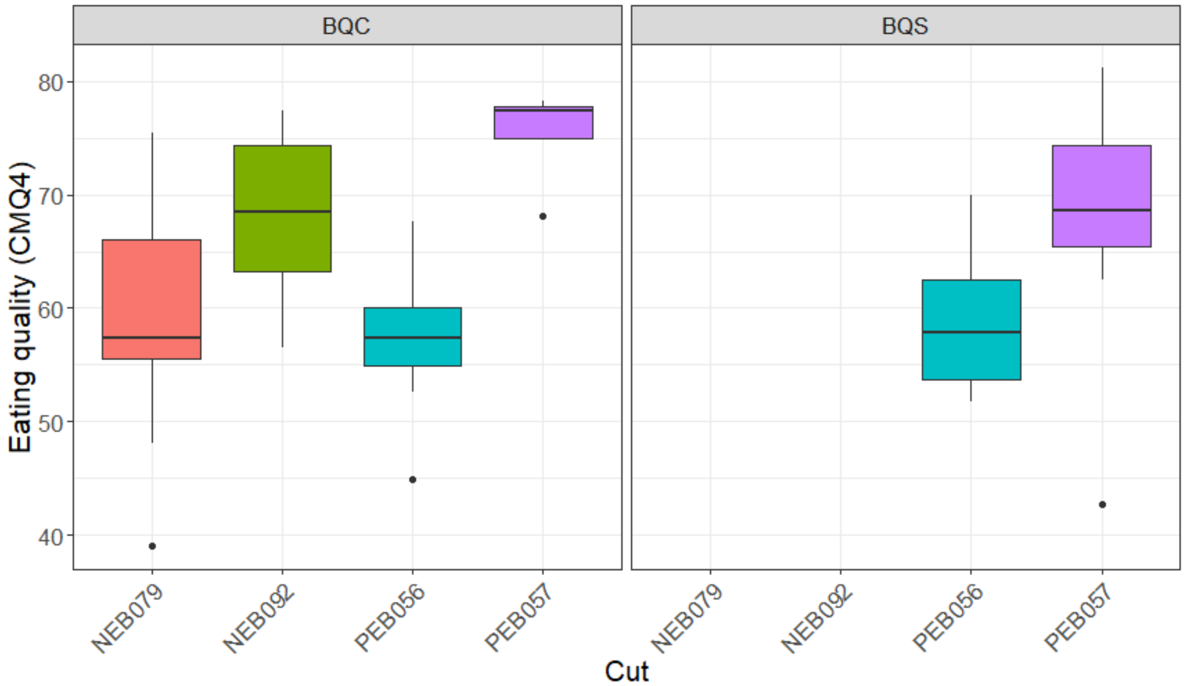
Table 11. Summary statistics for brisket muscles cooked by Texas BBQ (TBQ)

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
NEB079						
Mean (SD)	**(N=12)**	59.4 (10.4)	64.3 (11.4)	50.0 (10.3)	59.8 (10.4)	58.4 (11.7)
Median [Min, Max]		57.4 [39.0, 75.5]	63.8 [44.5, 81.8]	48.3 [37.7, 69.7]	60.3 [38.5, 74.2]	56.3 [35.0, 78.5]
NEB092						
Mean (SD)	**(N=12)**	68.2 (7.05)	74.4 (9.08)	61.9 (6.37)	66.3 (7.36)	67.2 (6.83)
Median [Min, Max]		68.5 [56.5, 77.4]	76.2 [55.3, 86.0]	60.9 [51.0, 73.8]	66.3 [56.7, 77.2]	67.0 [57.8, 75.3]
PEB056						
Mean (SD)	**(N=24)**	58.1 (5.90)	64.3 (10.5)	38.6 (9.66)	61.0 (6.78)	57.0 (6.31)
Median [Min, Max]		57.4 [44.9, 70.0]	65.1 [42.0, 83.8]	37.6 [24.0, 56.7]	60.7 [45.3, 72.7]	57.2 [45.7, 70.0]
PEB057						
Mean (SD)	**(N=12)**	70.3 (10.6)	80.3 (11.2)	67.7 (8.69)	66.8 (10.8)	68.8 (10.6)
Median [Min, Max]		70.7 [42.8, 81.2]	81.5 [55.0, 91.7]	69.3 [44.8, 80.8]	69.3 [38.8, 77.3]	68.8 [41.3, 81.0]

From Table 11 it would appear that the MQ4 value is heavily influenced by notably higher tenderness scores for all muscles and by a significantly reduced juiciness score for PEB056. The higher mean values for the PEB057 relative to PEB056 was consistent with other MSA studies utilising TBQ cooking. Both the NEB092 and PEB057 mean MQ4 values comfortably exceeded the MSA 4* threshold of 64 MQ4 whereas the NEB079 and PEB056 were in the upper 50% of MSA 3* quality, the lower threshold being 46 MQ4.

The two navel brisket muscles (NEB079 and NEB092) are thin whereas the point end muscles are larger with the PEB056 sufficiently large to provide two sensory samples. These were used to enable a within muscle and position comparison of serving in chopped or sliced form. The same comparison was made from alternate sides for the PEB057 muscle with results displayed in Fig. 16.

Figure 16. Box plots of CMQ4 score distribution by brisket muscle within serving form



As depicted in Fig. 16 and detailed in Table 12, while chopped (BQC) and sliced (BQS) serving forms were similar for the PEB056 the BQC form was superior for the PEB057.

Table 12. Summary statistics of sensory scales and MQ4 for brisket muscles and form

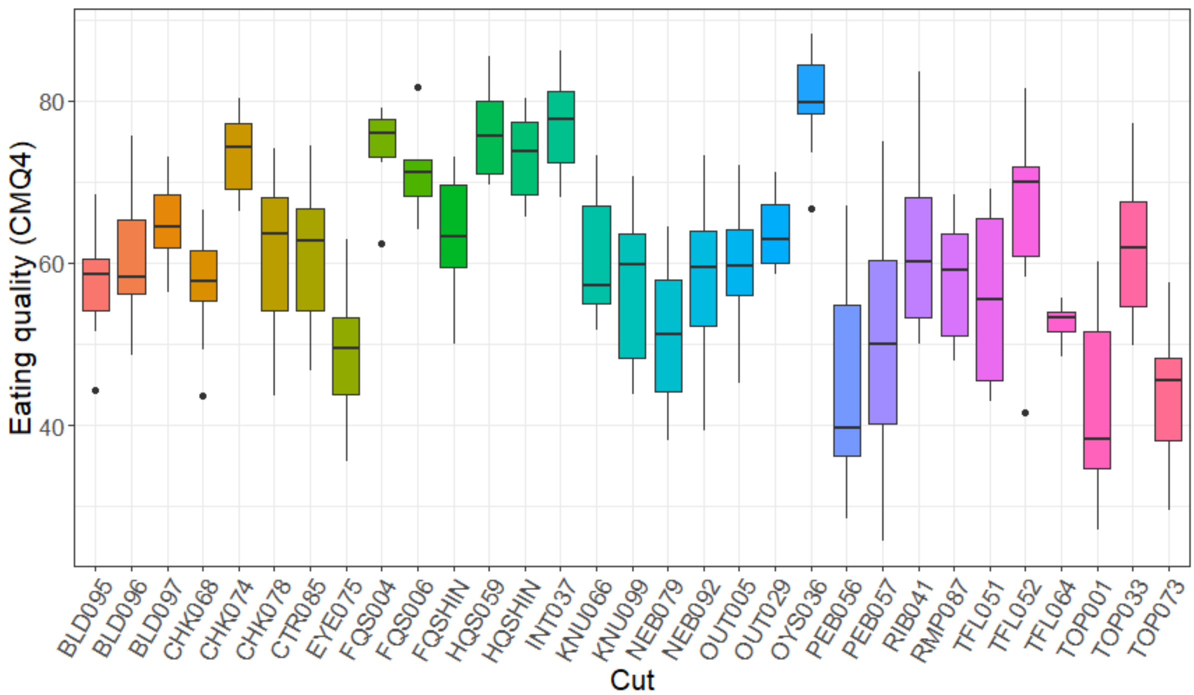
Cut	Prep	N	MQ4	Tenderness	Juiciness	Flavour	Overall
NEB079	**BQC** Mean (SD) Median [Min, Max]	(N=12)	59.4 (10.4) 57.4 [39.0, 75.5]	64.3 (11.4) 63.8 [44.5, 81.8]	50.0 (10.3) 48.3 [37.7, 69.7]	59.8 (10.4) 60.3 [38.5, 74.2]	58.4 (11.7) 56.3 [35.0, 78.5]
NEB092	**BQC** Mean (SD) Median [Min, Max]	(N=12)	68.2 (7.05) 68.5 [56.5, 77.4]	74.4 (9.08) 76.2 [55.3, 86.0]	61.9 (6.37) 60.9 [51.0, 73.8]	66.3 (7.36) 66.3 [56.7, 77.2]	67.2 (6.83) 67.0 [57.8, 75.3]
PEB056	**BQS** Mean (SD) Median [Min, Max]	(N=12)	57.6 (6.06) 57.4 [44.9, 67.6]	63.8 (12.2) 66.2 [42.0, 83.8]	38.0 (9.94) 37.2 [24.0, 56.0]	60.0 (6.82) 60.3 [45.3, 67.3]	56.1 (6.16) 55.8 [46.8, 66.5]
	BQC Mean (SD) Median [Min, Max]	(N=12)	58.7 (5.94) 57.9 [51.7, 70.0]	64.8 (8.97) 64.2 [51.0, 77.8]	39.3 (9.78) 37.6 [26.2, 56.7]	62.1 (6.86) 60.7 [52.0, 72.7]	57.8 (6.61) 57.8 [45.7, 70.0]
PEB057	**BQS** Mean (SD) Median [Min, Max]	(N=4)	75.3 (4.79) 77.5 [68.2, 78.2]	84.9 (4.28) 85.3 [80.2, 88.7]	71.9 (6.17) 70.1 [66.7, 80.8]	71.9 (4.95) 72.5 [65.3, 77.3]	73.7 (6.07) 75.4 [65.3, 78.7]
	BQC Mean (SD) Median [Min, Max]	(N=8)	67.8 (12.0) 68.6 [42.8, 81.2]	78.0 (13.1) 80.1 [55.0, 91.7]	65.6 (9.32) 66.8 [44.8, 74.2]	64.3 (12.2) 66.3 [38.8, 76.7]	66.4 (11.9) 67.9 [41.3, 81.0]

Further within animal comparisons were made between casserole (SC2) and Texas BBQ (TBQ) cooking with the SC2 MQ4 means lower for all 4 brisket muscles. This comparison included a within animal comparison of SC2 and TBQ, providing important data connection for modelling.

4.3.6 Slow cook samples

Box plots displaying the distribution of CMQ4 scores within each muscle tested are displayed in Fig. 17. Scores and median values are widely distributed with very clear differences between some cuts, the median oyster blade (OYS036) value exceeding the MSA 5* threshold and the topside adductor muscle (TOP001) and brisket plate (PEB056) medians below the MSA 3* threshold. The majority of muscles however are spread across the MSA 3* and 4* categories.

Figure 17. Box plot depiction of clipped MQ4 values of SC2 (slow cook) samples by muscle



Further detail of the individual sensory scales for each muscle and summary statistics are displayed in Table 13. It is noted that for all muscles the tenderness scale score exceeds each of the others, in most cases by at least 7 to 10 points or in the order of 10 to 20%.

These slow cook data also provided valuable information relating to ageing effects by muscle in addition to linkage to bull sex. Variation in SC2 results across a number of older MSA projects had created concern in statistical development of the V2.0 model. Acting on the side of caution, and consumer assurance, this had resulted in applying reduced ageing rates (50%) for SC2 cooked samples, despite the lack of an evident mechanism that could explain a cook x ageing impact.

Table 13. Summary statistics for sensory scales and CMQ4 scores by muscle for SC2 (slow cook) samples

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
BLD095	**(N=7)**					
Mean (SD)		57.2 (7.67)	67.1 (15.4)	50.8 (6.87)	55.0 (7.10)	54.0 (7.73)
Median [Min, Max]		58.6 [44.3, 68.4]	71.5 [40.7, 82.3]	47.8 [45.0, 65.2]	55.7 [44.8, 66.0]	52.8 [41.2, 66.3]
BLD096	**(N=7)**					
Mean (SD)		60.8 (8.75)	69.6 (5.13)	51.5 (11.1)	58.3 (9.42)	57.8 (9.33)
Median [Min, Max]		58.3 [48.6, 75.6]	68.3 [61.3, 76.3]	49.2 [35.3, 65.7]	58.7 [47.7, 76.2]	54.2 [47.3, 74.5]
BLD097	**(N=7)**					
Mean (SD)		64.9 (5.56)	71.5 (10.1)	61.0 (5.33)	62.7 (5.78)	63.3 (5.52)
Median [Min, Max]		64.4 [56.3, 73.2]	75.7 [56.8, 84.8]	58.5 [56.3, 70.2]	64.3 [54.7, 69.8]	63.7 [56.7, 72.3]
CHK068	**(N=14)**					
Mean (SD)		57.1 (6.00)	70.8 (5.21)	52.8 (8.15)	50.2 (8.20)	52.8 (6.91)
Median [Min, Max]		57.7 [43.6, 66.6]	71.9 [58.7, 76.8]	51.3 [39.8, 67.8]	50.6 [37.2, 61.7]	54.8 [43.5, 61.8]
CHK074	**(N=7)**					
Mean (SD)		73.3 (5.46)	86.4 (5.47)	76.7 (6.32)	67.4 (6.89)	69.5 (6.20)
Median [Min, Max]		74.2 [66.3, 80.2]	85.5 [79.8, 93.7]	78.2 [65.0, 86.0]	67.7 [56.7, 75.5]	72.7 [59.8, 75.7]
CHK078	**(N=7)**					
Mean (SD)		60.9 (11.2)	69.0 (13.3)	58.0 (8.43)	58.3 (10.4)	56.3 (11.7)
Median [Min, Max]		63.7 [43.7, 74.2]	68.7 [43.5, 84.2]	63.3 [47.0, 65.7]	56.2 [47.0, 72.0]	56.3 [39.2, 70.8]
CTR085	**(N=10)**					
Mean (SD)		61.1 (9.48)	73.7 (11.9)	58.3 (12.9)	55.7 (10.3)	58.4 (9.07)
Median [Min, Max]		62.7 [46.8, 74.5]	73.5 [53.8, 90.3]	55.8 [36.2, 77.3]	58.4 [41.5, 69.5]	61.8 [44.8, 71.5]
EYE075	**(N=13)**					
Mean (SD)		49.7 (8.11)	58.3 (11.1)	38.4 (10.0)	47.5 (7.74)	47.6 (8.15)
Median [Min, Max]		49.4 [35.6, 62.8]	58.8 [36.0, 77.2]	35.8 [25.0, 55.7]	45.3 [39.2, 63.8]	46.5 [32.3, 62.0]
FQS004	**(N=6)**					
Mean (SD)		74.0 (6.12)	81.7 (5.82)	74.1 (7.83)	68.9 (7.35)	69.9 (6.58)
Median [Min, Max]		76.0 [62.5, 79.1]	82.3 [71.2, 88.5]	75.9 [61.7, 83.0]	69.8 [57.0, 77.7]	72.6 [57.5, 74.8]
FQS006	**(N=5)**					
Mean (SD)		71.6 (6.51)	77.0 (5.64)	68.3 (7.07)	69.4 (5.68)	69.9 (8.22)
Median [Min, Max]		71.3 [64.1, 81.6]	75.2 [72.3, 86.2]	67.3 [58.3, 76.7]	68.3 [64.2, 78.7]	72.3 [59.7, 80.7]
FQSHIN	**(N=6)**					
Mean (SD)		63.3 (8.52)	74.4 (8.31)	63.8 (7.92)	56.9 (8.79)	59.8 (9.87)
Median [Min, Max]		63.3 [50.1, 73.2]	76.1 [61.3, 84.3]	62.4 [54.0, 74.0]	58.1 [42.7, 66.8]	61.8 [45.5, 70.8]
HQS059	**(N=8)**					
Mean (SD)		75.9 (5.81)	84.4 (6.02)	75.4 (4.85)	70.7 (9.40)	73.1 (7.85)
Median [Min, Max]		75.7 [69.6, 85.4]	83.6 [75.3, 94.2]	74.9 [68.2, 82.3]	70.8 [57.3, 83.7]	73.4 [64.0, 85.0]
HQSHIN	**(N=6)**					
Mean (SD)		73.1 (5.87)	79.4 (5.47)	73.5 (7.47)	69.8 (4.58)	71.8 (7.02)
Median [Min, Max]		73.7 [65.7, 80.2]	81.0 [71.5, 85.0]	73.5 [63.0, 81.8]	69.8 [64.5, 75.2]	69.5 [64.2, 82.7]
INT037	**(N=16)**					
Mean (SD)		77.1 (5.73)	83.4 (4.18)	77.5 (6.96)	73.0 (7.24)	77.1 (6.69)
Median [Min, Max]		77.8 [68.2, 86.2]	84.2 [76.2, 90.8]	79.0 [62.2, 87.2]	74.1 [60.5, 87.5]	77.9 [68.2, 88.0]
KNU066	**(N=7)**					
Mean (SD)		60.9 (8.13)	71.9 (11.6)	50.5 (13.3)	56.3 (7.31)	58.4 (7.34)
Median [Min, Max]		57.3 [51.8, 73.2]	72.5 [50.5, 82.5]	52.5 [32.8, 69.5]	56.7 [46.8, 68.3]	56.3 [49.8, 70.2]
KNU099	**(N=9)**					
Mean (SD)		57.0 (10.3)	67.1 (11.3)	42.0 (9.64)	55.5 (9.85)	54.5 (11.1)
Median [Min, Max]		59.9 [43.9, 70.7]	71.7 [52.2, 79.7]	44.2 [28.0, 56.2]	52.3 [41.8, 70.7]	52.8 [40.2, 68.8]
NEB079	**(N=17)**					
Mean (SD)		50.5 (8.84)	59.1 (11.1)	51.5 (9.48)	45.9 (10.5)	47.4 (9.13)
Median [Min, Max]		51.1 [38.2, 64.5]	58.0 [42.5, 76.2]	51.7 [37.0, 66.0]	44.8 [28.0, 60.5]	46.7 [34.0, 60.8]
NEB092	**(N=18)**					
Mean (SD)		58.0 (8.40)	64.1 (9.44)	61.4 (7.02)	53.7 (9.85)	54.7 (8.72)
Median [Min, Max]		59.4 [39.4, 73.3]	65.4 [43.2, 77.7]	61.8 [45.5, 73.5]	54.6 [33.2, 71.0]	56.6 [36.3, 71.5]
OUT005	**(N=14)**					
Mean (SD)		59.2 (7.95)	73.6 (6.62)	41.7 (12.9)	55.4 (9.60)	54.6 (9.74)
Median [Min, Max]		59.6 [45.2, 72.0]	73.3 [61.2, 80.8]	42.0 [18.5, 68.7]	53.6 [35.8, 67.8]	56.1 [38.0, 70.5]

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
OUT029						
Mean (SD)	**(N=7)**	63.9 (5.18)	72.1 (5.36)	55.4 (5.80)	60.9 (7.32)	62.1 (5.65)
Median [Min, Max]		62.9 [58.7, 71.2]	73.2 [62.5, 77.3]	57.7 [48.0, 62.8]	58.3 [52.7, 70.7]	59.8 [57.3, 71.2]
OYS036						
Mean (SD)	**(N=15)**	80.3 (5.76)	88.1 (5.27)	80.6 (6.37)	75.0 (6.99)	79.4 (6.61)
Median [Min, Max]		79.8 [66.7, 88.2]	88.2 [74.8, 94.3]	82.0 [68.8, 90.0]	76.5 [62.0, 85.0]	79.3 [65.0, 88.0]
PEB056						
Mean (SD)	**(N=18)**	44.6 (11.8)	53.0 (13.9)	34.8 (11.8)	41.7 (13.7)	43.4 (12.1)
Median [Min, Max]		39.7 [28.5, 67.1]	51.5 [29.0, 79.3]	34.0 [18.2, 65.3]	37.8 [21.3, 63.5]	41.3 [24.0, 65.2]
PEB057						
Mean (SD)	**(N=18)**	50.5 (15.3)	55.0 (21.2)	47.5 (15.4)	48.0 (13.0)	48.7 (14.8)
Median [Min, Max]		50.1 [25.7, 74.9]	58.1 [19.3, 84.8]	51.2 [23.2, 74.2]	46.9 [23.0, 70.0]	47.3 [22.0, 74.0]
RIB041						
Mean (SD)	**(N=22)**	62.3 (10.2)	70.7 (11.1)	60.9 (12.3)	58.4 (11.1)	59.9 (11.2)
Median [Min, Max]		60.1 [50.0, 83.5]	70.5 [53.3, 94.2]	59.8 [36.0, 82.7]	58.8 [41.8, 83.2]	59.2 [46.7, 84.2]
RMP087						
Mean (SD)	**(N=11)**	58.1 (7.07)	64.1 (9.72)	51.1 (7.92)	56.3 (5.72)	56.5 (5.96)
Median [Min, Max]		59.1 [47.9, 68.4]	65.5 [49.5, 75.5]	50.8 [38.3, 63.5]	57.5 [44.5, 63.7]	56.5 [48.0, 66.0]
TFL051						
Mean (SD)	**(N=6)**	55.7 (11.5)	62.8 (14.1)	53.4 (10.9)	50.6 (12.4)	53.7 (11.4)
Median [Min, Max]		55.5 [42.9, 69.1]	66.1 [45.3, 76.7]	56.3 [37.5, 67.0]	45.7 [38.8, 67.2]	51.3 [42.0, 68.0]
TFL052						
Mean (SD)	**(N=6)**	65.6 (13.9)	69.8 (19.3)	68.4 (14.7)	62.6 (11.7)	64.0 (14.0)
Median [Min, Max]		70.1 [41.6, 81.5]	78.7 [40.2, 88.3]	72.0 [40.3, 82.3]	63.3 [42.5, 78.7]	66.7 [38.3, 79.7]
TFL064						
Mean (SD)	**(N=6)**	52.6 (2.51)	52.7 (9.01)	46.9 (6.17)	55.8 (5.32)	51.6 (2.96)
Median [Min, Max]		53.3 [48.5, 55.6]	54.1 [38.7, 61.5]	46.3 [39.7, 55.2]	57.3 [47.0, 61.2]	51.0 [47.2, 55.2]
TOP001						
Mean (SD)	**(N=9)**	43.2 (11.2)	52.3 (16.9)	33.5 (9.43)	41.9 (11.0)	39.6 (10.7)
Median [Min, Max]		38.3 [27.1, 60.1]	51.0 [24.5, 76.5]	32.7 [22.0, 52.3]	47.0 [25.3, 54.2]	36.2 [22.5, 54.0]
TOP033						
Mean (SD)	**(N=9)**	62.4 (9.95)	75.4 (8.23)	59.5 (11.5)	57.2 (11.3)	58.2 (11.6)
Median [Min, Max]		62.0 [49.9, 77.1]	78.5 [61.8, 84.5]	56.8 [48.0, 79.0]	53.2 [42.7, 76.2]	59.3 [45.2, 77.2]
TOP073						
Mean (SD)	**(N=18)**	44.1 (7.85)	53.3 (11.3)	31.0 (8.70)	43.0 (8.28)	40.6 (8.55)
Median [Min, Max]		45.6 [29.6, 57.6]	51.1 [37.8, 74.7]	28.3 [16.3, 46.7]	44.8 [29.5, 57.0]	42.8 [26.7, 56.2]

4.3.7 Roast samples

Table 14 displays summary statistics for each sensory scale and MQ4 values of consumer tested supplementary roast samples. While numbers are too low for any definitive discussion it is noted that the tenderness score exceeds the flavour score for higher quality muscles whereas the reverse is noted for those in the lower quality category.

Table 14. Summary statistics for sensory scales and CMQ4 scores by muscle for RST (roast) samples

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
BLD096						
Mean (SD)	**(N=2)**	40.6 (9.16)	34.6 (15.7)	45.3 (3.18)	42.7 (4.71)	41.7 (7.78)
Median [Min, Max]		40.6 [34.2, 47.1]	34.6 [23.5, 45.7]	45.3 [43.0, 47.5]	42.7 [39.3, 46.0]	41.7 [36.2, 47.2]
CHK078						
Mean (SD)	**(N=1)**	43.7 (NA)	34.0 (NA)	43.3 (NA)	49.5 (NA)	47.2 (NA)
Median [Min, Max]		43.7 [43.7, 43.7]	34.0 [34.0, 34.0]	43.3 [43.3, 43.3]	49.5 [49.5, 49.5]	47.2 [47.2, 47.2]
CTR085						
Mean (SD)	**(N=1)**	41.3 (NA)	44.2 (NA)	43.8 (NA)	49.5 (NA)	40.3 (NA)
Median [Min, Max]		41.3 [41.3, 41.3]	44.2 [44.2, 44.2]	43.8 [43.8, 43.8]	49.5 [49.5, 49.5]	40.3 [40.3, 40.3]
CUB081						
Mean (SD)	**(N=1)**	62.5 (NA)	70.3 (NA)	60.5 (NA)	56.8 (NA)	60.5 (NA)
Median [Min, Max]		62.5 [62.5, 62.5]	70.3 [70.3, 70.3]	60.5 [60.5, 60.5]	56.8 [56.8, 56.8]	60.5 [60.5, 60.5]
EYE075						
Mean (SD)	**(N=2)**	51.8 (16.4)	53.5 (19.1)	51.3 (8.25)	55.1 (16.9)	49.8 (18.4)
Median [Min, Max]		51.8 [40.2, 63.3]	53.5 [40.0, 67.0]	51.3 [45.5, 57.2]	55.1 [43.2, 67.0]	49.8 [36.8, 62.8]
KNU066						
Mean (SD)	**(N=1)**	50.1 (NA)	49.2 (NA)	48.0 (NA)	52.2 (NA)	54.5 (NA)
Median [Min, Max]		50.1 [50.1, 50.1]	49.2 [49.2, 49.2]	48.0 [48.0, 48.0]	52.2 [52.2, 52.2]	54.5 [54.5, 54.5]
KNU099						
Mean (SD)	**(N=2)**	50.3 (18.0)	43.2 (14.8)	54.7 (24.0)	55.5 (16.5)	50.7 (21.9)
Median [Min, Max]		50.3 [37.6, 63.0]	43.2 [32.7, 53.7]	54.7 [37.7, 71.7]	55.5 [43.8, 67.2]	50.7 [35.2, 66.2]
OUT005						
Mean (SD)	**(N=2)**	25.7 (13.3)	21.3 (10.8)	26.6 (11.9)	28.9 (13.1)	27.1 (18.5)
Median [Min, Max]		25.7 [16.3, 35.1]	21.3 [13.7, 29.0]	26.6 [18.2, 35.0]	28.9 [19.7, 38.2]	27.1 [14.0, 40.2]
RMP005						
Mean (SD)	**(N=1)**	59.2 (NA)	65.8 (NA)	69.5 (NA)	50.7 (NA)	63.0 (NA)
Median [Min, Max]		59.2 [59.2, 59.2]	65.8 [65.8, 65.8]	69.5 [69.5, 69.5]	50.7 [50.7, 50.7]	63.0 [63.0, 63.0]
RMP087						
Mean (SD)	**(N=1)**	45.7 (NA)	37.8 (NA)	48.7 (NA)	54.8 (NA)	45.0 (NA)
Median [Min, Max]		45.7 [45.7, 45.7]	37.8 [37.8, 37.8]	48.7 [48.7, 48.7]	54.8 [54.8, 54.8]	45.0 [45.0, 45.0]
RMP131						
Mean (SD)	**(N=1)**	68.4 (NA)	69.7 (NA)	72.5 (NA)	63.7 (NA)	69.3 (NA)
Median [Min, Max]		68.4 [68.4, 68.4]	69.7 [69.7, 69.7]	72.5 [72.5, 72.5]	63.7 [63.7, 63.7]	69.3 [69.3, 69.3]
RMP231						
Mean (SD)	**(N=1)**	68.1 (NA)	79.8 (NA)	59.3 (NA)	68.7 (NA)	63.8 (NA)
Median [Min, Max]		68.1 [68.1, 68.1]	79.8 [79.8, 79.8]	59.3 [59.3, 59.3]	68.7 [68.7, 68.7]	63.8 [63.8, 63.8]
TDR034						
Mean (SD)	**(N=1)**	79.7 (NA)	82.3 (NA)	71.5 (NA)	78.2 (NA)	79.7 (NA)
Median [Min, Max]		79.7 [79.7, 79.7]	82.3 [82.3, 82.3]	71.5 [71.5, 71.5]	78.2 [78.2, 78.2]	79.7 [79.7, 79.7]
TDR062						
Mean (SD)	**(N=2)**	72.6 (3.94)	79.3 (7.07)	69.5 (1.41)	69.3 (8.37)	73.2 (6.13)
Median [Min, Max]		72.6 [69.8, 75.4]	79.3 [74.3, 84.3]	69.5 [68.5, 70.5]	69.3 [63.3, 75.2]	73.2 [68.8, 77.5]
TOP073						
Mean (SD)	**(N=2)**	31.4 (15.5)	22.8 (19.8)	37.2 (15.6)	35.3 (11.4)	34.3 (17.6)
Median [Min, Max]		31.4 [20.5, 42.4]	22.8 [8.83, 36.8]	37.2 [26.2, 48.2]	35.3 [27.2, 43.3]	34.3 [21.8, 46.7]

4.3.8 Sous-vide samples

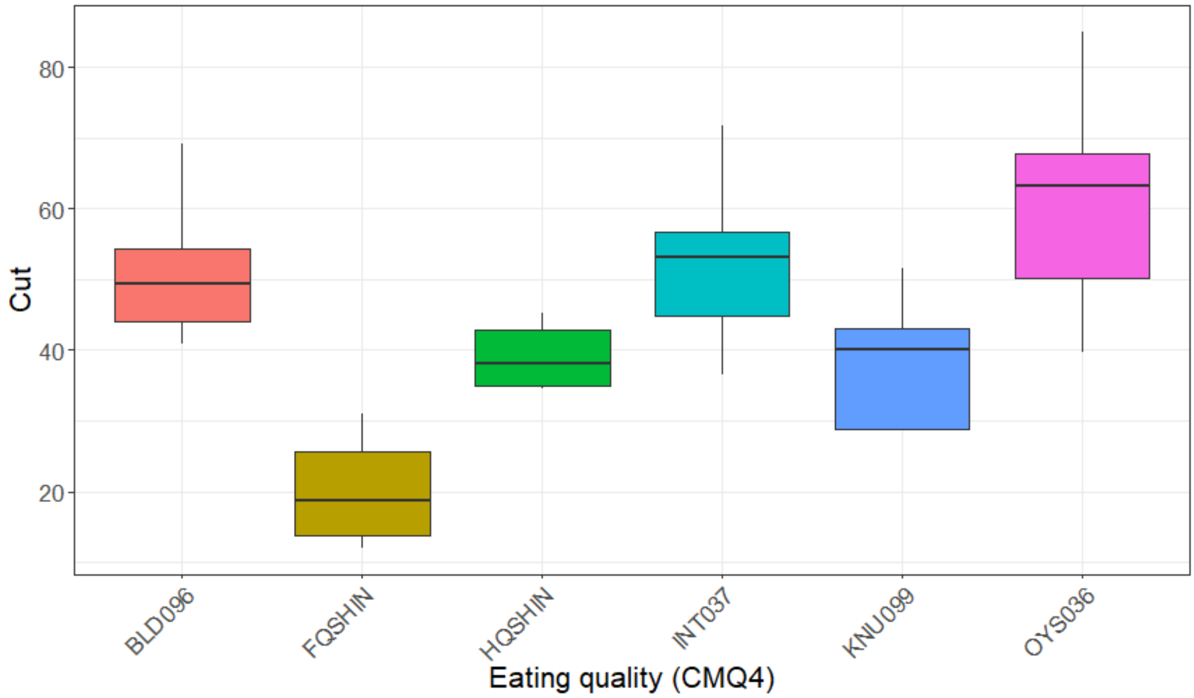
MSA sensory testing has commenced evaluation of sous-vide (SVD) cooking as an alternative to the SC2 (slow cook or casserole) method and separately for GRL (grill) cooking. This reflects the need to better understand and define commercial cooking system outcomes beyond those applicable to household kitchens. As described further in the methodology section the MSA developed SVD protocol specifies 3 hours of cooking in a vacuum bag of 22 cubes for 3 hours in a water bath at

62.5˚C following which the bags are drained and 300 ml of hot broth added to the cooked cubes. This differs from the SC2 protocol in that the 22 cubes (of identical size) are not browned and the hot broth is added after cooking.

In all case SVD samples were paired with SC2 for the same cuts within animal and evaluated within common consumer sessions with both SC2 and SVD samples able to be served after warming in the bain-maries.

Fig. 18 displays the sous-vide sample CMQ4 score distributions for each cut tested from this young bull project. The box plots display moderate score range with considerable separation between muscles. While the hind quarter shin (HQShin) is superior to the fore quarter (FQShin) both shins and the knuckle cover (KNU099) have median scores below the MSA 3* threshold of 46. The BLD096 muscle from the bolar blade and the intercostals medians are within the MSA 3* category with the oyster blade (OYS036) just below MSA 4*.

Figure 18. Box plot depiction of clipped MQ4 values of SVD (sous-vide) samples by muscle



More detailed statistics including all 4 sensory scales plus CMQ4 are presented for each muscle in Table 15. In contrast to the SC2 results for the same muscles the sensory scale values are similar rather than dominated by the tenderness scale. For these samples the SVD values are lower than the SC2 by around 5 MQ4 points for all bar the both hind and forequarter shins which are massively and significantly lower.

It should be noted that these observations are on very low sample numbers and need to be aggregated with substantially more data from complementary projects to arrive at any reliable conclusion regarding SVD to SC2 comparisons.

Table 15. Summary statistics for sensory scales and CMQ4 scores by muscle for SVD (sous-vide) samples

Cut	N	MQ4	Tenderness	Juiciness	Flavour	Overall
BLD096						
Mean (SD)	**(N=7)**	50.9 (9.95)	51.5 (11.5)	47.7 (12.4)	52.5 (9.05)	49.4 (10.3)
Median [Min, Max]		49.4 [41.0, 69.2]	52.5 [32.0, 65.7]	47.2 [34.0, 70.5]	50.0 [40.7, 69.7]	46.8 [37.0, 68.8]
FQSHIN						
Mean (SD)	**(N=6)**	20.1 (7.90)	14.4 (7.18)	24.5 (8.95)	23.6 (9.64)	17.6 (9.39)
Median [Min, Max]		18.8 [12.0, 30.9]	12.7 [8.00, 25.0]	23.3 [16.3, 41.2]	22.8 [10.7, 37.3]	14.8 [8.67, 29.0]
HQSHIN						
Mean (SD)	**(N=6)**	39.1 (4.74)	39.3 (7.23)	40.5 (5.44)	38.7 (4.55)	38.3 (5.72)
Median [Min, Max]		38.2 [34.5, 45.2]	36.5 [31.7, 49.0]	40.4 [34.2, 48.7]	39.3 [32.5, 42.8]	38.3 [32.0, 44.3]
INT037						
Mean (SD)	**(N=11)**	52.7 (10.5)	57.5 (12.5)	57.7 (12.9)	49.5 (9.60)	50.1 (12.0)
Median [Min, Max]		53.2 [36.6, 71.7]	58.2 [39.0, 77.2]	59.5 [36.7, 72.5]	49.7 [35.2, 69.7]	50.7 [33.3, 68.0]
KNU099						
Mean (SD)	**(N=9)**	38.6 (8.42)	33.1 (9.08)	34.6 (8.79)	43.1 (8.42)	39.5 (9.22)
Median [Min, Max]		40.2 [28.7, 51.5]	34.7 [19.5, 44.3]	32.8 [23.2, 48.2]	47.0 [33.0, 56.0]	40.5 [27.8, 54.0]
OYS036						
Mean (SD)	**(N=14)**	59.9 (13.2)	66.5 (15.9)	61.4 (14.0)	55.7 (12.4)	58.1 (13.0)
Median [Min, Max]		63.2 [39.7, 85.1]	69.2 [38.8, 92.3]	60.9 [35.7, 83.3]	56.5 [35.5, 82.0]	61.1 [36.7, 82.7]

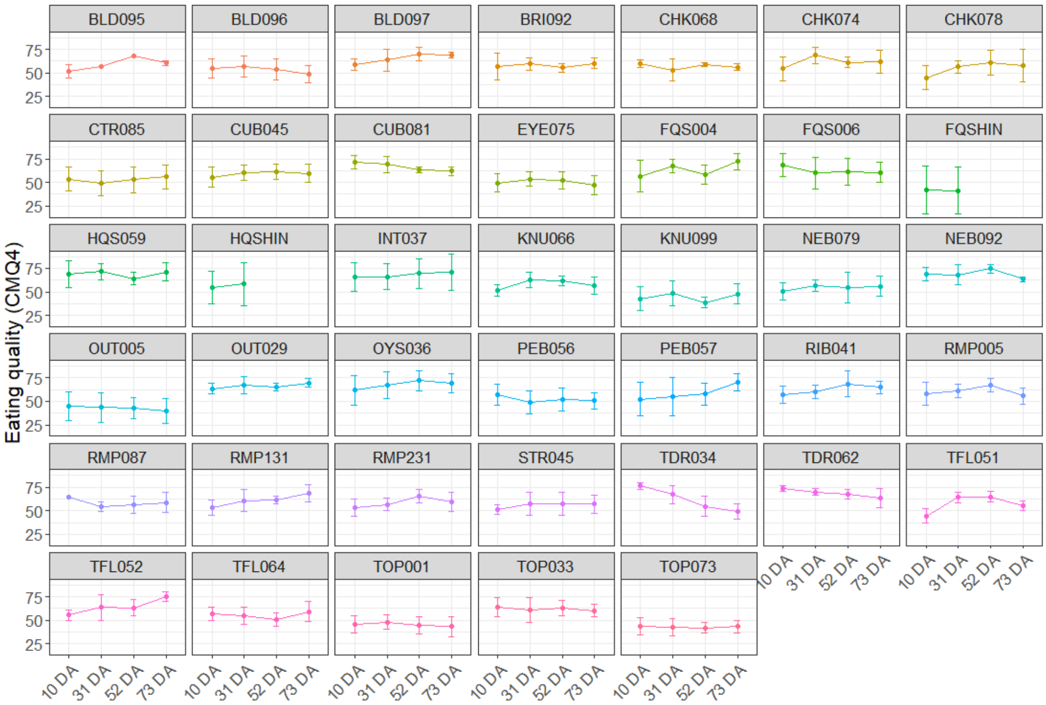
4.3.9 Ageing rates

All muscles were evaluated at multiple ageing periods to establish if bull sex might interact with ageing or muscle x ageing and further to pool with extensive data from other projects to inform ageing estimates in the MSA model, an objective being to build ageing curves beyond the current model limits of 40 days for tenderloin and 50 days for all other muscles. Samples were aged variously for 10, 31, 52 or 73 days after slaughter date. The number of ageing comparisons within animal for each muscle varied with size, with all compared for larger muscles and as few as 2, one from each side, for small muscles.

Importantly no cook x ageing interaction was found in these data which included substantial numbers of SC2 samples across 10 to 73 day ageing periods from a large number of muscles. This has important implications for MSA V2.0 model revision. A mentioned previously the current version has SC2 ageing restricted to 50% of the values applied to other cooking methods on the basis of conflicting existing, and predominantly older, data. The additional data will inform a review of SC2 ageing in the next model revision.

Fig. 19 displays ageing curves with error bars for all muscles tested from 10 to 73 days. As established by prior MSA data there were muscle interactions with ageing. MQ4 was not increased with ageing for the TDR034, TDR062 and CUB081 muscles and in fact tended to decline, whereas the CUB045, STR045, RMP131 and TFL052 increased. Other muscles initially improved and then declined. These observations need to be aggregated with more extensive data for accurate prediction but do establish that ageing varies widely across muscles in young bulls, as has been observed in steer and heifer cuts.

Figure 19. CMQ4 values and ageing curves by muscle from 10 to 73 days post-mortem



4.3.10 Statistical modelling and MQ4 prediction

Linear mixed-effect models were run to determine whether cook, days aged and cut were correlated with sensory CMQ4. A larger model was run first, considering all possible two-way interactions with carcase number as the random effect. All insignificant interactions were dropped and resulted in the following final model:

*cmq4 ~ cook * cut + d_aged * cut + (carcase_no)*

An analysis of deviance table is show below with the significant fixed effects (Table 16). There was no significant interaction between cook and days aged meaning that the ageing rate was similar across all cook types. It is important to note that whilst there are some significant findings, the number of samples becomes quite small when approaching a days aged level within cook and cut and therefore further investigation is needed for more definitive results.

Table 16. Analysis of deviance table for the final model predicting sensory clipped MQ4 (cmq4 ~ cook * cut + d_aged * cut + (carcase_no)

Attribute	Chisq	Df	Pr(>Chisq)
cook	317.149	5	< 2.2e-16 ***
cut	964.121	38	< 2.2e-16 ***
days aged	18.301	3	0.0003813 ***
cut*cook	167.553	41	< 2.2e-16 ***
cut*days aged	181.019	110	2.34e-05 ***

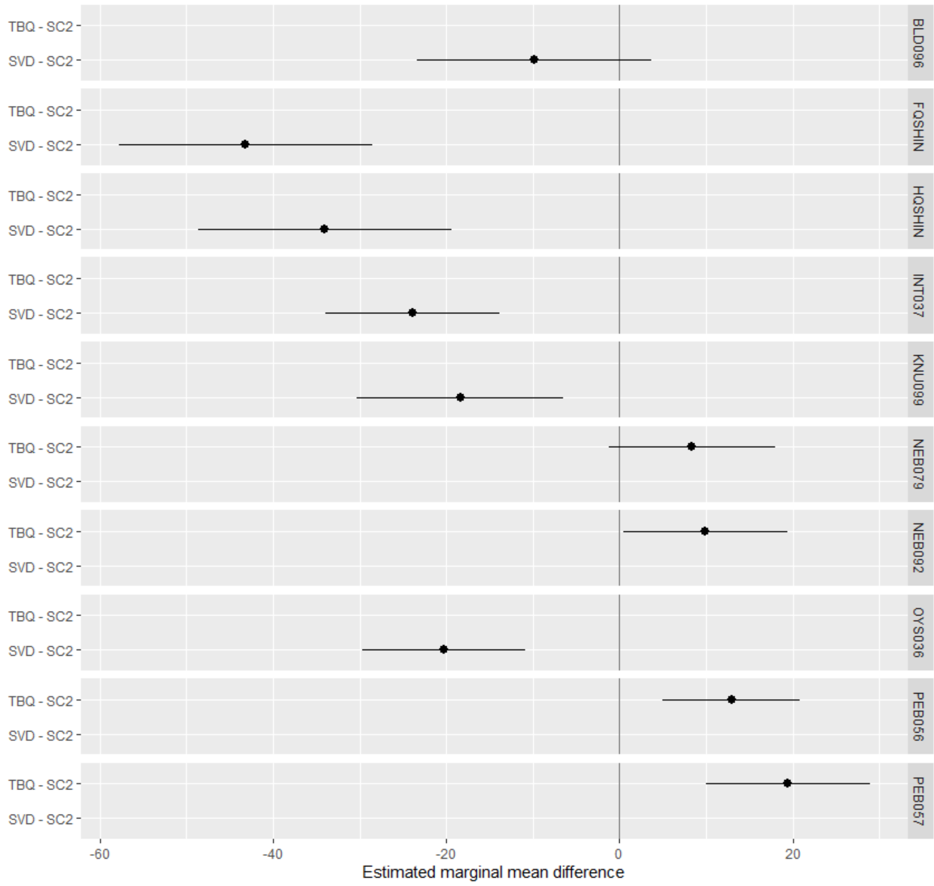
To determine the difference between cook types several pairwise comparisons within cut were performed (Table 17, Fig. 20). Of particular interest was the difference between slow cook and sous-vide and slow cook and Texas BBQ. In almost all cases except the BLD096 sous-vide samples had a significantly lower estimated mean than their slow cooked pair. Shin samples were considerably worse when cooked as sous-vide, losing up to 43 points in the case of the forequarter shin.

There was also a significant difference between Texas BBQ and slow cook estimated means in all cuts except NEB079. The Texas BBQ cook type is not in the MSA V2 model and results show that it is significantly better than its slow cook counterpart. It is recommended that Texas BBQ be added as a new cook type to the MSA model and that the current and complementary data from other MSA projects be used to develop the prediction for each brisket muscle and serving form.

Table 17. Pairwise comparison of the estimated marginal means by cut and the different cook types (Slow cook, Sous-vide and Texas BBQ)

contrast	estimate	SE	df	t.ratio	p.value
BLD096					
SVD - SC2	-9.9	4.59	784.1	-2.15	0.478
FQSHIN					
SVD - SC2	-43.2	4.96	784.1	-8.71	**<0.001**
HQSHIN					
SVD - SC2	-34	4.96	784.1	-6.85	**<0.001**
INT037					
SVD - SC2	-23.8	3.41	785.3	-6.99	**<0.001**
KNU099					
SVD - SC2	-18.4	4.05	784.1	-4.54	**<0.001**
OYS036					
SVD - SC2	-20.3	3.2	784.3	-6.33	**<0.001**
NEB079					
TBQ - SC2	8.4	3.26	785.9	2.56	0.159
NEB092					
TBQ - SC2	9.9	3.22	785.7	3.07	**0.033**
PEB056					
TBQ - SC2	12.9	2.7	786.4	4.78	**<0.001**
PEB057					
TBQ - SC2	19.4	3.22	785.7	6.03	**<0.001**

Figure 20. Estimated marginal mean difference between selected cook types

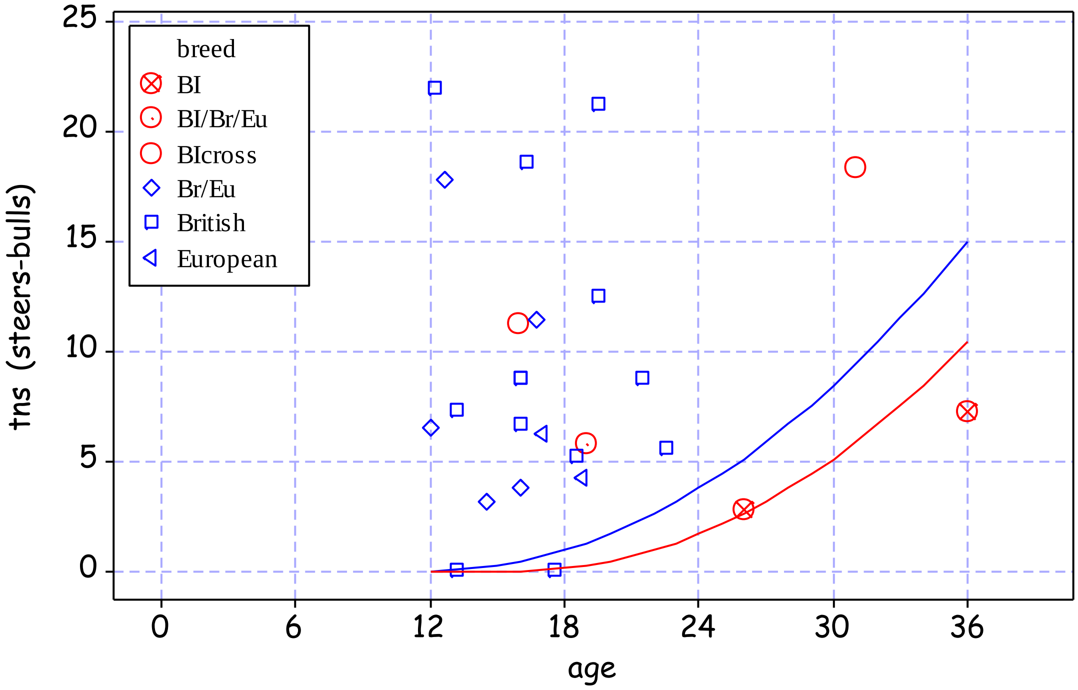


4.3.11 Bull prediction by draft MSA V2.0 procedure

In development of the MSA V2.0 prediction model Professor Ray Watson evaluated then available MSA protocol data from bulls. These data were sparse and drawn from two cuts collected from young high *bos-indicus* content bulls from northern Queensland and further data from Polish studies that included bulls and heifers, but no steers. A literature review was also conducted of studies that included bulls and sensory or shear force data and prospective relationships considered. From these data a draft bull prediction procedure was developed that included a "bull adjustment" related to ossification, carcase weight and hump height that prospectively could adjust for the degree of characteristic bull phenotype to account for a proposed increased effect related to increasing age and maturity. (While a castrated and entire calf might have near identical phenotype, and potentially eating quality, at 4 months of age, the same animals would differ greatly at 4 years of age, and in fact at 2 years or less). It was also established that *bos-indicus* cattle matured at a slower rate than British breeds as reflected by ossification scores. Fig 21 displays a plot produced by Dr Watson illustrating literature and data points relative to tenderness differences of steers and bulls for British and *bos-indicus* cattle at different age.

This procedure was not included in the final production model version as judged to have insufficient supporting data. The current project more than tripled the available bull data including additional muscles and cooking methods and contrasting dairy breed.

Figure 21. Suggested application of a bull penalty related to age for *bos-indicus* and British breeds



The data from the current project were evaluated utilising the draft procedure and compared to the observed consumer MQ4 values for all cut x cook combinations within the V2.0 model (Appendix 8.2). A number of combinations, and notably the TBQ cook method, in the current project were not included in the V2.0 version.

The predicted results for the grill cooking methods are particularly impressive, the more so for lack of original data with the slow cook (SC2) and stir fry estimates mostly lower than observed and more erratic. The underestimation of the SC2 is likely to be strongly influenced by ageing estimates which were set to 50% in the V2.0 model for SC2 as a conservative approach due to original data variance. The current data provides substantial SC2 data designed to clarify the SC2 estimates and ageing interaction. Given no cook x ageing effect was evident in these data it is likely that an ageing adjustment will be added to a revised version, at least in part moving the bull SC2 estimates closer.

The addition of the extensive bull data from this project in combination with the existing base will allow the bull prediction estimates to be further developed and it is anticipated that this will allow incorporation of bull in the next V2.0 revision. Although further data from an older age (15 to 18 months) cohort would provide further insurance.

5. Conclusion

The project achieved the primary goal of generating extensive data for 39 muscles collected from both sides of 18 young bull carcases. A total of 6 cooking methods were utilised with all muscles other than the CUB045 and STR045 (*M.longissimus dorsi)* tested by either 2 or 3 alternatives. These linkages were important in developing data comparisons between the slow cook/casserole (SC2), Texas BBQ (TBQ) and sous-vide (SVD) cooking methods. Ageing periods of 10, 31, 52 and 73 days were also tested within all muscles and cook types, with particular relevance to further examining potential ageing interaction with SC2.

These data provide valuable additional data for MSA prediction model development and in particular the addition of bull sex, the TBQ cooking method and ageing beyond 50 days. These model additions can extend the range of cattle eligible for MSA grading without compromising accuracy. The addition of young bulls also provides alternative production approaches that may compensate for removal of HGP implantation or castration, should these be desired for market access or welfare reasons. Development of higher pricing for young bull derived beef, substantiated by MSA grading and potentially related branding, may also encourage the raising and fattening of male dairy calves now either slaughtered as bobby veal or euthanised at birth.

5.1 Key findings

The primary project objective was data generation for pooling with other MSA data to further develop the MSA V2.0 prediction model. To this end data collected included:

- Novel data on pH declines related to electrical stunning.
- Sensory data on 39 muscles derived from young bulls cooked by 1 to 3 of 6 cooking methods adding substantially to existing MSA research data.
- Sensory data relating to novel circumstances of very low rib fat in conjunction with slow chilling rates.
- Within muscle and animal paired comparison of slow cook (SC2) with Texas BBQ (TBQ) and sous-vide (SVD) cooking methods.
- Muscle related sensory data for ageing periods of 10, 31, 52 and 73 days post slaughter.
- Cooking method related sensory data for ageing periods to 73 days of particular relevance to slow cooking.
- Extensive data to enable modelling of consumer MQ4 values for a large array of cut*cook combinations derived from young bull carcases.

Findings included:

Draft bull model algorithms produced reasonable estimates across muscles, particularly for grills.

- The TBQ cooking method provided outstanding potential to increase consumer value through a superior eating experience from brisket muscles.
- Sous-vide cooking did not increase scores and was detrimental for both FQ and HQ shin.
- Observed SC2 values typically exceeded draft model estimates which, while confounded with bull sex, indicated that ageing rates currently restricted for SC2, may need to be modified toward other cook method estimates.
- Ageing rates and curves were shown to interact with muscle, supporting the current MSA approach of individual muscle estimates.
- For some high value muscles eating quality deteriorated with ageing (tenderloin and spinalis) whereas as others increased and plateaued whilst further muscles increased for a period after which they declined.
- This indicated that an ageing decline curve may be required in addition to the curbed incline adapted within current estimates which could be an important outcome for export product.

5.2 Benefits to industry

The project provides several benefits to industry. Within the primary objective these data may assist towards a pathway for young bulls being eligible for MSA grading. In addition to broadening cattle supply alternatives young bull eligibility will enable eating quality guaranteed bull sourced supply to Muslim or other markets that prefer bull for cultural or religious reasons. Further, young bull production provides a safeguard against any regulatory or market pressures to remove HGP use or to ban, severely restrict or add unacceptable cost for castration. Development of higher pricing for young bull derived beef, substantiated by MSA grading and potentially related branding, may also encourage the raising and fattening of male dairy calves now either slaughtered as bobby veal or euthanised at birth.

Further benefit to industry is provided by introduction of Texas BBQ cooking for brisket muscles creating significant eating quality and related consumer value enhancement.

Additional data on extended ageing periods and individual muscle relationships can also inform optimum ageing practice with particular relevance to export shipments.

5.3 Acknowledgements

The collaboration of the Central Agri group and Mr Colin Reidy in sourcing the cattle and adapting boning room practice to enable accurate cut collection is gratefully acknowledged. The extensive contribution of CSU and UNE staff and students in conducting all subsequent operations from cutup to sensory testing, often under time and or COVID pressured conditions is also greatly appreciated. Lastly, but by no means least, the outstanding statistical foundation developed by Dr Ray Watson for a proposed bull model adjustment within the MSA V2.0 model prediction is acknowledged.

6. Future research and recommendations

Further research arising from the current project findings is recommended in the following areas:

1. In combination with existing data further study of extended ageing periods across muscles in conjunction with variation in ageing temperatures and alternative packaging to establish more precise recommended muscle specific practices.
2. Controlled study of different chilling regimes and pH decline interactions from knock to rigor mortis in conjunction with differing fat cover with particular reference to low coverage. This may have implications for optimal protocol for veal and other young lean carcase beef.
3. It is recommended that principal cuts from a further cohort of young bulls of heavier carcase weight be evaluated to confirm MQ4 prediction accuracy within a typical UK / Irish regime of 15-month-old bulls with carcase weights of around 300kg.

7. References

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Polkinghorne, (2020). BeefQ project report

8. Appendix

8.1 MSA consumer questionnaire

TPB TPB

Thank you for your participation today with our meat tasting

Our team is here to help you during your session and make this easy for you.

Before you start please listen to the instructions on how to use the scales contained in this questionnaire

Please use a black pen to fill in the form and where asked:

write crosses in boxes like this........... ☒

mark on the line scale like this... Not Juicy — Very Juicy

In between each sample please cleanse your palate by:

* first......... taking a sip of diluted apple juice
* then.......... chew a piece of bread
* and then..........take another sip of diluted apple juice

We are after YOUR opinion and therefore ask that you do not talk to anyone else in the room during the research session.

Now just a few questions about yourself (All this information is strictly confidential)

Date ☐☐☐☐☐☐

Your Group's Name ____________________

1. Please write in the boxes the postcode you normally live in ☐☐☐☐

2. Age Group: *(Use **X** in one box only)*

18,19 ☐ 20-25 ☐ 26-30 ☐ 31-39 ☐ 40-60 ☐ 61-70 ☐

3. Gender: *(Use **X** in one box only)*

Male ☐ Female ☐

4. What is the occupation of the main income earner in your household?:

*(Use **X** in one box only)*

☐ Manager
☐ Professionals (includes health professional etc.)
☐ Technicians and Trade Workers
☐ Community and Personal Services Workers
☐ Clerical and Administrative workers
☐ Sales Workers (includes retail sales etc.)
☐ Machinery operators and Drivers
☐ Labourers
☐ Home Duties
☐ Student
☐ Other

TPB TPB

TPB TPB

Please use a black pen to fill in the form and write crosses in boxes like this ☒

5. How often do you eat Beef?
(in any form such as steaks, roasts, stews, casseroles, kebabs, BBQ etc.?
*(Use **X** in one box only)*

- ☐ Daily
- ☐ 4-5 times a week
- ☐ 2-3 times a week
- ☐ Weekly
- ☐ Fortnightly
- ☐ Monthly
- ☐ Never eat beef

6.1. How many adults (18 and over) normally live in your household ?
*(Use **X** in one box only)*

- ☐ 1 Adult
- ☐ 2 Adults
- ☐ 3 Adults
- ☐ 4 Adults
- ☐ 5 Adults
- ☐ 6 Adults
- ☐ 7 Adults
- ☐ 8 and over adults

6.2 How many children under 18 years normally live in your household??
*(Use **X** in one box only)*

- ☐ 0 Children
- ☐ 1 Child
- ☐ 2 children
- ☐ 3 Children
- ☐ 4 Children
- ☐ 5 Children
- ☐ 6 Children
- ☐ 7 and over children

7 Please read the following statements
*and use **X** in one box only for the one statement that applies to you*

- ☐ I enjoy red meat. It's an important part of my diet
- ☐ I like red meat well enough. It's a regular part of my diet
- ☐ I do eat some red meat although, truthfully it wouldn't worry me if I didn't
- ☐ I rarely / never eat red meat

8. When you eat beef, such as steaks, what level of cooking do you prefer?
*(Use **X** in one box only)*

- ☐ Blue
- ☐ Rare
- ☐ Medium / Rare
- ☐ Medium
- ☐ Medium / Well done
- ☐ Well done

9. What level of income best categorises your combined household income ?
*(Use **X** in one box only)*

- ☐ Below $ 25,000 per year
- ☐ $ 25,001 - $$ 50,000 per year
- ☐ $ 50,000 - $ 75,000 per year
- ☐ $ 75,001 - $ 100,000 per year
- ☐ $ 100,000 - $ 125,000 per year
- ☐ $ 125,000 - $ 150,000 per year
- ☐ More than $ 150,000 per year
- ☐ Prefer not to say

10. What level of education have you reached? *(Use **X** in one box only for the highest level achieved)*

- ☐ Did not complete Secondary School
- ☐ Completed Secondary School
- ☐ A College/ TAFE course
- ☐ University Graduate

11. What is your cultural heritage ?
*(Use **X** in one box only)*

- ☐ Australian
- ☐ British descent
- ☐ European descent
- ☐ Asian descent
- ☐ Other
- ☐ Prefer not to say

TPB TPB

TPB TPB

All information collected in this survey is strictly confidential

PRODUCT:

Tenderness

Not Tender Very Tender

Juiciness

Not Juicy Very Juicy

Liking of Flavour

Dislike Extremely Like Extremely

Overall Liking

Dislike Extremely Like Extremely

Please mark **X** in one of the following boxes to rate the quality of the beef sample you have just eaten

Choose **one** only (you must make a choice)

- Unsatisfactory
- Good everyday quality
- Better than everyday quality
- Premium quality

TPB TPB

Based on the beef you have just consumed:
Please mark the line at the price per Kg you believe best reflects the value for each category.

Unsatisfactory Quality

$0/kg $10/kg $20/kg $30/kg $40/kg $50/kg $60/kg $70/kg $80/kg

Good Everyday Quality

$0/kg $10/kg $20/kg $30/kg $40/kg $50/kg $60/kg $70/kg $80/kg

Better Than Everyday Quality

$0/kg $10/kg $20/kg $30/kg $40/kg $50/kg $60/kg $70/kg $80/kg

Premuim Quality

$0/kg $10/kg $20/kg $30/kg $40/kg $50/kg $60/kg $70/kg $80/kg

Are you the regular purchaser for your family ? *(Use* **X** *in one box only)*

☐ Yes
☐ No

8.2 Comparison of estimated and observed MQ4 utilising the draft MSA V2.0 prediction procedure

In the following tables values of NA indicate that particular muscle x cook combinations are not currently within the MSA V2.0 model and hence unable to be compared.

8.2.1 Summary statistics of observed MQ4 and predicted MQ4 for cuts cooked as a GRL (grill) from the MSA V2.0 model with sex at either B (bull) or M (steer)

Cut	N	Observed MQ4	Bull PMQ	Male PMQ
BLD096				
Mean (SD)	**(N=18)**	53.3 (10.4)	53.9 (1.91)	54.4 (1.60)
Median [Min, Max]		54.7 [30.6, 71.2]	53.6 [51.1, 58.7]	54.1 [51.9, 58.7]
CHK074				
Mean (SD)	**(N=18)**	57.5 (8.83)	56.3 (2.74)	56.7 (2.52)
Median [Min, Max]		56.3 [41.5, 75.2]	56.3 [52.0, 61.1]	56.5 [52.6, 61.1]
CHK078				
Mean (SD)	**(N=9)**	51.4 (14.8)	54.2 (1.93)	54.4 (1.80)
Median [Min, Max]		50.3 [27.4, 78.3]	53.9 [50.8, 57.2]	54.2 [51.1, 57.3]
CTR085				
Mean (SD)	**(N=12)**	47.4 (11.2)	52.9 (1.85)	53.3 (1.88)
Median [Min, Max]		45.6 [30.6, 66.9]	53.0 [49.7, 55.6]	53.6 [50.1, 56.0]
CUB045				
Mean (SD)	**(N=56)**	59.3 (9.22)	58.4 (2.80)	58.9 (2.61)
Median [Min, Max]		59.4 [35.6, 76.1]	58.6 [52.7, 64.1]	59.1 [53.4, 64.0]
CUB081				
Mean (SD)	**(N=19)**	67.5 (7.33)	71.7 (1.59)	72.3 (1.25)
Median [Min, Max]		67.2 [57.0, 81.5]	71.0 [69.3, 75.7]	72.0 [70.3, 75.6]
EYE075				
Mean (SD)	**(N=18)**	48.2 (8.85)	48.5 (1.71)	48.9 (1.58)
Median [Min, Max]		48.2 [30.0, 60.6]	48.3 [44.9, 51.7]	48.6 [45.4, 51.7]
KNU066				
Mean (SD)	**(N=13)**	56.1 (8.70)	50.2 (2.48)	50.7 (2.37)
Median [Min, Max]		58.3 [39.1, 67.2]	50.2 [46.4, 54.3]	51.0 [47.1, 54.3]
KNU099				
Mean (SD)	**(N=18)**	40.9 (8.54)	43.0 (2.14)	43.4 (1.98)
Median [Min, Max]		40.0 [27.7, 55.7]	42.5 [39.9, 48.4]	43.3 [40.4, 48.3]
OUT005				
Mean (SD)	**(N=36)**	37.3 (9.91)	37.0 (1.89)	37.4 (1.68)
Median [Min, Max]		36.6 [16.5, 56.1]	36.7 [34.3, 41.9]	36.8 [35.0, 41.9]
OYS036				
Mean (SD)	**(N=17)**	61.6 (8.90)	66.4 (2.48)	66.9 (2.14)
Median [Min, Max]		61.8 [47.9, 80.7]	65.9 [63.3, 72.5]	66.3 [64.1, 72.4]
RMP005				
Mean (SD)	**(N=18)**	61.7 (9.30)	62.7 (2.17)	63.2 (1.91)
Median [Min, Max]		62.2 [46.4, 76.6]	62.5 [58.9, 67.2]	62.9 [59.8, 67.1]
RMP131				
Mean (SD)	**(N=17)**	59.5 (10.2)	53.9 (2.85)	54.4 (2.69)
Median [Min, Max]		60.2 [43.9, 79.0]	54.0 [50.0, 60.3]	54.9 [50.8, 60.2]
RMP231				
Mean (SD)	**(N=17)**	58.5 (8.99)	57.0 (2.75)	57.5 (2.59)
Median [Min, Max]		58.6 [45.1, 75.4]	57.8 [51.5, 62.2]	58.3 [52.3, 62.1]
STR045				
Mean (SD)	**(N=58)**	55.7 (10.2)	56.1 (4.03)	56.6 (3.90)
Median [Min, Max]		55.6 [31.2, 73.4]	56.9 [47.7, 62.7]	57.4 [48.4, 62.7]
TDR034				
Mean (SD)	**(N=18)**	62.4 (13.0)	72.0 (0.847)	72.5 (0.702)
Median [Min, Max]		61.8 [40.6, 80.2]	71.9 [70.7, 73.6]	72.3 [71.7, 74.0]
TDR062				
Mean (SD)	**(N=18)**	68.4 (7.02)	73.1 (0.847)	73.6 (0.702)
Median [Min, Max]		70.1 [49.8, 76.4]	73.0 [71.8, 74.7]	73.4 [72.8, 75.1]
TOP001				
Mean (SD)	**(N=18)**	46.8 (7.19)	47.0 (2.09)	47.4 (2.06)
Median [Min, Max]		47.5 [35.0, 61.4]	47.8 [43.7, 50.1]	47.9 [44.0, 50.0]
TOP073				
Mean (SD)	**(N=36)**	42.9 (7.12)	38.0 (2.83)	38.4 (2.73)
Median [Min, Max]		42.2 [21.2, 60.2]	38.2 [32.5, 43.0]	38.4 [33.2, 42.9]

8.2.2 Summary statistics of observed MQ4 and predicted MQ4 for cuts cooked as a SC2 (slow cook) from the MSA V2.0 model with sex at either B (bull) or M (steer)

Cut	N	Observed MQ4	Bull PMQ	Male PMQ
BLD095				
Mean (SD)	**(N=7)**	57.2 (7.67)	42.5 (1.42)	42.9 (1.26)
Median [Min, Max]		58.6 [44.3, 68.4]	42.2 [40.9, 44.8]	42.5 [41.6, 44.9]
BLD096				
Mean (SD)	**(N=7)**	60.8 (8.75)	57.5 (1.27)	57.9 (1.02)
Median [Min, Max]		58.3 [48.6, 75.6]	57.4 [55.6, 59.3]	57.7 [56.4, 59.3]
BLD097				
Mean (SD)	**(N=7)**	64.9 (5.56)	60.5 (1.42)	60.9 (1.26)
Median [Min, Max]		64.4 [56.3, 73.2]	60.2 [58.9, 62.8]	60.5 [59.6, 62.9]
CHK068				
Mean (SD)	**(N=14)**	57.1 (6.00)	52.2 (1.04)	52.6 (0.923)
Median [Min, Max]		57.7 [43.6, 66.6]	52.2 [50.9, 54.6]	52.4 [51.6, 54.7]
CHK074				
Mean (SD)	**(N=7)**	73.3 (5.46)	62.8 (1.20)	63.2 (1.07)
Median [Min, Max]		74.2 [66.3, 80.2]	62.7 [61.4, 65.2]	63.0 [62.1, 65.3]
CHK078				
Mean (SD)	**(N=7)**	60.9 (11.2)	59.5 (1.29)	59.9 (1.16)
Median [Min, Max]		63.7 [43.7, 74.2]	59.3 [57.9, 62.0]	59.8 [58.6, 62.0]
CTR085				
Mean (SD)	**(N=10)**	61.1 (9.48)	54.0 (1.11)	54.5 (0.865)
Median [Min, Max]		62.7 [46.8, 74.5]	53.7 [52.9, 55.8]	54.1 [53.7, 55.8]
EYE075				
Mean (SD)	**(N=13)**	49.7 (8.11)	51.5 (1.70)	51.8 (1.62)
Median [Min, Max]		49.4 [35.6, 62.8]	51.3 [47.8, 54.0]	52.0 [48.3, 54.0]
FQS004				
Mean (SD)	**(N=6)**	74.0 (6.12)	57.3 (1.65)	57.5 (1.42)
Median [Min, Max]		76.0 [62.5, 79.1]	57.7 [55.0, 59.2]	57.7 [55.5, 59.3]
FQS006				
Mean (SD)	**(N=5)**	71.6 (6.51)	57.3 (0.889)	57.5 (1.20)
Median [Min, Max]		71.3 [64.1, 81.6]	57.3 [56.4, 58.5]	57.5 [56.3, 59.0]
FQSHIN				
Mean (SD)	**(N=6)**	63.3 (8.52)	58.1 (0.905)	58.3 (1.15)
Median [Min, Max]		63.3 [50.1, 73.2]	57.9 [57.2, 59.5]	58.0 [57.2, 60.0]
HQS059				
Mean (SD)	**(N=8)**	75.9 (5.81)	57.4 (0.976)	57.6 (1.14)
Median [Min, Max]		75.7 [69.6, 85.4]	57.5 [56.2, 58.7]	57.8 [56.2, 58.9]
HQSHIN				
Mean (SD)	**(N=6)**	73.1 (5.87)	62.5 (0.905)	62.7 (1.15)
Median [Min, Max]		73.7 [65.7, 80.2]	62.3 [61.6, 63.9]	62.3 [61.6, 64.4]
INT037				
Mean (SD)	**(N=16)**	77.1 (5.73)	58.3 (0.703)	58.5 (0.671)
Median [Min, Max]		77.8 [68.2, 86.2]	58.3 [57.2, 59.7]	58.3 [57.8, 59.9]
KNU066				
Mean (SD)	**(N=7)**	60.9 (8.13)	53.9 (1.02)	54.3 (0.964)
Median [Min, Max]		57.3 [51.8, 73.2]	53.7 [52.2, 55.1]	54.4 [53.0, 55.4]
KNU099				
Mean (SD)	**(N=9)**	57.0 (10.3)	45.1 (0.694)	45.6 (0.489)
Median [Min, Max]		59.9 [43.9, 70.7]	44.9 [44.2, 46.3]	45.6 [45.0, 46.4]
NEB079				
Mean (SD)	**(N=17)**	50.5 (8.84)	NA (NA)	NA (NA)
Median [Min, Max]		51.1 [38.2, 64.5]	NA [NA, NA]	NA [NA, NA]
NEB092				
Mean (SD)	**(N=18)**	58.0 (8.40)	NA (NA)	NA (NA)
Median [Min, Max]		59.4 [39.4, 73.3]	NA [NA, NA]	NA [NA, NA]

Cut	N	Observed MQ4	Bull PMQ	Male PMQ
OUT005				
Mean (SD)	**(N=14)**	59.2 (7.95)	51.7 (1.19)	52.0 (1.10)
Median [Min, Max]		59.6 [45.2, 72.0]	51.5 [49.8, 53.7]	51.8 [50.4, 54.0]
OUT029				
Mean (SD)	**(N=7)**	63.9 (5.18)	61.4 (1.50)	61.7 (1.59)
Median [Min, Max]		62.9 [58.7, 71.2]	61.1 [59.4, 63.2]	61.7 [59.7, 63.8]
OYS036				
Mean (SD)	**(N=15)**	80.3 (5.76)	66.3 (2.34)	66.7 (2.03)
Median [Min, Max]		79.8 [66.7, 88.2]	66.1 [63.3, 71.8]	66.9 [64.2, 71.8]
RIB041				
Mean (SD)	**(N=22)**	62.3 (10.2)	49.4 (0.221)	49.5 (0.172)
Median [Min, Max]		60.1 [50.0, 83.5]	49.4 [49.1, 49.7]	49.6 [48.9, 49.7]
RMP087				
Mean (SD)	**(N=11)**	58.1 (7.07)	63.9 (2.16)	64.3 (1.88)
Median [Min, Max]		59.1 [47.9, 68.4]	63.6 [59.7, 66.9]	64.3 [60.6, 66.9]
TFL051				
Mean (SD)	**(N=6)**	55.7 (11.5)	54.4 (0.758)	54.7 (0.569)
Median [Min, Max]		55.5 [42.9, 69.1]	54.5 [53.3, 55.5]	54.8 [53.9, 55.4]
TFL052				
Mean (SD)	**(N=6)**	65.6 (13.9)	62.2 (0.758)	62.5 (0.569)
Median [Min, Max]		70.1 [41.6, 81.5]	62.3 [61.2, 63.4]	62.7 [61.7, 63.3]
TFL064				
Mean (SD)	**(N=6)**	52.6 (2.51)	63.9 (0.758)	64.2 (0.569)
Median [Min, Max]		53.3 [48.5, 55.6]	64.0 [62.8, 65.0]	64.3 [63.4, 64.9]
TOP001				
Mean (SD)	**(N=9)**	43.2 (11.2)	54.2 (2.34)	54.5 (2.29)
Median [Min, Max]		38.3 [27.1, 60.1]	55.0 [50.4, 56.8]	55.3 [50.7, 56.7]
TOP033				
Mean (SD)	**(N=9)**	62.4 (9.95)	63.6 (1.86)	63.9 (1.62)
Median [Min, Max]		62.0 [49.9, 77.1]	63.2 [61.5, 67.4]	63.5 [62.2, 67.3]
TOP073				
Mean (SD)	**(N=18)**	44.1 (7.85)	46.4 (2.67)	46.7 (2.55)
Median [Min, Max]		45.6 [29.6, 57.6]	45.7 [42.9, 51.4]	45.9 [43.0, 51.3]

8.2.3 Summary statistics of observed MQ4 and predicted MQ4 for cuts cooked as a SFR (stir fry) from the MSA V2.0 model with sex at either B (bull) or M (steer)

Cut	N	Observed MQ4	Bull PMQ	Male PMQ
BLD097				
Mean (SD)	**(N=12)**	65.7 (9.59)	NA (NA)	NA (NA)
Median [Min, Max]		68.6 [48.1, 77.3]	NA [NA, NA]	NA [NA, NA]
EYE075				
Mean (SD)	**(N=11)**	54.8 (9.21)	48.5 (1.84)	48.8 (1.68)
Median [Min, Max]		57.6 [35.9, 69.7]	48.2 [44.8, 51.0]	48.5 [45.3, 51.0]
FQS004				
Mean (SD)	**(N=10)**	58.3 (10.7)	NA (NA)	NA (NA)
Median [Min, Max]		60.2 [42.0, 72.3]	NA [NA, NA]	NA [NA, NA]
FQS006				
Mean (SD)	**(N=9)**	57.8 (12.7)	NA (NA)	NA (NA)
Median [Min, Max]		60.4 [35.9, 73.0]	NA [NA, NA]	NA [NA, NA]
HQS059				
Mean (SD)	**(N=9)**	63.4 (9.79)	NA (NA)	NA (NA)
Median [Min, Max]		60.6 [47.0, 78.6]	NA [NA, NA]	NA [NA, NA]
OUT029				
Mean (SD)	**(N=9)**	68.2 (6.35)	60.1 (1.44)	60.4 (1.41)
Median [Min, Max]		70.2 [59.5, 78.4]	60.2 [57.3, 61.8]	60.5 [57.2, 61.8]
TFL051				
Mean (SD)	**(N=7)**	58.3 (10.8)	58.9 (1.45)	59.0 (1.32)
Median [Min, Max]		59.2 [37.1, 71.2]	58.4 [57.3, 61.1]	58.4 [57.6, 61.1]
TFL052				
Mean (SD)	**(N=9)**	62.4 (9.31)	62.2 (1.49)	62.4 (1.37)
Median [Min, Max]		62.0 [49.1, 76.9]	62.2 [60.7, 65.2]	62.3 [61.0, 65.2]
TFL064				
Mean (SD)	**(N=12)**	56.8 (9.71)	61.9 (1.60)	62.1 (1.44)
Median [Min, Max]		55.1 [42.4, 69.6]	61.6 [59.4, 64.7]	61.8 [59.7, 64.7]
TOP033				
Mean (SD)	**(N=12)**	61.0 (7.84)	59.2 (2.61)	59.5 (2.35)
Median [Min, Max]		60.9 [46.1, 74.9]	59.2 [55.4, 63.8]	59.5 [56.0, 63.8]

8.2.4 Summary statistics of observed MQ4 and predicted MQ4 for cuts cooked as a SVD (stir fry) from the MSA V2.0 model with sex at either B (bull) or M (steer)

Cut	N	Observed MQ4	Bull PMQ	Male PMQ
BLD096				
Mean (SD)	**(N=4)**	56.8 (8.99)	57.2 (1.36)	57.6 (1.12)
Median [Min, Max]		54.4 [49.4, 69.2]	57.3 [55.6, 58.7]	57.5 [56.4, 59.0]
INT037				
Mean (SD)	**(N=1)**	59.0 (NA)	NA (NA)	NA (NA)
Median [Min, Max]		59.0 [59.0, 59.0]	NA [NA, NA]	NA [NA, NA]
KNU099				
Mean (SD)	**(N=2)**	43.9 (5.21)	48.4 (0.638)	48.9 (0.356)
Median [Min, Max]		43.9 [40.2, 47.5]	48.4 [47.9, 48.8]	48.9 [48.7, 49.2]