Final report

Lamb MSA Mark II Limited Cut x Cook

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Abstract

Under the current Meat Standards Australia sheepmeat pathways system, guidelines surrounding pH-temperature decline rates are such that electrically stimulated carcases will enter rigor mortis at a temperature above 18°C and therefore 5 days of ageing is recommended. However, there are limited studies available that assess the impact of extended ageing on lamb eating quality in combination with electrical stimulation, in a variety of cuts. From lamb (n = 160) and yearling (n = 40) carcases, the right and left knuckle, loin, outside, eye of rack, rump, eye of shoulder and topside were removed and aged for two out of three ageing periods (5, 14 or 21 days). Samples were assessed by untrained consumers for tenderness, juiciness, flavour liking and overall liking. The effect of ageing time on overall liking scores as a representation of all sensory traits was conducted using linear mixed effects models. Additionally, the effect of temperature at pH 6 and pH at 18°C on overall liking scores as ageing time increased were analysed. As ageing time increased from 5 to 14 days and 5 to 21 days, there was a significant improvement in the overall liking of the eye of rack, knuckle, loin, outside and rump cuts. However, beyond 14 days ageing there was little additional improvement in eating quality. When corrected for temperature at pH 6, the cut by ageing time differences disappeared and as such temperature at pH 6 accounted for some variation between different cut by ageing times. However, variation in cut by ageing time eating quality remained when corrected for pH 18°C. The eating quality of Dorper sired lambs was considered less acceptable than Maternal, Merino and Terminal sired lambs at each ageing time. These differences between lamb sire type groups remained when corrected for either temperature at pH 6 or pH at 18°C, with overall liking scores increasing from 5 to 14 and 5 to 21 days ageing. In addition, an age class effect was evident with Merino lambs being more acceptable than Merino yearlings, with a similar score difference at 5, 14 and 21 days of ageing, even when corrected for temperature at pH 6 or pH at 18°C. The results demonstrated improvement in eating quality across increasing days ageing however extended ageing beyond 14 days showed no additional benefit. The ageing effect reduced when correcting for temperature at pH 6 or pH at 18°C and confirms current MSA sheepmeat pathways guidelines can improve eating quality by ageing in combination with electrical stimulation. The ageing difference on eating quality between sire types indicated that other factors may impact the variation and extent of ageing observed.

Executive summary

The current Meat Standards Australia (MSA) pathways system is designed to improve the overall eating quality of sheepmeat through identifying and controlling for critical factors along the supply chain. Whilst it defines best practice procedures, the current model is unable to predict the consumer-based eating quality of specific cuts. Development of MSA Mark II, a cut-based prediction model, is currently underway (Pannier et al., 2018; Pethick et al., 2015) with a pilot version (unpublished) established on the Sheep CRC and MLA Resource flock eating quality data available for several cuts by two cooking methods (grill: loin, topside, outside, knuckle, rump; roast: leg, shoulder, rack). Factors impacting the phenotypic eating quality variation have previously been defined (Pannier et al., 2018), however the impact of post-slaughter procedures such as extended ageing time (i.e. up to 21 days) are yet to be explored extensively for a wide range of cuts as current research is limited to shorter ageing times and only a few cuts. Incorporation of data obtaining to these requirements is needed to expand the current available database so that further inputs into the MSA Mark II model can be commercially rolled out in the future.

Post-slaughter, the anaerobic metabolism in muscles lowers muscle pH through lactic acid production. The rate at which the muscle pH lowers is defined as the pH decline, finally reaching ultimate pH at around 24 hr post-mortem. The interaction between pH and temperature decline of muscles when carcases chill, can impact on the proteolytic activity of muscles (Koohmaraie, 1996) and subsequent eating quality outcome of muscles (Thompson et al., 2005b). However reduced eating quality as a result of post-mortem processing can be overcome by extended ageing (Thompson et al., 2005b). Therefore, under the current MSA pathways system, the recommendations for pH decline and temperature (calculated as temperature at pH 6 and pH at 18°C) post-slaughter vary for short (5–10 d) and longer (>10 d) aged products. For Achilles hung lamb carcases that undergo electrical stimulation, it is anticipated that the temperature at pH 6 falls between 18 and 35°C, and as such a minimum of 5 days of ageing is required (Meat and Livestock Australia, 2019). For lamb carcases that undergo no electrical stimulation, it is anticipated that the temperature at pH 6 falls between 8 and 18°C, and as such a minimum of 10 days of ageing is required (Meat and Livestock Australia, 2019).

In this report, the effect of ageing times on various cuts was explored. From 160 lambs and 40 yearlings, the right and left eye of rack, eye of shoulder, knuckle, loin, outside, rump and topside were collected and aged for either 5, 14 or 21 days. These cuts were assessed across 64 consumer tasting sessions, whereby 3,840 participants consumed a total of 2,304 test cuts. Consumer sessions were conducted following standard MSA grilling protocols, with groups of 60 untrained consumers assessing six test samples for tenderness, juiciness, flavour and overall liking following a Latin square design. As consumer sensory scores are highly correlated (Shorthose & Harris, 1991), overall liking has been used as a representative of the sensory traits in this study with the data of the other traits (tenderness, juiciness, flavour and MQ4) listed in the appendix.

A key finding of this project was the improvement of overall liking scores across the eye of rack, knuckle, loin, outside and rump cuts from 5 to 14 days of ageing and 5 to 21 days ageing. The smallest increase in overall liking was exhibited in the outside (3.6 scores), with the greatest improvement in the knuckle (6.9 scores) between 5 and 14 days. Further, ageing cuts from 14 to 21 days showed no additional benefit to overall liking scores. The inclusion of the covariate temperature at pH 6 accounted for the variation in cut overall liking scores from 5 to 14 and 5 to 21 days ageing. In comparison, when pH at 18°C was included, cut and ageing time differences remained, with some effect magnitude reduced. The results demonstrate that eating quality can be improved after process-induced shortening through extended ageing and electrical stimulation.

Additionally, there was a lamb sire type effect whereby overall liking scores of Dorper sired lambs was lower than those of Maternal, Merino and Terminal sired lambs. This was also evident at the 5, 14 and 21 days of ageing. When corrected for temperature at pH 6 or pH 18°C, these sire type differences remained, indicating that other factors (i.e. genetics) may impact the variation and extent of ageing observed. Also, overall liking of Merino yearling cuts scored lower than from Merino lambs, and this was evident across each of the ageing times, with a similar difference exhibited between the 5, 14 and 21 days of ageing. The inclusion of temperature at pH 6 or pH 18°C in the model remained the variation observed in overall liking scores between the age classes.

Fundamentally, the dataset of this project with inclusion of the different ageing times (5, 14 and 21 days) for various lamb and Merino yearling animals can be combined with previously collected eating quality data available in the MSA Mark II model. This will allow for further development of the MSA Mark II model for future prediction of lamb cuts at different ageing times. This can be utilised to segregate cuts into preferential ageing times to maximise the eating quality potential of individual cuts based on specific market requirements.

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1. Background

Lamb eating quality is influenced by pre- and post-slaughter factors (Russell et al., 2005). As such, the Australian sheepmeat industry has implemented the Meat Standards Australia (MSA) pathways system to manage critical control points along the supply chain. One of these factors is ageing time post-mortem. As the majority of improvement from ageing occurs in the first five days post-slaughter (Thompson et al., 2005b), MSA graded sheepmeat is required to be aged for a minimum five-day period before being sold to consumers.

Post-mortem ageing is reliant on the breakdown of proteins caused by proteolytic enzyme activity (Ouali, 1992). Ageing causes muscle fibres to weaken, leading to myofibrillar structural disruption and results in improved eating quality (Muchenje et al., 2009). Proteolytic activity is principally influenced by the interaction between pH and temperature decline of muscles (Koohmaraie, 1996). However, depending on the pH and temperature decline interaction, there can be large variation in the rate and extent of post-mortem ageing on eating quality attributes (Koohmaraie, 1996). This leads to inconsistencies in eating quality experienced by consumers. Under the MSA pathways system, electrical stimulation of carcases prior to chilling is used to accelerate the rate of decline in pH to prevent cold shortening, hence maximising eating quality (Meat and Livestock Australia, 2019). In addition, the MSA pH-temperature guidelines for achilles hung carcases that undergo electrical stimulation are for carcases to reach temperature at pH 6 between 18 and 35°C. Ultimate pH (ideally 5.4 to 5.7) is then achieved around 24 hr post-slaughter.

Ageing time has been primarily associated with an improvement in textural attributes, including tenderness and juiciness (Shorthose et al., 1986; Wheeler & Koohmaraie, 1994). Thompson et al. (2005b) reported an improvement in tenderness, juiciness, overall liking, and flavour liking of the loin and outside, primarily from 2 to 5 days of ageing. Likewise, other previous studies demonstrating the effects of ageing time on lamb eating quality have been limited to short ageing times (Hopkins et al., 2005; Shaw et al., 2005). Under the updated MSA cut-based eating quality prediction model, inclusion of further ageing times beyond 5 days will assist in the further deployment of the model across the industry including markets that specify a longer ageing time. Further, exploration of the effect of ageing on eating quality of various cuts from the carcase is important as the biochemical structure of muscles within a carcase is variable, contributing to the differences reported in eating quality between cuts (e.g., Pannier et al., 2014; Payne et al., 2020; Pethick et al., 2005; Thompson et al., 2005a; Thompson et al., 2005b).

Older animals are less acceptable for eating quality than younger animals (Hopkins et al., 2006), however little to no difference has been reported between lambs and yearlings in some studies (Pannier et al., 2019; Pethick et al., 2005). As animals age, cross-linking of collagen increases and collagen solubility declines, causing meat to become tougher (Astruc, 2014; Young & Braggins, 1993), and exhibit a stronger flavour (Hopkins et al., 2006; Young et al., 2005), although through extended ageing, eating quality of older animals may be improved.

Therefore, we hypothesised that as ageing time increases there will be an improvement in lamb eating quality across different cuts tested (eye of rack, eye of shoulder, knuckle, loin, outside, rump and topside), although variation in cut eating quality at a given ageing time will exist. The pH measurements of temperature at pH 6 and pH at 18°C will, in part, help to explain the variation in cut eating quality across the ageing time. Finally, yearlings will have a poorer eating quality than lambs, although this will differ across the different cuts.

2. Objectives

The direct project objectives were:

- Conduct sensory panels (n=60) with Australian untrained consumers as per the Meat Standards Australia (MSA) protocols testing 108 lambs (Maternals, Terminals , Merino's) and 36 shedding breed lambs (Dorpers) from the MLA Genetic Resource flock, and 36 hoggets (Merino's) from a satellite flock.
- Gather additional information from the untrained consumer panel members such as simple demographic and willingness to pay information (as per the normal MSA protocols for sensory evaluation).
- Understand eating quality differences between lamb, hoggets and shedding breed lambs.
- Understand eating quality differences with respect to different ageing times (5, 14, 21 days).
- Provide the raw data for each session back to the Sheep Resource Flock Data.

At a high level this project will contribute to;

- The inclusion of this data into the development of the MSA Mark II cuts-based sheepmeat model.
    - The data will allow for the prediction of 2 new cut (eye of rack and eye of shoulder) x cook (grill) combinations in addition to the short loin, topside, rump, outside and knuckle.
    - The data will allow for the prediction of eating quality with the inclusion of different cut ageing times (5, 14, 21 days of ageing).
- The inclusion of this data in the development of breeding values for the MSA based eating quality of lamb.
- The inclusion of this data in understanding the phenotypic and genetic relationships between sensory scores and other indicators of meat quality (i.e. lean meat yield, intramuscular fat, shear force and muscle structural properties).

3. Methodology

3.1 Experimental design and slaughter details

Yearlings (n = 40) and lambs (n = 160) from the Meat and Livestock Australia (MLA) Genetic Resource flock located at Katanning (WA) were used in this study. Female and wether lambs were the progeny of key industry Dorper (Dorper, White Dorper), Maternal (Border Leicester, Commercial, Coopworth, Corriedale, Dohne Merino, Prime Samm), Merino (Merino, Poll Merino) and Terminal (Commercial, Poll Dorset, Southdown, Suffolk, White Suffolk) sires. Only wether Merino-sired yearlings were used in this study. Animals were raised on an extensive pasture grazing system, but were fed grain, hay, or feedlot pellets when required.

Lambs were assigned to one of three small groups (kill groups) of approximately 50 animals each. All yearlings were additionally allocated to kill group one. The day before slaughter, animals were yarded for six hours and weighed. They were then transported to a commercial abattoir where they were held in lairage overnight. Following commercial standards, the lambs were slaughtered with medium voltage electrical stimulation applied (Pearce et al., 2010). Carcases were trimmed according to AUS-MEAT specifications (Annoymous, 2020) prior to chilling at 3-4°C overnight. The following day, the carcases were transported to Murdoch University for manual bone-out.

3.2 Carcase measurements

Immediately following slaughter, hot standard carcase weight (HSCW) and GR tissue depth (taken between the 12th and 13th ribs, 11cm from the carcase mid-line) were measured on each carcase. The average carcase weight of the lambs and yearlings was 21.06 kg (± 3.01 kg) and 27.92 kg (± 2.77 kg), respectively. Measurements of pH were taken at four time intervals within the first 24 hr based on target carcase temperatures of approximately 35°C, 20°C and 12°C, as well as at 24 hr post-mortem (Pearce et al., 2010). Measurements of pH were taken on the caudal portion of the left *M. Longissimus lumborum* (shortloin). The carcase temperature reached at pH 6 and the pH of the carcase at 18°C were calculated as indicators of the rate of pH and temperature decline during the first 24 hr post-slaughter. All muscle pH and temperature measurements were obtained using a temperature-compensating meter and probe, with a stainless-steel cylindrical probe attached (TPS WP80M meters with IJ44A pH probes, TPS Australia, Springwood, Qld, Australia).

3.3 Sensory cut preparation and consumer sessions

The loin (AUS-MEAT 5150), topside cap off (AUS-MEAT 5077), knuckle (AUS-MEAT 5072), outside (AUS-MEAT 5075), rump (AUS-MEAT 5074), eye of shoulder (AUS-MEAT 5151), eye of rack (AUS-MEAT 5153), and adductor (obtained from AUS-MEAT 5077) were removed from both sides of all carcases. The left and right cuts were treated as individual cuts, except for the rump and eye of shoulder where the left and right sides were considered as a single cut due to the smaller size of these compared to the others. All cuts were denuded of outer subcutaneous fat and epimysium.

Each cut was sliced into five 15 mm thick steaks, vacuum packed and aged at 2°C for either 5, 14 or 21 days such that the same cut from each carcase was aged for 2 of the 3 ageing times. Ageing times were allocated through a pairwise design based on their left and right position within the carcase (Table 1). Samples were frozen at approximately -20°C at the corresponding ageing time. All adductors were aged for 5 days to be used as starter samples.

Table 1. Pairwise design across the ageing times and cut position within the carcase.

Lamb 1				Lamb 2				Lamb 3		
Rotate through ageing times				Rotate through ageing times				Rotate through ageing times		
L	R			L	R			L	R	
5	14	Loin		5	21	Loin		14	21	Loin
5	21	Topside		14	21	Topside		14	5	Topside
14	21	Outside		14	5	Outside		21	5	Outside
14	5	Knuckle		21	5	Knuckle		21	14	Knuckle
21	5	Eye Rack		21	14	Eye Rack		5	14	Eye Rack
21	14	Eye FQ/Rump		5	14	Eye FQ/Rump		5	21	Eye FQ/Rump

Lamb 4				Lamb 5				Lamb 6		
Rotate through ageing times				Rotate through ageing times				Rotate through ageing times		
L	R			L	R			L	R	
14	5	Loin		21	5	Loin		21	14	Loin
21	5	Topside		21	14	Topside		5	14	Topside
21	14	Outside		5	14	Outside		5	21	Outside
5	14	Knuckle		5	21	Knuckle		14	21	Knuckle
5	21	Eye Rack		14	21	Eye Rack		14	5	Eye Rack
14	21	Eye FQ/Rump		14	5	Eye FQ/Rump		21	5	Eye FQ/Rump

Untrained consumers were used to assess the eating quality of the various lamb cuts following MSA protocols (Thompson et al., 2005a; Watson et al., 2008). Briefly, samples were cooked to medium doneness on a Silex grill (S-tronic steaker, Silex, Hamburg, Germany), rested for two minutes, halved, and served to pairs of consumers such that each sample was tasted by ten different consumers. Each sample was assessed on 100 mm scale lines for tenderness, juiciness, flavour and overall liking, with 0 representing least preferred. All consumers first received a common sample to familiarise themselves with the process (Table 2). This was followed by six test samples, allocated by a 6x6 Latin square design (Watson et al., 2008). In total, 64 sessions were conducted, with 3,840 consumers evaluating 2,304 cuts (equating to 23,040 taste samples; Table 2).

Table 2. Number of cuts used in tasting sessions according to ageing time and animal class.

Days of ageing	5		14		21	
	Lamb	Yearling	Lamb	Yearling	Lamb	Yearling
Adductor	304	0	0	0	0	0
Eye of rack	102	26	102	26	100	28
Eye of shoulder	53	15	49	13	51	11
Knuckle	100	28	102	26	102	26
Loin	100	28	102	26	102	26
Outside	102	26	100	28	102	26
Rump	49	12	51	14	52	14
Topside	102	26	102	26	100	28

3.4 Statistical analysis

To test the effect of ageing time on eating quality, analyses of the ten individual consumer responses per cut for overall liking were conducted in R (R Core Team, 2022) using a linear mixed effects model as a representation of all sensory traits given the high correlation between sensory attributes (correlation coefficients for overall liking by tenderness, juiciness and flavour are 0.85, 0.84 and 0.91; for tenderness by juiciness and flavour are 0.79 and 0.76; for juiciness by flavour is 0.79). The base model for overall liking included fixed effects for cut (eye of rack, eye of shoulder, knuckle, loin, outside, rump, topside), ageing time (5, 14, 21 days), sire type-age class as a single term (Dorper lamb, Maternal lamb, Merino lamb, Merino yearling, Terminal lamb), sex within a sire type-age class (female and wether of each lamb sire type, wether Merino yearling). Random terms included animal identification, kill group, sire, and consumer identification within grill session. First- and second-class interactions were included with non-significant terms ($P > 0.05$) removed in a stepwise manner.

Temperature at pH 6 and pH at 18°C were tested individually within the base model to determine their effect with ageing time on eating quality of different cuts. The covariate models included all relevant interactions with fixed-effects and the covariate terms, as well as the covariate quadratic effect. Through stepwise regression, non-significant terms ($P > 0.05$) were removed from the model.

Additionally, HSCW and the pH and temperature measures were also analysed as dependent variables in order to determine if phenotypic differences existed between the sire type-age class groups used in this study. In this case, the models included fixed effects for sire type-age class, sex within a sire type-age class and kill group within a sire type-age class, and sire was included as a random term. Non-significant terms ($P > 0.05$) were removed in a stepwise manner.

4. Results

Animals (lambs and yearlings) used (with available data) in the overall liking base model analysis are described in Table 3. Age class comparisons were only made between Merino lambs and yearlings given that yearlings were entirely Merino sired. Sire type comparisons were made only within the lambs because there was an equal distribution of females and wethers across the four different lamb sire types (Table 3). Table 4 demonstrates the unadjusted means and range of the HSCW, loin pH at 24 hr, temperature at pH 6 and pH at 18°C covariates included in the base model.

Table 3. Number of lambs and yearlings included in the base model (n = 180), according to sire type and sex.

Age class	Sire type	Sex	No. of animals
Lamb	Dorper	F	16
		M	17
	Maternal	F	17
		M	14
	Merino	F	18
		M	21
	Terminal	F	21
		M	16
Yearling	Merino	M	40

Table 4. Unadjusted mean and standard deviation (with range) for hot standard carcase weight (HSCW), loin pH at 24 hr, temperature at pH 6, pH at 18°C.

Age class	Sire type	No. of sires	HSCW (kg)		Loin pH at 24 hr		Temp. at pH 6 (°C)		pH at 18°C	
			n	Mean ± SD (min - max)	n	Mean ± SD (min - max)	n	Mean ± SD (min - max)	n	Mean ± SD (min - max)
Lamb	Dorper	14	33	21.40 ± 1.63 (18.70- 25.00)	33	5.76 ± 0.16 (5.38 - 6.18)	25	14.1 ± 7.8 (3.1 - 27.9)	31	6.1 ± 0.2 (5.7 - 6.5)
	Maternal	23	31	20.59 ± 2.65 (17.10 - 27.50)	31	5.82 ± 0.14 (5.61 - 6.21)	19	14.3 ± 7.2 (2.1 - 26.8)	30	6.2 ± 0.2 (5.8 - 6.6)
	Merino	20	39	18.20 ± 1.97 (13.60 - 22.10)	39	5.87 ± 0.22 (5.60 - 6.50)	16	12.4 ± 4.3 (6.4 - 23.7)	35	6.3 ± 0.2 (5.9 - 6.7)
	Terminal	28	37	23.45 ± 2.38 (18.40 - 26.90)	37	5.82 ± 0.16 (5.37 - 6.20)	28	13.5 ± 6.0 (2.6 - 25.0)	35	6.2 ± 0.2 (5.9 - 6.8)
Yearling	Merino	11	40	27.92 ± 2.77 (19.70 - 32.40)	40	5.96 ± 0.22 (5.48 - 6.39)	16	15.6 ± 7.2 (6.8 - 33.5)	30	6.2 ± 0.2 (5.7 - 6.9)

The mean values of pH at 18°C and temperature at pH 6 ranged between 6.13 to 6.28 pH units and 12.4 to 15.6°C, respectively (Table 4). A proportion of carcases (n = 45) used in this experiment are cold shortened based on data lower than 12°C for temperature at pH 6.

4.1 Effect of cut and ageing time on eating quality scores

The outcomes of the eating quality base model are presented in Table 5 with the predicted mean overall liking scores for the significant effect of cut by ageing time for the cuts tested shown in Table 6.

Table 5. F-values, numerator, and denominator degrees of freedom for the effects of the overall liking base linear mixed effects model including the eye of rack, eye of shoulder, knuckle, loin, outside, rump and topside cuts.

Effect	F-value	NDF	DDF
Cut	1109.27**	6	17990.1
Ageing	136.54**	2	17993.3
Sire type-age class	12.71**	4	93.4
Sex (sire type-age class)	0.38	4	176.1
Cut x ageing	2.33**	12	19656.4
Cut x sire type-age class	3.67**	24	19193.3
Ageing x sire type-age class	3.54**	8	19017.3
Cut x sex (sire type-age class)	1.65*	24	19029.4
Cut x ageing x sire type-age class	1.41*	48	19435.5

NDF, DDF: numerator and denominator degrees of freedom; * $P < 0.05$, ** $P < 0.01$.

Table 6. Least square means ± SE for the effect of cut by ageing for overall liking sensory scores.

Cut	Days of ageing		
	5	14	21
Eye of rack	$72.5 \pm 0.6^{a\ (x)}$	$76.4 \pm 0.6^{a\ (y)}$	$76.3 \pm 0.6^{a\ (y)}$
Eye of shoulder	$68.3 \pm 0.8^{b\ (x)}$	$71.9 \pm 0.8^{b\ (x)}$	$71.9 \pm 0.8^{b\ (x)}$
Knuckle	$61.3 \pm 0.6^{c\ (x)}$	$68.2 \pm 0.6^{c\ (y)}$	$67.4 \pm 0.6^{c\ (y)}$
Loin	$62.8 \pm 0.6^{c\ (x)}$	$67.8 \pm 0.6^{c\ (y)}$	$67.4 \pm 0.6^{c\ (y)}$
Outside	$52.2 \pm 0.6^{d\ (x)}$	$55.8 \pm 0.6^{d\ (y)}$	$57.9 \pm 0.6^{d\ (y)}$
Rump	$63.0 \pm 0.8^{c\ (x)}$	$66.5 \pm 0.8^{c\ (x,y)}$	$68.7 \pm 0.8^{b,c\ (y)}$
Topside	$44.1 \pm 0.6^{e\ (x)}$	$46.7 \pm 0.6^{e\ (x)}$	$46.6 \pm 0.6^{e\ (x)}$

Cut differences within a column means with different letters (a-e) differ significantly ($P < 0.05$);
Ageing differences within a row with different letters (x-y) differ significantly ($P < 0.05$).

4.1.1 Ageing times

Increasing ageing times, significantly increased overall liking scores ($P < 0.05$; Table 6) for the eye of rack, knuckle, loin, outside and rump cuts. Predominantly, differences were observed for each cut with higher scores at 14 and 21 days compared to the 5 days of ageing. For the rump, there was a significant difference between 5 and 21 days of ageing, with no significant difference observed from 5 to 14 days of ageing. The largest improvement due to ageing was observed for the knuckle with overall liking scores increasing by 6.9 units from 5 to 14 days (Table 6), compared to only a 3.6 score increase for the outside over this 9-day ageing period. From 5 to 21 days of ageing there was a significant increase in overall liking of the eye of rack, knuckle, loin, outside and rump. No eating quality improvement across ageing times was found for the eye of shoulder and topside cuts, and from 14 to 21 days for any of the cuts tested.

4.1.2 Cut differences

At 5 and 14 days of ageing, all cuts were significantly different (P < 0.05) from one another, except the knuckle, loin and rump were not significantly different from each other (P < 0.05). At 21 days of ageing, there was no significant difference (P > 0.05) in overall liking of the eye of shoulder and rump, and the knuckle, loin, and rump, however all other cuts were significantly different from one another (P < 0.05). The eye of rack was consistently the highest scoring cut across each of the three ageing times, followed by the eye of shoulder, with the topside being the least preferred cut for the grill cooking method. There was a 28.4, 29.7 and 29.7 overall liking score difference between the eye of rack and topside at 5, 14 and 21 days of ageing (P < 0.01).

4.2 Effect of sire type and age class on eating quality scores

4.2.1 Sire type

The predicted means of the sire type-age class groups across all ageing times of the base model are presented in Table 7, with the predicted means of each sire type-age class according to each ageing time shown in Table 8. Sire type comparisons could only be made within the lamb group in this dataset given yearlings were only Merino sired. On average, the consumer-assessed overall liking scores from Dorper sired lambs were generally lower than for the Maternal, Terminal and Merino sired lambs, with no differences observed between the latter three sire type groups.

Table 7. Least square means ± SE for the effect of sire type-age class for overall liking sensory scores.

Age Class	Sire type	Overall liking
Lamb	Dorper	60.5 ± 0.8 ^{a}
Lamb	Maternal	66.0 ± 0.7 ^{b}
Lamb	Merino	66.4 ± 0.7 ^{b}
Lamb	Terminal	65.1 ± 0.7 ^{b}
Yearling	Merino	59.6 ± 0.8 ^{a}

Sire type differences within a column with different letters (a-b) differ significantly (P < 0.05)

Table 8. Least square means ± SE for the effect of ageing by sire type-age class for overall liking sensory scores.

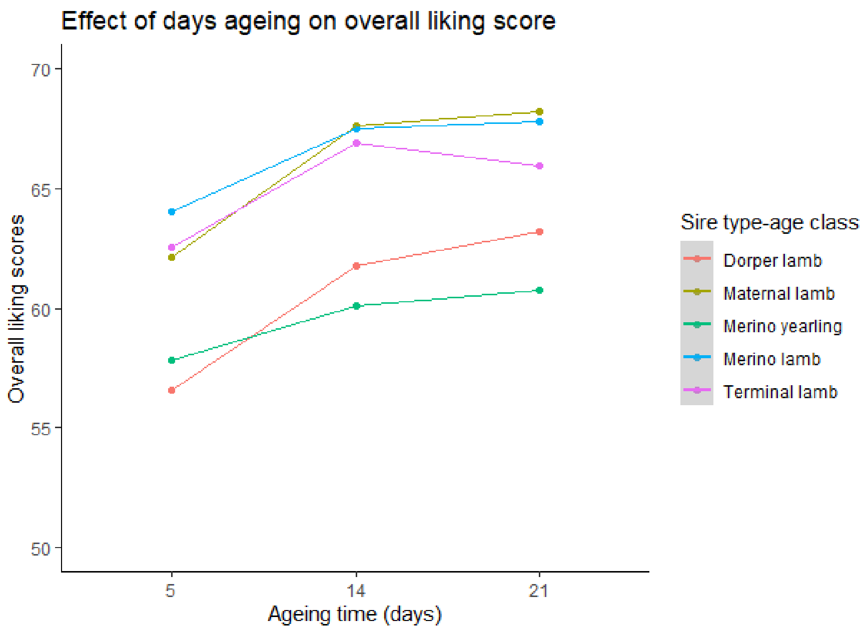
Sire type-age class	Days of ageing		
	5	14	21
Dorper lamb	56.6 ± 0.9 $^{a\,(x)}$	61.8 ± 0.9 $^{a\,(y)}$	63.2 ± 0.9 $^{a,b\,(y)}$
Maternal lamb	62.1 ± 0.9 $^{b\,(x)}$	67.6 ± 0.9 $^{b\,(y)}$	68.2 ± 0.9 $^{c\,(y)}$
Merino lamb	64.0 ± 0.8 $^{b\,(x)}$	67.5 ± 0.8 $^{b\,(y)}$	67.8 ± 0.8 $^{c\,(y)}$
Terminal lamb	62.5 ± 0.8 $^{b\,(x)}$	66.9 ± 0.8 $^{b\,(y)}$	65.9 ± 0.8 $^{a,c\,(y)}$
Merino yearling	57.8 ± 0.9 $^{a\,(x)}$	60.1 ± 0.9 $^{a\,(y)}$	60.6 ± 0.9 $^{b\,(y)}$

Sire type differences within a column with different letters (a-c) differ significantly (P < 0.05);
Ageing differences within a row with different letters (x-y) differ significantly (P < 0.05).

The effect of sire type-age class on overall liking scores also differed between the different ageing times. As ageing time increased, there was a significant increase (P < 0.05; Table 8) in overall liking scores for the Dorper, Maternal, Merino and Terminal sired lambs, and Merino yearlings. These differences were observed at 14 and 21 days of ageing compared to 5 days. The largest improvement due to ageing was observed in the Maternal sired lambs with overall liking increasing by 5.5 scores from 5 to 14 days (Fig. 1), compared to the Merino yearlings where there was an increase of only 2.3 scores over the same ageing period. No significant differences were observed beyond 14 days of ageing.

Within ageing times, lamb sire type comparisons showed that Dorper lambs were significantly different compared to the Maternal, Merino and Terminal sired lambs at 5 and 14 days of ageing, whereas at 21 days of ageing the difference between Dorper lambs and Terminal sired lambs did not exist.

Figure 1. Impact of number of days of ageing on overall liking scores according by sire type-age class groups.



4.2.2 Age class

Age class also had a significant effect on eating quality scores with Merino yearlings having on average 6.9 overall liking scores lower compared to Merino sired lambs across all ageing times ($P < 0.05$; Table 7). This effect was also observed within each ageing time with Merino yearlings having 6.2, 7.4 and 7.2 overall liking scores lower than the Merino lambs at 5, 14 and 21 days of ageing (Table 8).

4.3 Inclusion of pH and temperature measures

To test whether ageing time differences in eating quality were accounted for by muscle pH and temperature, temperature at pH 6 and pH at 18 °C were tested individually within the base models.

4.3.1 Temperature at pH 6

4.3.1.1 Effect on eating quality

The temperature at pH 6 had a curvilinear effect on eating quality for the different cuts tested ($P < 0.05$; Fig. 3), however did not differ across the different ageing times ($P > 0.05$; Fig. 2). Beyond 18°C, overall liking scores increased by 4.8 scores up to 33.5°C, whereas eating quality scores were lower in carcases cooler than 18°C (Fig. 3).

Figure 2: Effect of days ageing on the cut overall liking scores, corrected for temperature at pH 6.

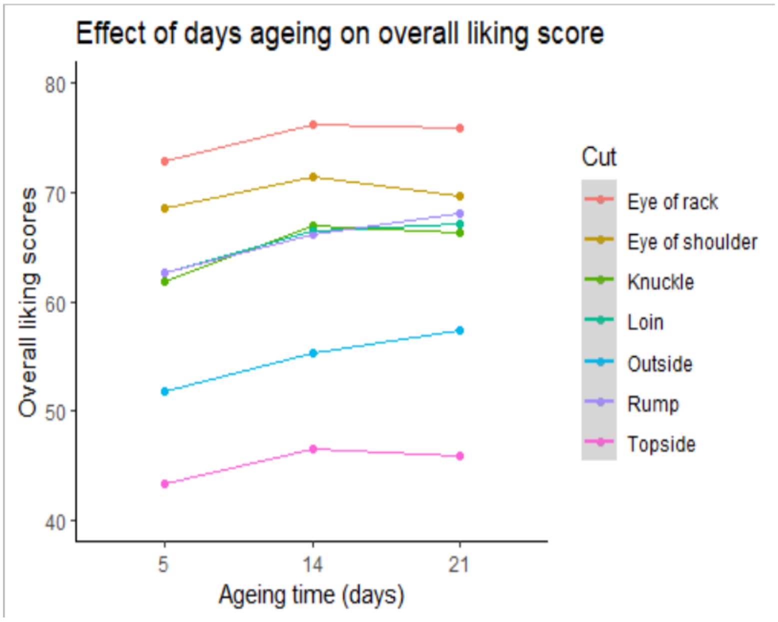
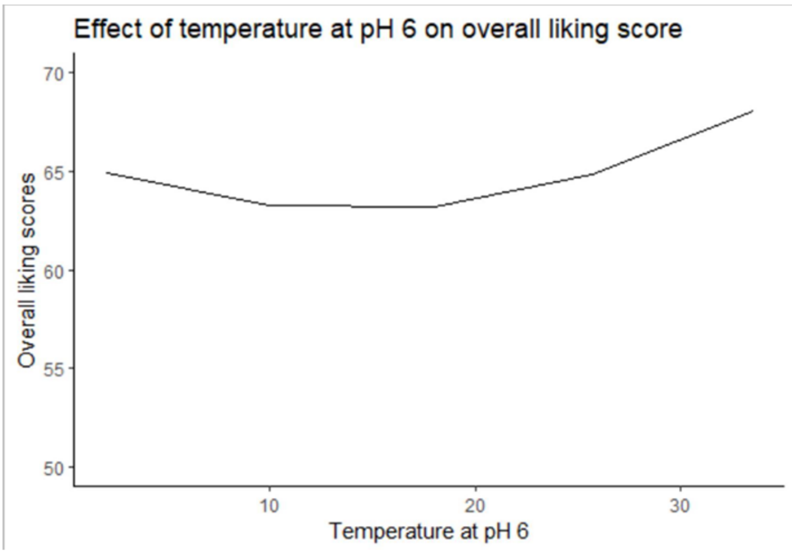


Figure 3: Relationship between temperature at pH 6 and overall liking scores.



4.3.1.2 Ageing times and cut differences

Compared to the base model, the effect of ageing on overall liking scores remained significant (P < 0.05; Table 9) however was no longer observed for each cut. On average across all cuts, increasing ageing times from 5 to 14 days, increased overall liking scores by 3.7 scores, and 3.9 scores from 5 to 21 days. No difference was observed between 14 and 21 days of ageing.

Table 9. Least square means ± SE of the base model corrected for temperature at pH 6, for the effect of cut by ageing for overall liking sensory scores.

Cut	Days ageing		
	5	14	21
Eye of rack	72.8 ± 0.8 $^{a (x)}$	76.2 ± 0.9 $^{a (x)}$	76.0 ± 0.9 $^{a (x)}$
Eye of shoulder	68.6 ± 1.1 $^{a (x)}$	71.5 ± 1.1 $^{b (x)}$	69.8 ± 1.2 $^{b (x)}$
Knuckle	61.9 ± 0.8 $^{b (x)}$	67.0 ± 0.8 $^{b (y)}$	66.3 ± 0.9 $^{b (y)}$
Loin	62.6 ± 0.8 $^{b (x)}$	66.5 ± 0.8 $^{b (y)}$	67.1 ± 0.8 $^{b (y)}$
Outside	51.7 ± 0.8 $^{c (x)}$	55.3 ± 0.8 $^{c (y)}$	57.4 ± 0.8 $^{c (y)}$
Rump	62.6 ± 1.1 $^{b (x)}$	66.2 ± 1.2 $^{b (x,y)}$	68.1 ± 1.1 $^{b (y)}$
Topside	43.4 ± 0.8 $^{d (x)}$	46.5 ± 0.9 $^{d (x)}$	46.0 ± 0.8 $^{d (x)}$

Cut differences within a column with different letters (a-d) differ significantly (P < 0.05);
Ageing differences within a row with different letters (x-y) differ significantly (P < 0.05).

4.3.1.3 Sire type and age class differences

With the inclusion of temperature at pH 6 into the base model, variation between Dorper sired lambs with Maternal, Merino and Terminal sired lambs still exists (Table 10). When corrected for temperature at pH 6, on average Dorper sired lambs scored 4.6, 4.8 and 6.6 overall liking scores lower than Terminal, Maternal and Merino sired lambs, compared to 4.6, 5.5 and 5.9 units in the base model.

Table 10. Least square means ± SE of the base model corrected for temperature at pH 6, for the effect of sire type-age class for overall liking sensory scores.

Age Class	Sire type	Overall liking
Lamb	Dorper	59.9 ± 0.9 ^{a}
Lamb	Maternal	64.7 ± 0.9 ^{b}
Lamb	Merino	66.5 ± 1.0 ^{b}
Lamb	Terminal	64.5 ± 0.8 ^{b}
Yearling	Merino	59.5 ± 1.1 ^{a}

Sire type differences within a column with different letters (a-b) differ significantly (P < 0.05)

Table 11. Least square means ± SE of the base model corrected for temperature at pH 6, for the effect of ageing according to sire type-age class for overall liking sensory scores.

Sire type-age class	Days ageing		
	5	14	21
Dorper lamb	56.0 ± 1.0 $^{a (x)}$	60.7 ± 1.0 $^{a (y)}$	62.9 ± 1.0 $^{a,b (y)}$
Maternal lamb	60.8 ± 1.1 $^{b,c (x)}$	66.4 ± 1.1 $^{b (y)}$	66.9 ± 1.1 $^{a (y)}$
Merino lamb	64.6 ± 1.2 $^{c (x)}$	67.2 ± 1.2 $^{b (x)}$	67.7 ± 1.2 $^{a (x)}$

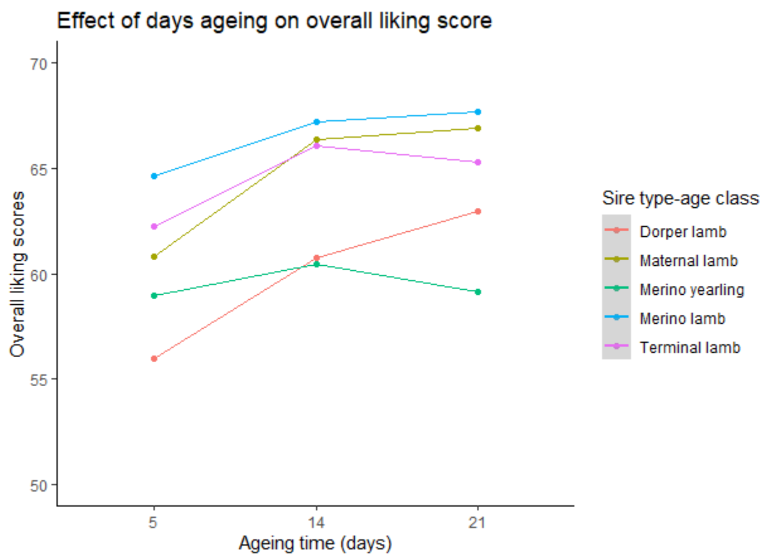
Terminal lamb	62.2 ± 0.9 b,c (x)	66.1 ± 0.9 b (y)	65.3 ± 1.2 a (y)
Merino yearling	59.0 ± 1.2 a,b (x)	60.4 ± 1.2 a (x)	59.1 ± 0.9 b (x)

Sire type differences within a column with different letters (a-c) differ significantly (P < 0.05);
Ageing differences within a row with different letters (x-y) differ significantly (P < 0.05).

When corrected for temperature at pH 6, the sire type-age class by ageing effect remained in the model. Similar to the base model, there was a significant increase (P < 0.01) in overall liking scores for the Dorper, Maternal and Terminal sired lambs from 5 to 14, and 5 to 21 days of ageing (Table 11). The Maternal, Dorper and Terminal sired lambs increased by 5.6, 4.7 and 3.9 overall liking scores from 5 to 14 days, compared to 5.5, 5.2 and 4.3 scores in the base model (Table 8). The ageing differences for the Merino lambs and yearlings was no longer present (P > 0.05) between 5 and 14 days, and 5 and 21 days of ageing, when corrected for temperature at pH 6.

Within ageing times, at 5 and 14 days, lamb sire type comparisons remained significantly different (P < 0.05) between Dorper sired lambs compared to Maternal, Merino and Terminal sired lambs. However, at 21 days ageing, there was no longer a significant difference (P > 0.05) between Dorper lambs compared to Maternal, Terminal and Merino lambs (Fig. 4).

Figure 4. Impact of number of days ageing, corrected for temperature at pH 6, on overall liking scores according to sire type-age class groups.



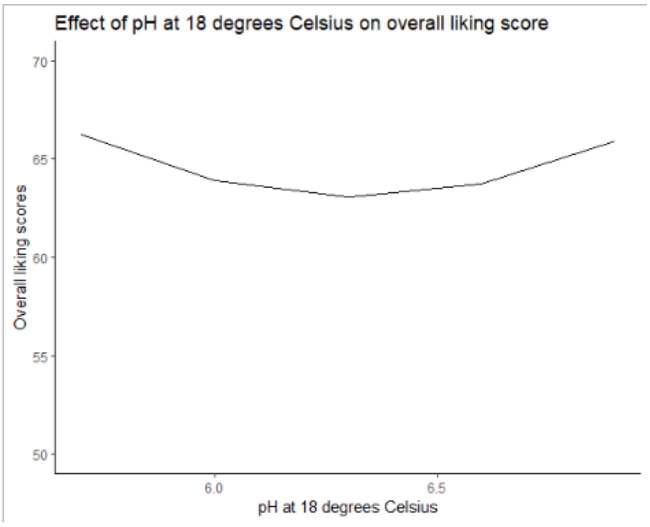
The significant effect of age class remained when correcting for temperature at pH 6 within the base model. On average, Merino yearlings were 7.0 overall liking scores lower than Merino lambs, a very similar magnitude to the base model (6.9 scores). This effect also remained within each ageing time with Merino yearlings having 5.6, 6.8 and 8.6 overall liking scores lower than Merino lambs at 5, 14 and 21 days of ageing.

4.3.2 pH at 18°C

4.3.2.1 Effect on eating quality

The pH at 18°C had a curvilinear effect for the different cuts tested ($P < 0.05$), and this differed across the ageing times ($P < 0.05$). Below a pH of 6.0, there was an increase of 2.3 overall liking scores to 5.7 pH units.

Figure 5. Relationship between pH at 18°C and overall liking scores



4.3.2.2 Ageing times and cut differences

Across ageing times, the mean eating quality differences, although slightly reduced in magnitude, between the 5 and 14 days of ageing remained significant ($P < 0.01$; Table 12) for the eye of rack, knuckle, loin, and outside cuts when including pH at 18°C in the base model. In addition, a significant increase ($P < 0.05$) in overall liking scores between 5 and 14 days was now present for the eye of shoulder, rump and topside when pH at 18°C was included in the base model. Between 5 and 21 day aged samples, a substantial increase of between 4.0 and 6.5 overall liking scores remained evident for the eye of rack, loin, knuckle, rump and outside ($P < 0.01$).

Compared to the base model, inclusion of pH at 18°C retained most cut differences within the three ageing times, however the eye of shoulder was no longer significantly different from the knuckle and rump ($P > 0.05$) at 14 days of ageing.

Table 12. Least square means ± SE of the base model corrected for pH at 18°C, for the effect of cut by ageing for overall liking sensory scores.

Cut	Days ageing		
	5	**14**	**21**
Eye of rack	71.8 ± 0.7 $^{a\,(x)}$	75.3 ± 0.7 $^{a\,(y)}$	75.8 ± 0.7 $^{a\,(y)}$
Eye of shoulder	67.4 ± 1.0 $^{b\,(x)}$	71.5 ± 0.9 $^{b\,(y)}$	71.4 ± 1.0 $^{b\,(x,y)}$
Knuckle	61.3 ± 0.7 $^{c\,(x)}$	68.1 ± 0.7 $^{b,c\,(y)}$	67.0 ± 0.7 $^{c\,(y)}$
Loin	62.2 ± 0.7 $^{c\,(x)}$	67.0 ± 0.7 $^{c\,(y)}$	66.7 ± 0.7 $^{c\,(y)}$
Outside	51.8 ± 0.7 $^{d\,(x)}$	55.9 ± 0.7 $^{d\,(y)}$	58.3 ± 0.7 $^{d\,(y)}$
Rump	63.0 ± 0.9 $^{c\,(x)}$	67.4 ± 1.0 $^{b,c\,(y)}$	69.0 ± 1.0 $^{b,c\,(y)}$
Topside	43.5 ± 0.7 $^{e\,(x)}$	46.6 ± 0.7 $^{e\,(y)}$	46.4 ± 0.7 $^{e\,(x,y)}$

Cut differences within a column with different letters (a-e) differ significantly (P < 0.05)
Ageing differences within a row with different letters (x-y) differ significantly (P < 0.05).

4.3.2.3 Sire type and age class differences

With pH at 18°C included in the base model, the variation between Dorper sired lambs compared to Maternal, Merino and Terminal sired lambs remained significant across the different ageing times as the sire type-age class by ageing effect remained in the model when corrected for pH at 18°C. At 5 and 14 days of ageing, Dorper sired lambs had significant lower (P < 0.05) overall liking scores compared to the Maternal, Merino and Terminal sired lambs, when corrected for pH at 18°C (Table 13; Fig. 6).

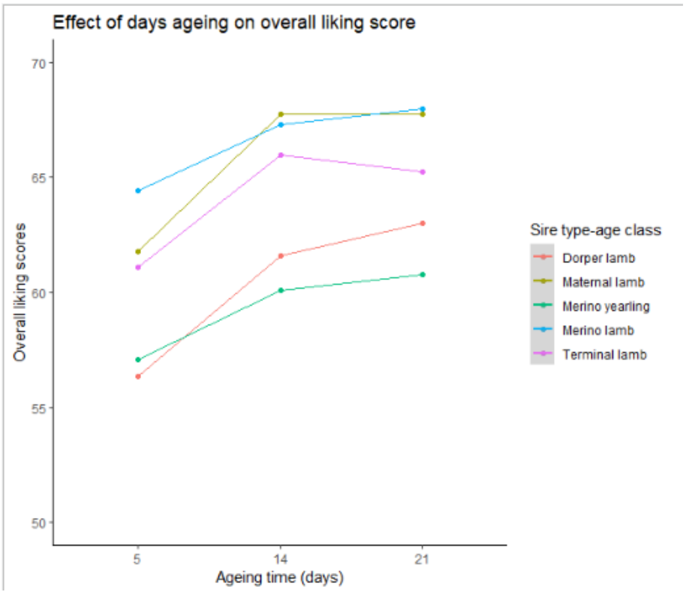
Furthermore, a significant increase (P < 0.05) in overall liking scores remained for the Dorper, Maternal, Merino and Terminal sired lambs and Merino yearlings between 5 and 14, and 5 and 21 days ageing when pH at 18°C was included in the base model (Table 13). From 5 to 14 days ageing, there was an increase of 2.9, 4.9, 5.2 and 5.9 overall liking scores for Merino, Terminal, Dorper and Maternal sired lambs, compared to the base model increases of 3.5, 4.3, 5.2 and 5.5 scores.

Table 13. Least square means ± SE of the base model corrected for pH at 18°C, for the effect of ageing by sire type-age class for overall liking sensory scores.

Sire type-age class	Days ageing		
	5	**14**	**21**
Dorper lamb	56.4 ± 0.9 $^{a\,(x)}$	61.6 ± 0.9 $^{a\,(y)}$	63.0 ± 0.9 $^{a,b\,(y)}$
Maternal lamb	61.8 ± 0.9 $^{b\,(x)}$	67.7 ± 0.9 $^{b\,(y)}$	67.8 ± 0.9 $^{c\,(y)}$
Merino lamb	64.4 ± 0.9 $^{b\,(x)}$	67.3 ± 0.9 $^{b\,(y)}$	68.0 ± 0.9 $^{c\,(y)}$
Terminal lamb	61.1 ± 0.9 $^{b\,(x)}$	66.0 ± 0.9 $^{b\,(y)}$	65.2 ± 0.9 $^{a,c\,(y)}$
Merino yearling	57.1 ± 1.0 $^{a\,(x)}$	60.1 ± 1.0 $^{a\,(y)}$	60.8 ± 1.0 $^{b\,(y)}$

Sire type differences within a column with different letters (a-c) differ significantly (P < 0.05);
Ageing differences within a row with different letters (x-y) differ significantly (P < 0.05).

Figure 6. Impact of number of days ageing, corrected for pH at 18°C, on overall liking scores according to sire type-age class groups.



The significant effect of age class between the Merino lambs and Merino yearlings remained when pH at 18°C was included in the base model. On average, Merino yearlings were 7.0 overall liking scores lower than Merino lambs when corrected for pH at 18°C. Within each ageing time, this effect also remained with Merino yearlings having 7.3, 7.2 and 7.2 overall liking scores lower at 5, 14 and 21 days of ageing than Merino lambs.

4.4 pH and temperature measures

Outcomes of the linear mixed effects models of HSCW and the pH and temperature dependent variables are presented in Table 14. There were no significant differences between any of the sire type-age class groups for loin pH at 24 hr, temperature at pH 6 and pH at 18°C, except for the Merino lambs compared to the Terminal lambs and Merino yearlings which had a 0.07 and 0.15 unit higher pH at 18°C. There were significant differences between HSCW of the Merino lambs compared to the Terminal sired lambs (5.53 kg) and Merino yearlings (8.87 kg)

Table 14. Least square means ± SE for the effect of sire type-age class on hot standard carcase weight (HSCW), loin pH at 24 hr, temperature at pH 6 and pH at 18°C.

Age Class	Sire type	HSCW (kg)	Temp. at pH 6 (°C)	pH at 18°C
Lamb	Dorper	21.50 ± 0.68 ^{ab}	13.81 ± 1.87 ^{a}	6.13 ± 0.05 ^{a,b}
Lamb	Maternal	21.10 ± 0.58 ^{ab}	10.78 ± 2.05 ^{a}	6.23 ± 0.04 ^{a,b}
Lamb	Merino	18.16 ± 0.60 ^{a}	12.32 ± 2.17 ^{a}	6.29 ± 0.04 ^{a}
Lamb	Terminal	23.69 ± 0.55 ^{b}	13.27 ± 1.51 ^{a}	6.22 ± 0.04 ^{b}
Yearling	Merino	27.03 ± 0.74 ^{b}	16.16 ± 2.21 ^{a}	6.14 ± 0.06 ^{b}

Sire type-age class within a column with different letters differ significantly (P < 0.05).

5. Discussion

5.1 Effect of cut and ageing time on eating quality scores

Partially supporting our hypothesis, there was an increase in overall liking scores of the eye of rack, knuckle, loin, outside, and rump as days of ageing increased from 5 to 14, and 5 to 21 days. However, there was no additional benefit to ageing cuts from 14 to 21 days. These findings align with previous work which found increases in eating quality with increased days of ageing (Thompson et al., 2005b). Tenderness, juiciness, flavour liking and overall liking had the greatest improvement from 2 to 5 days of ageing in the loin and outside cuts, with little improvement seen from 5 days to 14 days of ageing (Thompson et al., 2005b). Similarly, improved eating quality scores were observed when loin samples were aged from 1 to 3 to 5 days of ageing (Hopkins et al., 2005) and from 2 to 4 days of ageing (Shaw et al., 2005). Given that ageing rates found in sheepmeat are more rapid (Thompson et al., 2005b) than those previously reported in beef (Shorthose et al., 1986), it is possible that beyond 14 days of ageing, undesirable flavours become apparent (Juarez et al., 2010; Thompson et al., 2005b), which may explain no change in overall liking scores from 14 to 21 days of ageing. Furthermore, increased moisture loss in cuts aged from 14 to 21 days may have occurred as intramuscular moisture levels are known to play an important role during the cooking process (Juarez et al., 2010).

For the rump, overall liking scores increased from 5 to 21 days only, with no significant ($P < 0.05$) increase from 5 to 14 days (Table 6). The slower rate of overall liking improvement found in the rump may signify lower proteolytic activity within this cut which has previously been reported in beef (Rhee et al., 2004). In addition, differences in muscle composition and structure of this cut may have contributed to this effect (Rhee et al., 2004). In contrast to our initial hypothesis, there was no improvement in overall liking of the eye of shoulder and topside across the three ageing times, perhaps as a result of muscle compositional attributes, including the high level of connective tissue present within the eye of shoulder cut, and the mediation of moisture loss during ageing (Juarez et al., 2010).

As expected, the largest amount of variation in the base model was explained by differences in cut eating quality, agreeing with previous studies (Pannier et al., 2014; Payne et al., 2020; Polkinghorne et al., 2008). Variations in cut eating quality can be explained by varying levels of intramuscular fat and moisture content (Kosulwat et al., 2003; Pannier et al., 2014), sarcomere length (Wheeler & Koohmaraie, 1999), fibre type (Lefaucheur, 2010) and connective tissue (Astruc, 2014). However, similarities in the overall liking scores of the knuckle, loin and rump samples independent of ageing time were found in this study.

5.2 Effect of sire type and age class on eating quality scores

For all lamb sire type groups, increasing ageing time from 5 to 14 days improved overall liking scores, with no improvement beyond 14 days of ageing. This confirms the rapid ageing rate in sheep (Thompson et al., 2005b) and the improved eating quality benefits of the combination of ageing and electrical stimulation.

The sire type by ageing interaction impacted on overall liking scores with Dorper lambs producing less acceptable meat compared to Maternal, Merino and Terminal sired lambs within all three ageing times. This is in contrast to Snowder and Duckett (2003) who reported higher sensory scores for tenderness and juiciness in Dorper lamb chops compared to Terminal sired lamb chops at 10 days of ageing. However, the latter study only comprised of 10 lamb chops per sire type and trained panellists (n= 8) were used to assess the products (Snowder & Duckett, 2003), and as such, this may account for the discrepancy seen between studies. To our knowledge there are limited studies comparing the eating quality attributes of grilled cuts from Dorper lambs with Maternal, Merino and Terminal sired lambs, making comparison with the literature difficult. Furthermore, there was no significant difference between the sire type-age class groups for HSCW, which could have affected the rate of pH decline, and as such the sire type-age class group differences may be attributed to other genetic factors accounting for these differences. Further investigation is required to understand the sire type effects by potentially the inclusion of specific sire type breeding values.

Supporting our hypothesis, there was a decline in overall liking scores as animal age increased. This agrees with previous findings of Hopkins et al. (2006) and Jeremiah et al. (1971). However, previous studies have reported no difference in overall liking scores between Merino lamb and yearling loins (Pannier et al., 2019; Pethick et al., 2005), indicating the potential to develop yearling products at a more premium price point. As animals age, the amount of insoluble collagen within the muscles increases due to crosslinking (Young & Braggins, 1993), reducing the eating quality (Hopkins et al., 2007). However, because different muscles have different amounts of connective tissue (Astruc, 2014), there is a varying degree of impact across different cuts. This may explain why Pannier et al. (2019) and Pethick et al. (2005) reported no differences between Merino lamb and yearling loins, as the loin is known to have a lower proportion of connective tissue compared to cuts particularly from the leg (Rhee et al., 2004). Whereas in this study, across the average of the seven different cuts, an age class difference was present. The results of this study support the conclusion of Jeremiah (2000) that for maximum consumer appeal, lambs should be marketed before 12 months of age.

The age class by ageing time interaction remained across the 5, 14 and 21 days with Merino yearlings scoring between 6.2 and 7.4 overall liking points lower than Merino lambs. These differences between Merino lambs and yearlings at each ageing time were similar. Therefore, there is a similar impact of days of ageing on the improvement of eating quality regardless of animal age.

5.3 Impact of pH-temperature decline

A large proportion of animals from this study were cold shortened as evidenced through low mean temperatures at pH 6 (Table 5). Cold shortening occurs through the rapid cooling of carcases directly after slaughter, prior to the formation of lactic acid from glycogen. Increased muscle shortening is a consequence of cold shortening (Jaime et al., 1992; Marsh & Leet, 1966). Sarcomere shortening is generally accepted as the cause of toughening in carcases 24 hr post-slaughter, and over time proteolysis disrupts the myofibrillar structure, resulting in improved tenderness (Wheeler & Koohmaraie, 1994). The impact of cold shortening on sensory attributes other than tenderness has not been extensively explored.

Temperature at pH 6 accounted for all of the eating quality differences in cuts between ageing times, as the cut by ageing time interaction was no longer significant with the inclusion of temperature at pH 6 in the base model. These results are similar to the outcomes of Thompson et al. (2005b), whereby findings suggested that ageing of the loin and outside to 14 days may provide little improvement when adjusted for temperature at pH 6. However, there was an increase of 4.1 and 3.2 overall liking scores reported in the loin and outside between 2 and 5 days ageing when corrected for temperature at pH 6 (Thompson et al., 2005b). Although there was no 2 day ageing category in the current study, the results from 5 to 14 days ageing align with those of Thompson et al. (2005b) in that improvement in eating quality occurs with increased ageing time. Therefore, it is speculated that a larger increase in overall liking scores would have been observed between 2 and 5 days ageing in our study than what was established between 5 and 14 days, due to the more rapid ageing rates found in sheepmeat (Thompson et al., 2005b).

In contrast, the inclusion of pH at 18 °C into the base model did not account for all the variation in eating quality between the different cuts across the three ageing times, as the cut by ageing time interaction remained significant in the model. Due to the high correlation between temperature at pH 6 and pH at 18 °C (-0.90; not presented), this was an unexpected finding. However, although temperature at pH 6 and pH at 18 °C are both measurements of the rate of decline to determine when carcases enter rigor mortis and are highly correlated (-0.90), variation between them still exists.

The sire type by ageing impact on overall liking remained in the model with the inclusion of temperature at pH 6, indicating that lamb sire type differences exist beyond just differences in temperature at pH 6. As highlighted above, HSCW was not different between the lamb sire type groups, and as such the observed differences may be attributed to other factors which need to be explored. In addition, the effect of age class remained when corrected for temperature at pH 6. Although Merino yearling carcases were heavier than Merino lamb carcases, this was corrected for through the temperature at pH 6 covariate, and as the variation in overall liking scores between lambs and yearlings is not reduced, it is likely other factors are contributing to the differences exhibited in age class and requires further investigation, especially as these differences remained consistent across each of the ageing times.

The inclusion of pH at 18 °C into the base model reported similar outcomes as the inclusion of temperature at pH 6 for the sire type by ageing effects. Due to the high correlation between these traits, this was not surprising.

6. Conclusion

Extended ageing to 14 or 21 days did improve lamb eating quality compared to 5 days, however ageing lamb cuts from 14 to 21 days provides no additional improvement in overall liking scores. The extent of ageing differs between cuts and is likely due to a multitude of factors including rigor contraction, glycogen availability at slaughter and muscle composition and structure. As pH at 18°C and temperature at pH 6 accounted for a proportion of the variance in overall liking, this demonstrated that poor eating quality as a result of process-induced shortening can be overcome by extended ageing. Dorper sired lamb differences with Maternal, Merino and Terminal sired lambs were present across each of the ageing times suggesting that other genetic factors may impact the variation and extent of ageing observed. A consistent difference at 5, 14 and 21 days of ageing between Merino lambs and yearlings was found, suggesting that animal age related muscle compositional factors may be causing this variation. Of particular importance from this study at an industry level is the requirement for development of maximum ageing times for cuts so that depreciation in eating quality due to ageing does not occur.

6.1 Key findings

Key finding from this project include:

- Extended ageing to 14 or 21 days did improve lamb eating quality with little improvement beyond 14 days.
- Ageing of the eye of shoulder and topside to 14 or 21 days does not improve the overall liking compared to 5 days.
- Overall liking of the rump cut benefits from being aged to 21 days compared to 5 and 14 days.
- Temperature at pH 6 accounts for the differences between cuts across the ageing times.
- Dorper sired lambs produce the least acceptable meat, with Maternal, Merino and Terminal sired lamb cuts being of similar quality.
- At 5, 14 and 21 days ageing, lamb sire type differences between Dorper lambs compared to Maternal, Merino and Terminal sired lambs are considered less acceptable.
- The eating quality of Merino yearlings is found to be less acceptable compared to Merino lambs, regardless of ageing time.

6.2 Benefits to industry

The data of this project will be incorporated into the MSA eating quality database where it will be utilised to inform the prediction of MSA graded products at a commercial level. In particular, it will deliver an expanded version of the MSA Mark II cut-based model for lamb with the inclusion of ageing time as a factor in the model.

7. Future research and outcomes

Future work will look at:

- The effect of loin residual glycogen on lamb eating quality of a variety of cuts.
- The impact of individual cut residual glycogen on lamb eating quality.
- Understanding factors accounting for differences in sire type eating quality: Dorper sired lambs vs. Maternal, Merino and Terminal sired lambs.
- Analysis to understand inclusion of Dorper sired lambs within the new developed MSA cut-based model.
- Analysis to understand impact of minimum MSA HSCW requirement in relation to pH outcomes and effect on ageing times.
- Impact of lambs versus yearlings within the new developed MSA cut-based model (with also the inclusion of older eating quality datasets including both animal groups).
- Impact of ASBVs on the ageing potential of the different lamb sire types.
- Development of maximum ageing times for cuts so that depreciation in eating quality due to ageing does not occur.

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9. Appendix

Additional Tables are provided for the outcomes of tenderness, juiciness, flavour and MQ4 as the main analysis in the report describes overall liking as a representation of all sensory traits given the high correlation between sensory attributes.

MQ4 has been calculated as MQ4 = 0.3×tenderness + 0.1×juiciness + 0.3× flavour + 0.3×overall liking

Base Model Tables:

Table Apx.1. Least square means ± SE for the effect of cut by ageing for sensory trait scores.

Cut	Days of ageing		
	5	14	21
	Tenderness		
Eye of rack	74.7 ± 0.8 $^{a\,(x)}$	78.8 ± 0.8 $^{a\,(y)}$	79.0 ± 0.8 $^{a\,(y)}$
Eye of shoulder	67.0 ± 1.0 $^{b\,(x)}$	72.6 ± 1.0 $^{b\,(y)}$	72.1 ± 1.0 $^{b\,(y)}$
Knuckle	61.1 ± 0.8 $^{c\,(x)}$	69.1 ± 0.8 $^{b,c\,(y)}$	68.7 ± 0.8 $^{b\,(y)}$
Loin	63.4 ± 0.8 $^{b,c\,(x)}$	68.9 ± 0.8 $^{c\,(y)}$	69.1 ± 0.8 $^{b\,(y)}$
Outside	46.3 ± 0.8 $^{d\,(x)}$	50.3 ± 0.8 $^{d\,(y)}$	54.0 ± 0.8 $^{c\,(z)}$
Rump	61.7 ± 1.0 $^{c\,(x)}$	66.2 ± 1.0 $^{c\,(y)}$	68.1 ± 1.0 $^{b\,(y)}$
Topside	36.6 ± 0.8 $^{e\,(x)}$	39.3 ± 0.8 $^{e\,(x,y)}$	39.9 ± 0.8 $^{d\,(y)}$
	Juiciness		
Eye of rack	71.0 ± 0.8 $^{a\,(x)}$	74.5 ± 0.8 $^{a\,(y)}$	74.0 ± 0.8 $^{a\,(y)}$
Eye of shoulder	70.3 ± 1.0 $^{a,b\,(x)}$	72.5 ± 1.0 $^{a\,(x)}$	73.3 ± 1.0 $^{a\,(x)}$
Knuckle	58.1 ± 0.8 $^{c\,(x)}$	64.9 ± 0.8 $^{b\,(y)}$	64.4 ± 0.8 $^{b\,(y)}$
Loin	59.6 ± 0.8 $^{b,c,d\,(x)}$	64.2 ± 0.8 $^{b\,(y)}$	63.5 ± 0.8 $^{b\,(y)}$
Outside	52.2 ± 0.8 $^{e\,(x)}$	55.8 ± 0.8 $^{c\,(y)}$	58.1 ± 0.8 $^{c\,(y)}$
Rump	61.8 ± 1.0 $^{d\,(x)}$	64.5 ± 1.0 $^{b\,(x,y)}$	66.5 ± 1.0 $^{b\,(y)}$
Topside	43.5 ± 0.8 $^{f\,(x)}$	45.5 ± 0.8 $^{d\,(x)}$	45.4 ± 0.8 $^{d\,(x)}$
	Flavour		
Eye of rack	71.5 ± 0.6 $^{a\,(x)}$	74.8 ± 0.6 $^{a\,(y)}$	74.6 ± 0.6 $^{a\,(y)}$
Eye of shoulder	68.2 ± 0.8 $^{b\,(x)}$	71.1 ± 0.8 $^{b\,(x)}$	71.9 ± 0.8 $^{a\,(x)}$
Knuckle	61.0 ± 0.6 $^{c\,(x)}$	67.3 ± 0.6 $^{c\,(y)}$	66.5 ± 0.6 $^{b\,(y)}$
Loin	63.8 ± 0.6 $^{d\,(x)}$	67.7 ± 0.6 $^{c\,(y)}$	67.2 ± 0.6 $^{b\,(y)}$
Outside	55.3 ± 0.6 $^{e\,(x)}$	58.0 ± 0.6 $^{d\,(y)}$	59.6 ± 0.6 $^{c\,(y)}$
Rump	62.9 ± 0.8 $^{c,d\,(x)}$	67.1 ± 0.8 $^{c\,(y)}$	68.5 ± 0.8 $^{b\,(y)}$
Topside	48.3 ± 0.6 $^{f\,(x)}$	50.4 ± 0.6 $^{e\,(x)}$	50.0 ± 0.6 $^{d\,(x)}$
	MQ4		
Eye of rack	72.7 ± 0.6 $^{a\,(x)}$	76.5 ± 0.6 $^{a\,(y)}$	76.4 ± 0.6 $^{a\,(y)}$
Eye of shoulder	68.1 ± 0.8 $^{b\,(x)}$	71.9 ± 0.8 $^{b\,(y)}$	72.1 ± 0.8 $^{b\,(y)}$
Knuckle	60.8 ± 0.6 $^{c\,(x)}$	67.9 ± 0.6 $^{c\,(y)}$	67.3 ± 0.6 $^{c\,(y)}$
Loin	63.0 ± 0.6 $^{c\,(x)}$	67.7 ± 0.6 $^{c\,(y)}$	67.4 ± 0.6 $^{c\,(y)}$
Outside	51.3 ± 0.6 $^{d\,(x)}$	54.8 ± 0.6 $^{d\,(y)}$	57.3 ± 0.6 $^{d\,(y)}$
Rump	62.4 ± 0.8 $^{c\,(x)}$	66.4 ± 0.8 $^{c\,(y)}$	68.3 ± 0.8 $^{b,c\,(y)}$
Topside	43.1 ± 0.6 $^{e\,(x)}$	45.5 ± 0.6 $^{e\,(x)}$	45.8 ± 0.6 $^{e\,(x)}$

Cut differences within a column without common letters (a-c) differ significantly (P < 0.05);
Ageing differences within a row without common letters (x-y) differ significantly (P < 0.05).

Increasing ageing times significantly increased juiciness and flavour liking scores (P < 0.05; Table Apx.1) for the eye of rack, knuckle, loin, outside and rump cuts, and the tenderness scores of all cuts.

The largest effect of ageing was seen within tenderness scores. The MQ4 scores also significantly increased ($P < 0.05$; Apx.1) for all cuts, except the topside. Predominantly, differences were observed for each cut with higher scores at 14 and 21 days compared to 5 days of ageing. The largest improvement due to ageing was observed for the knuckle cut from 5 to 14 days of ageing. No improvement in juiciness and flavour scores across ageing times was found for the eye of shoulder and topside cuts. In addition, no eating quality improvement was observed from 14 to 21 days of ageing for any of the cuts tested, except the tenderness of the outside which further improved by 3.7 scores over the 7-day ageing period.

On average, all consumer-assessed sensory scores and the MQ4 score, from Dorper sired lambs were generally lower than for the Merino, Maternal and Terminal sired lambs, with no differences observed between the latter three sire type groups (Table Apx.2).

Table Apx.2 Least square means ± SE for the effect of sire type-age class for sensory trait scores.

Age Class	Sire type	Tenderness	Juiciness	Flavour	MQ4
Lamb	Dorper	58.5 ± 1.0 [a]	58.8 ± 0.9 [a]	61.4 ± 0.7 [a]	60.0 ± 0.8 [a]
Lamb	Maternal	65.8 ± 1.0 [b]	64.4 ± 0.9 [b]	66.0 ± 0.7 [b]	65.8 ± 0.8 [b]
Lamb	Merino	66.0 ± 0.9 [b]	64.5 ± 0.9 [b]	66.8 ± 0.6 [b]	66.2 ± 0.7 [b]
Lamb	Terminal	63.9 ± 0.9 [b]	62.8 ± 0.9 [b]	65.3 ± 0.6 [b]	64.6 ± 0.7 [b]
Yearling	Merino	57.0 ± 1.1 [a]	59.8 ± 1.0 [a]	61.0 ± 0.7 [a]	59.2 ± 0.8 [a]

Sire type differences within a column without common letters (a-b) differ significantly ($P < 0.05$).

The effect of sire type-age class also differed between the different ageing times for tenderness, juiciness, flavour and MQ4 scores. Within ageing times, lamb sire type comparisons showed that Dorper lambs were significantly different (lower) compared to the Maternal, Merino and Terminal sired lambs at 5 and 14 days of ageing, whereas at 21 days of ageing, the difference between Dorper and Terminal sired lambs did not exist for tenderness, juiciness, flavour and MQ4 scores (Table Apx.3). Also, there was no difference between flavour scores for Dorper and Maternal sired lambs at 21 days ageing.

As ageing time increased, there was a significant increase ($P < 0.05$; Apx.3) in sensory trait scores for the Dorper, Maternal, Merino and Terminal sired lambs, and Merino yearlings. These differences were observed at 14 and 21 days of ageing compared to 5 days, as well as from 14 to 21 days in Dorper sired lambs for tenderness. Beyond 14 days of ageing, no further improvement in eating quality was observed for any of the sire type-age class categories.

Age class had a significant effect on eating quality scores with Merino yearlings having tenderness, flavour and juiciness scores, on average, 9.0, 5.8 and 4.7 units lower compared to Merino sired lambs across all ageing times ($P < 0.01$; Table Apx.2). This effect was also observed within each ageing time with Merino yearlings having between 3.7 to 7.7, 6.0 to 10.5, and 4.5 to 8.9 eating quality scores (across tenderness, flavour and juiciness) lower than the Merino sired lambs at 5, 14 and 21 days of ageing (Table Apx.3). The largest effect of age class was seen within tenderness scores. There was also a significant effect of age class on MQ4 scores with Merino yearlings being on average 7.0 units lower than Merino sired lambs across all ageing times ($P < 0.01$; Table Apx.2). Within each ageing time, there was also a significant effect ($P < 0.01$; Table Apx.3) with Merino yearlings having 6.1, 7.9 and 7.1 MQ4 scores lower than the Merino sired lambs at 5, 14 and 21 days of ageing.

Table Apx.3. Least square means ± SE for the effect of ageing by sire type-age class for sensory trait scores.

Sire type-age class	Days of ageing		
	5	14	21
	Tenderness		
Dorper lamb	53.8 ± 1.1 a (x)	59.5 ± 1.1 a (y)	62.3 ± 1.1 a (z)
Maternal lamb	61.7 ± 1.1 b (x)	67.4 ± 1.1 b (y)	68.4 ± 1.1 b (y)
Merino lamb	62.6 ± 1.0 b (x)	67.9 ± 1.0 b (y)	67.5 ± 1.0 b (y)
Terminal lamb	60.5 ± 1.0 b (x)	65.8 ± 1.0 b (y)	65.3 ± 1.0 a,b (y)
Merino yearling	54.9 ± 1.2 a (x)	57.4 ± 1.2 a (y)	58.6 ± 1.2 a (y)
	Juiciness		
Dorper lamb	55.0 ± 1.0 a (x)	59.8 ± 1.0 a (y)	61.7 ± 1.0 a (y)
Maternal lamb	61.4 ± 1.0 b,c (x)	65.7 ± 1.0 b (y)	66.2 ± 1.0 b (y)
Merino lamb	62.1 ± 0.9 b (x)	65.8 ± 0.9 b (y)	65.6 ± 0.9 b (y)
Terminal lamb	60.7 ± 1.0 b (x)	64.4 ± 1.0 b (y)	63.4 ± 1.0 a,b (y)
Merino yearling	58.4 ± 1.1 a,c (x)	59.8 ± 1.1 a (x,y)	61.1 ± 1.1 a (y)
	Flavour		
Dorper lamb	58.0 ± 0.8 a (x)	62.4 ± 0.8 a (y)	63.9 ± 0.8 a,b (y)
Maternal lamb	63.1 ± 0.8 b (x)	67.5 ± 0.8 b (y)	67.4 ± 0.8 a,b (y)
Merino lamb	64.6 ± 0.7 b (x)	67.8 ± 0.7 b (y)	67.9 ± 0.7 b (y)
Terminal lamb	63.2 ± 0.7 b (x)	66.7 ± 0.7 b (y)	66.0 ± 0.7 a,b (y)
Merino yearling	59.2 ± 0.8 a (x)	61.6 ± 0.8 a (y)	62.1 ± 0.8 c (y)
	MQ4		
Dorper lamb	56.1 ± 0.9 a (x)	61.0 ± 0.9 a (y)	62.9 ± 0.9 a,b (y)
Maternal lamb	62.1 ± 0.9 b (x)	67.3 ± 0.9 b (y)	67.9 ± 0.9 c (y)
Merino lamb	63.5 ± 0.8 b (x)	67.6 ± 0.8 b (y)	67.6 ± 0.8 c (y)
Terminal lamb	61.9 ± 0.8 b (x)	66.3 ± 0.8 b (y)	65.4 ± 0.8 a,c (y)
Merino yearling	57.4 ± 0.9 a (x)	59.7 ± 0.9 a (y)	60.5 ± 0.9 b (y)

Sire type differences within a column without common letters (a-c) differ significantly ($P < 0.05$);
Ageing differences within a row without common letters (x-y) differ significantly ($P < 0.05$).

Base Model Tables when cold shortened animals were removed:

Animals with temperature at pH 6 lower than 12 °C were removed from the analysis (n = 45) and the MQ4 base model analysis was repeated. Within this model, the overall ageing effect remained though slightly reduced in magnitude between 5 to 14 days, and 5 to 21 days, however the interaction of cut by ageing time was no longer significant as the effect between 5 and 14 days ageing was only present for the knuckle and the loin cut having a reduced and similar magnitude respectively (Table Apx.4; from 7.1 to 2.2 for knuckle and from 4.7 to 4.9 for the loin).

Table Apx.4. Least square means ± SE for the effect of cut by ageing for sensory trait scores.

Cut	Days of ageing		
	5	14	21
	MQ4 (cold shortened animals removed)		
Eye of rack	74.9 ± 1.2 a (x)	77.4 ± 1.2 a (x)	77.1 ± 1.6 a (x)
Eye of shoulder	69.2 ± 1.4 b (x)	72.7 ± 1.6 a,b (x)	71.8 ± 1.6 a,b (x)
Knuckle	62.3 ± 1.2 c (x)	67.3 ± 1.2 b,c (y)	66.5 ± 1.2 b (x,y)
Loin	64.0 ± 1.2 b,c (x)	68.9 ± 1.2 b,c (y)	67.6 ± 1.2 b (x,y)
Outside	51.5 ± 1.2 d (x)	54.3 ± 1.2 d (x,y)	56.6 ± 1.2 c (y)
Rump	59.7 ± 1.7 c (x)	64.9 ± 1.6 c (x,y)	67.9 ± 1.4 b (y)
Topside	42.2 ± 1.2 e (x)	45.6 ± 1.2 e (x)	45.4 ± 1.2 d (x)

Cut differences within a column without common letters (a-c) differ significantly ($P < 0.05$);
Ageing differences within a row without common letters (x-y) differ significantly ($P < 0.05$).

Sire type-age class and sire type-age class by ageing effect remained significant within the MQ4 model when cold shortened animals were removed and average Dorper lambs were significantly lower in MQ4 score compared to Maternal, Merino and Terminal sired lambs, however this differed within ageing times with the effect seen at 5 days of ageing and not at 14 or 21 days of ageing (Table Apx.5).

Table Apx.5. Least square means ± SE for the effect of ageing by sire type-age class for sensory trait scores.

Sire type-age class	Days of ageing		
	5	14	21
	MQ4 (cold shortened animals removed)		
Dorper lamb	54.7 ± 1.5 $^{a\,(x)}$	61.2 ± 1.5 $^{a\,(y)}$	63.0 ± 1.5 $^{a,b\,(y)}$
Maternal lamb	62.4 ± 1.5 $^{b\,(x)}$	67.1 ± 1.5 $^{a\,(y)}$	68.8 ± 1.5 $^{a\,(y)}$
Merino lamb	64.0 ± 1.7 $^{b\,(x)}$	67.7 ± 1.7 $^{a\,(x)}$	66.1 ± 1.7 $^{a,b\,(x)}$
Terminal lamb	62.2 ± 1.3 $^{b\,(x)}$	66.3 ± 1.3 $^{a\,(y)}$	65.2 ± 1.3 $^{a,b\,(x,y)}$
Merino yearling	59.5 ± 1.8 $^{a,b\,(x)}$	59.9 ± 1.8 $^{a\,(x)}$	60.4 ± 1.8 $^{b\,(x)}$

Sire type differences within a column without common letters (a-c) differ significantly (P < 0.05); Ageing differences within a row without common letters (x-y) differ significantly (P < 0.05).

Furthermore, as ageing time increased, there was a significant increase (P < 0.5; Table Apx.5) in sensory trait scores for the Dorper, Maternal, and Terminal sired lambs from 5 to 14 days ageing, however this effect was no longer seen for the Merino lambs and yearlings. MQ4 scores also increased from 5 to 21 days of ageing for the Dorper and Maternal sired lambs.

Base Model Tables when corrected for temperature at pH 6:

Inclusion of temperature at pH 6 in the base models accounted for all of the eating quality differences in cuts between ageing times, as the cut by ageing time interaction was no longer significant as ageing differences disappeared for some cuts or magnitudes of the ageing effects reduced for other cuts.

The sire type-age class effect remained significant for flavour only when corrected for temperature at pH 6, with Dorpers being lower in sensory scores by 3.7, 6.1, and 3.9 scores compared to Maternal, Merino, and Terminal sired lambs. The sire type-age class effect was no longer observed for tenderness, juiciness and MQ4. The sire type-age class by ageing effect remained significant for juiciness, flavour and MQ4 (Table Apx.6).

When the MQ4 model was repeated with the exclusion of the cold-shortened animals, the sire type-age class, and sire type-age class by ageing effect remained (Table Apx.6).

Table Apx.6. Least square means ± SE of the base model corrected for temperature at pH 6, for the effect of ageing according to sire type-age class for lamb sensory scores.

Sire type-age class	Days of ageing		
	5	14	21
		Tenderness	
Dorper lamb	54.4 ± 1.3 $^{a\,(x)}$	59.7 ± 1.3 $^{a\,(y)}$	62.3 ± 1.3 $^{a,b\,(y)}$
Maternal lamb	60.7 ± 1.5 $^{b,c\,(x)}$	66.6 ± 1.5 $^{b\,(y)}$	68.2 ± 1.5 $^{c\,(y)}$
Merino lamb	63.9 ± 1.6 $^{c\,(x)}$	68.7 ± 1.8 $^{b\,(x)}$	66.9 ± 1.7 $^{a,c\,(x)}$
Terminal lamb	61.0 ± 1.3 $^{b,c\,(x)}$	66.1 ± 1.3 $^{b\,(y)}$	64.8 ± 1.3 $^{a,c\,(y)}$
Merino yearling	55.5 ± 1.7 $^{a,b\,(x)}$	57.4 ± 1.7 $^{a\,(x)}$	56.3 ± 1.7 $^{b\,(x)}$
		Juiciness	
Dorper lamb	55.2 ± 1.2 $^{a\,(x)}$	60.0 ± 1.2 $^{a\,(y)}$	62.1 ± 1.2 $^{a,b\,(y)}$
Maternal lamb	60.1 ± 1.3 $^{a,b\,(x)}$	64.8 ± 1.3 $^{a,b\,(y)}$	66.3 ± 1.3 $^{a,b\,(y)}$
Merino lamb	63.1 ± 1.4 $^{b,c\,(x)}$	65.8 ± 1.4 $^{b\,(x)}$	65.2 ± 1.4 $^{a,b\,(x)}$
Terminal lamb	61.3 ± 1.1 $^{b,c\,(x)}$	64.5 ± 1.1 $^{a,b\,(y)}$	63.3 ± 1.1 $^{a,b\,(x,y)}$
Merino yearling	60.2 ± 1.6 $^{a,c\,(x)}$	60.9 ± 1.5 $^{a,b\,(x)}$	59.7 ± 1.5 $^{b\,(x)}$
		Flavour	
Dorper lamb	57.8 ± 0.9 $^{a\,(x)}$	61.6 ± 0.9 $^{a,b\,(y)}$	63.5 ± 1.0 $^{a,b\,(y)}$
Maternal lamb	61.6 ± 1.0 $^{a\,(x)}$	65.9 ± 1.0 $^{a\,(y)}$	66.5 ± 1.0 $^{a\,(y)}$
Merino lamb	65.8 ± 1.1 $^{b,c\,(x)}$	67.3 ± 1.1 $^{c\,(x)}$	68.1 ± 1.1 $^{a\,(x)}$
Terminal lamb	62.9 ± 0.8 $^{b\,(x)}$	66.3 ± 0.8 $^{c\,(y)}$	65.4 ± 0.8 $^{a\,(x,y)}$
Merino yearling	60.6 ± 1.1 $^{a,c\,(x)}$	62.4 ± 1.1 $^{b,c\,(x)}$	60.6 ± 1.1 $^{b\,(x)}$
		MQ4	
Dorper lamb	56.5 ± 1.0 $^{a\,(x)}$	61.1 ± 1.0 $^{a\,(y)}$	63.0 ± 1.0 $^{a,b\,(y)}$
Maternal lamb	61.2 ± 1.1 $^{a,b\,(x)}$	66.6 ± 1.1 $^{b\,(y)}$	67.8 ± 1.1 $^{a,b\,(y)}$
Merino lamb	64.7 ± 1.2 $^{b\,(x)}$	67.2 ± 1.2 $^{b\,(x)}$	67.7 ± 1.2 $^{b\,(x)}$
Terminal lamb	62.3 ± 0.9 $^{b\,(x)}$	66.3 ± 0.9 $^{b\,(y)}$	65.0 ± 0.9 $^{b\,(y)}$
Merino yearling	59.2 ± 1.3 $^{a,b\,(x)}$	60.7 ± 1.3 $^{a\,(x)}$	59.5 ± 1.3 $^{a\,(x)}$
		MQ4 (cold shortened animals removed)	
Dorper lamb	54.3 ± 1.5 $^{a\,(x)}$	60.8 ± 1.5 $^{a,b\,(y)}$	62.7 ± 1.5 $^{a,b\,(y)}$
Maternal lamb	62.0 ± 1.5 $^{b\,(x)}$	66.9 ± 1.5 $^{a,c\,(y)}$	68.4 ± 1.5 $^{a\,(y)}$
Merino lamb	65.1 ± 1.7 $^{b\,(x)}$	68.9 ± 1.7 $^{c\,(x)}$	67.2 ± 1.7 $^{a,b\,(x)}$
Terminal lamb	62.6 ± 1.3 $^{b\,(x)}$	66.6 ± 1.3 $^{c\,(y)}$	65.8 ± 1.3 $^{a,b\,(y)}$
Merino yearling	59.0 ± 1.7 $^{a,b\,(x)}$	59.6 ± 1.8 $^{b\,(x)}$	59.7 ± 1.7 $^{b\,(x)}$

Sire type differences within a column without common letters (a-c) differ significantly ($P < 0.05$);
Ageing differences within a row without common letters (x-y) differ significantly ($P < 0.05$).

<u>Base Model Tables when corrected for pH at 18°C:</u>

Compared to the base model, inclusion of pH at 18°C retained most cut differences within the three ageing times for juiciness and MQ4 score (Table Apx.7) with similar magnitudes. No cut by ageing time effect was observed for flavour and tenderness.

The sire type-age class effect disappeared whereas the sire type-age class by ageing effect remained for all traits except tenderness (Table Apx.8). Generally, variation between Dorper sired lambs compared to Maternal, Merino and Terminal sired lambs was still evident with Dorper sired lambs having lower sensory scores at 5 and 14 days of ageing when corrected for pH at 18°C (Table Apx.8).

A significant increase (P < 0.05) in sensory scores for Dorper, Maternal, Merino and Terminal sired lambs between 5 and 14, and 5 and 21 days ageing when pH at 18°C was included in the base model was observed (Table Apx.8).

Table Apx.7. Least square means ± SE of the base model corrected for pH at 18°C, for the effect of cut by ageing for lamb sensory scores.

Cut	Days of ageing		
	5	14	21
	Juiciness		
Eye of rack	70.8 ± 0.9 a (x)	73.2 ± 0.9 a (x)	73.6 ± 0.9 a (x)
Eye of shoulder	70.3 ± 1.1 a (x)	72.4 ± 1.1 a (x)	73.0 ± 1.1 a (x)
Knuckle	58.2 ± 0.9 b (x)	64.5 ± 0.9 b (y)	64.1 ± 0.9 b (y)
Loin	58.9 ± 0.9 b,c (x)	63.0 ± 0.9 b (y)	62.4 ± 0.9 b (y)
Outside	51.9 ± 0.9 d (x)	55.5 ± 0.9 c (y)	58.3 ± 0.9 c (y)
Rump	62.2 ± 1.1 c (x)	65.8 ± 1.2 b (x,y)	67.5 ± 1.1 b (y)
Topside	43.5 ± 0.9 e (x)	45.5 ± 0.9 d (x)	45.3 ± 0.9 d (x)
	MQ4		
Eye of rack	72.1 ± 0.7 a (x)	75.2 ± 0.7 a (y)	75.8 ± 0.7 a (y)
Eye of shoulder	67.3 ± 0.9 b (x)	71.5 ± 0.9 b (y)	71.4 ± 0.9 b (y)
Knuckle	61.0 ± 0.7 c (x)	67.7 ± 0.7 c (y)	66.8 ± 0.7 c (y)
Loin	62.4 ± 0.7 c (x)	66.7 ± 0.7 c (y)	66.6 ± 0.7 c (y)
Outside	51.0 ± 0.7 d (x)	54.5 ± 0.7 d (y)	57.3 ± 0.7 d (y)
Rump	62.5 ± 0.9 c (x)	67.2 ± 1.0 c (y)	68.7 ± 0.9 b,c (y)
Topside	42.8 ± 0.7 e (x)	45.2 ± 0.7 e (x)	45.4 ± 0.7 e (x)

Cut differences within a column without common letters (a-c) differ significantly (P < 0.05);
Ageing differences within a row without common letters (x-y) differ significantly (P < 0.05).

Table Apx.8. Least square means ± SE of the base model corrected for pH at 18°C, for the effect of ageing by sire type-age class for lamb sensory scores.

Sire type-age class	Days of ageing		
	5	14	21
	Overall liking		
Dorper lamb	56.4 ± 0.9 a (x)	61.6 ± 0.9 a (y)	63.0 ± 0.9 a,b (y)
Maternal lamb	61.8 ± 0.9 b (x)	67.7 ± 0.9 b (y)	67.8 ± 0.9 c (y)
Merino lamb	64.4 ± 0.9 b (x)	67.3 ± 0.9 b (y)	68.0 ± 0.9 c (y)
Terminal lamb	61.1 ± 0.9 b (x)	66.0 ± 0.9 b (y)	65.2 ± 0.9 a,c (y)
Merino yearling	57.1 ± 1.0 a (x)	60.1 ± 1.0 a (y)	60.8 ± 1.0 b (y)
	Juiciness		
Dorper lamb	55.0 ± 1.1 a (x)	59.7 ± 1.1 a,b (y)	61.8 ± 1.1 a (y)
Maternal lamb	61.3 ± 1.1 b (x)	65.8 ± 1.1 c (y)	65.8 ± 1.1 a (y)
Merino lamb	62.6 ± 1.1 b (x)	65.9 ± 1.1 c (y)	65.4 ± 1.1 a (y)
Terminal lamb	59.7 ± 1.0 b (x)	63.7 ± 1.0 b,c (y)	63.0 ± 1.0 a (y)
Merino yearling	58.3 ± 1.2 a,b (x)	59.1 ± 1.2 a (x,y)	61.3 ± 1.2 a (y)
	Flavour		

Dorper lamb	58.2 ± 0.8 [a (x)]	62.4 ± 0.8 [a (y)]	64.1 ± 0.8 [a,b (y)]
Maternal lamb	63.2 ± 0.8 [b (x)]	67.6 ± 0.8 [b (y)]	67.3 ± 0.8 [a,c (y)]
Merino lamb	65.5 ± 0.8 [b (x)]	67.6 ± 0.8 [b (x)]	68.2 ± 0.8 [c (y)]
Terminal lamb	62.6 ± 0.7 [b,c (x)]	66.2 ± 0.7 [b (y)]	65.6 ± 0.7 [b,c (y)]
Merino yearling	59.1 ± 0.8 [a,c (x)]	61.4 ± 0.8 [a (x)]	62.3 ± 0.8 [b (y)]
		MQ4	
Dorper lamb	56.0 ± 0.9 [a (x)]	60.8 ± 0.9 [a (y)]	62.7 ± 0.9 [a,b (y)]
Maternal lamb	61.9 ± 0.9 [b (x)]	67.2 ± 0.9 [b (y)]	67.5 ± 0.9 [c (y)]
Merino lamb	63.7 ± 0.9 [b (x)]	67.4 ± 0.9 [b (y)]	67.9 ± 0.9 [c (y)]
Terminal lamb	60.9 ± 0.9 [b,c (x)]	65.2 ± 0.9 [b (y)]	64.7 ± 0.9 [a,c (y)]
Merino yearling	57.0 ± 1.0 [a,c (x)]	59.5 ± 1.0 [a (y)]	60.2 ± 1.0 [b (y)]

Sire type differences within a column without common letters (a-c) differ significantly ($P < 0.05$);
Ageing differences within a row without common letters (x-y) differ significantly ($P < 0.05$).

Key findings of this project were the improvement of sensory scores from 5 to 14 days of ageing and 5 to 21 days ageing for most cuts, with minimal differences existing for all sensory traits tested. All sensory traits behaved in a similar manner given the halo effect between the sensory traits. Beyond 14 days of ageing there was little improvement seen in eating quality. The inclusion of the covariate temperature at pH 6 accounted for the variation in cut by ageing for all sensory traits. Whereas inclusion of pH at 18°C, accounted for some of the variation in cut by ageing as difference were still observed for juiciness and MQ4. Additionally, removing cold shortened animals in the MQ4 model demonstrated that the extent of ageing did no longer differ between cuts, however improvement of ageing across all cuts remained, slightly reduced in magnitude, from 5 to 14 days of ageing. Further consideration of the data is required to potentially include these ageing differentials into the MSA model.

Dorper sired lambs had lower eating quality scores compared to Maternal, Merino and Terminal sired lambs at the 5, 14 and 21 days of ageing for all sensory traits. When corrected for temperature at pH 6 or pH at 18°C, these sire type differences remained except for tenderness, indicating that other factors (i.e. genetics) may impact the variation and extent of ageing observed for most sensory traits.