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Cuts based MSA lamb development – lamb turn off and packaging effects

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Abstract

Phase 1 New versus old season lambs
Consumer eating quality scores of new season (NS; n=150) and old season lambs (OS; n=151) across 8 cuts of the carcase were evaluated. Cuts for grilling were the loin, topside, knuckle, outside and rump, while cuts for roasting included the shoulder, leg and rack. Each cut was scored by untrained consumers for tenderness, juiciness, liking of flavour and overall liking. Consumers could not differentiate between NS and OS lamb for most cuts across all eating quality traits, though preferred NS lamb for the rump and knuckle cuts by a small margin of 3 consumer points. This is potentially due to decreases in collagen solubility that result in increased muscle toughness, which has been shown to occur rapidly with increased age in those two particular cuts. Our results show little difference in quality between NS and OS lamb, despite the current perception that NS lamb is of higher quality due to its younger age.

Phase 2 Packaging
The impact of high oxygen modified atmosphere packaging (MAP) with 80% oxygen (MAP80), lower oxygen MAP with 40% oxygen (MAP40) and vacuum skin packaging (VSP) under different retail display times (3 or 8 days) on the sensory scores of lamb meat was evaluated. Consumer sensory scores for overall liking, tenderness, juiciness and liking of flavour were assessed on the M. *longissimus lumborum* (loin) and M. *semimembranosus* (topside) of 144 lambs. Loin samples generally had more acceptable sensory scores than topside samples across all packaging treatments. Increasing the display time from 3 to 8 days reduced sensory scores for both cuts within each MAP treatment, yet remained relatively unchanged for VSP samples. In general, within a cut and display time, VSP samples had the highest sensory scores, followed by samples under MAP40, followed by samples under MAP80 which had the lowest sensory scores. Similar to previous studies, our results confirm the detrimental impact of high oxygen MAP on lamb meat eating quality. Our results also provide the sheepmeat industry with a new MAP mixture containing lower oxygen concentration which has a reduced detrimental impact on eating quality compared to the widely used high (80%) oxygen MAP.

Executive summary

Phase 1 New versus old season lambs

There is a current industry perception that new season (NS) lamb has higher quality than old season (OS) lamb. OS lambs are aged between 10-12 months old, and are slower growing carry over lambs, often sold during autumn or winter. NS lambs are aged between 5-8 months old, are fast growing and often sold as “spring lamb” at retail. The branding of “spring lamb” to consumers is synonymous with a high quality product, and therefore receives a higher price at retail than OS lambs sold in autumn. The industry perception that NS lamb has better quality than OS lamb is therefore due to retail marketing, in combination with the known negative impact of increasing animal age on eating quality.

There is little evidence to support an age-related difference between NS and OS lamb. Previous work found no differences in eating quality scores in the loin, a high quality cut, between lamb and yearling. However, lambs scored higher in comparison to yearlings for the topside, a low quality cut (Pannier et al., 2018). The current study analysed consumer scores of multiple cuts that range in quality from NS and OS lambs. The findings of this study will identify consumer scores for multiple cuts and multiple cooking methods that have not yet been thoroughly tested in Australian sheepmeat. These results will directly contribute to the new Meat Standards Australia (MSA) sheepmeat grading model (MSA Mark II).

Our findings showed that consumers overall could not differentiate between NS and OS lamb. There was no difference in eating quality between the two age classes for the loin, leg, shoulder and rack. Between NS and OS lambs consumers scored no different for tenderness, liking of flavour and overall liking in the topside, as well as tenderness, juiciness and overall liking in the outside. In contrast, sensory scores for all eating quality traits in the knuckle and rump were lower for OS lambs compared to NS lambs, which was most prominent in one particular flock. OS lambs did score lower in the knuckle and the rump across by 3 consumer points compared to NS lambs.

Phase 2 Packaging

The red meat industry experiences significant industry losses due to the discolouration of meat under retail display. This is especially important for lamb meat which tends to discolour and change from red to brown in approximately 48 hours under traditional overwrap packaging. Because of this rapid discolouration, the meat industry has adopted alternative packaging methods to extend the retail shelf life of meat. Modified atmosphere packaging (MAP) is one form of packaging that has received significant industry investment as it sustains the desirable cherry red colour of meat and thus extends shelf life. However, recent studies in both lamb and beef have shown the high oxygen concentration in MAP, typically 80% oxygen and 20% carbon dioxide, can negatively impact eating quality, especially tenderness.

This experiment follows-on from a study which identified a minimum threshold of oxygen within MAP (40% oxygen, MAP40) required to maintain similar meat colour to the standard high oxygen MAP (80% oxygen, MAP80) mixture (described below). The study showed that MAP40 maintained a desirable meat colour under retail display conditions and therefore its effect on eating quality was tested to observe if a minimised negative impact on eating quality exists compared to MAP80. The current study explored the effects of different display times between the widely adopted high oxygen MAP80 to lower oxygen concentration MAP40 and vacuum skin packaging (VSP), and compared the subsequent impacts on consumer sensory scores. This is particularly important in light of recent findings that the widely adopted high oxygen MAP has detrimental effects on sensory attributes of meat such as tenderness, juiciness, flavour and overall liking. The findings from this study could then be used as a guide to processors and retailers on the optimal oxygen concentration

within MAP that produces the best outcome, both in terms of visual meat colour appeal and eating quality for consumers.

Our findings showed loin samples scored significantly higher than topside samples for all eating quality traits, across all display times and packaging types. Increasing display time from day 3 to day 8 reduced overall liking scores by 4.2 scores, across both muscles and packaging types, which was consistent for the other eating quality traits. When comparing the different packing types at a given site, generally VSP samples had 5.7 eating quality scores more than samples in MAP40, and 9.6 scores more than samples in MAP80 for overall liking at the Kirby site. This effect was consistent for the other eating quality traits; tenderness, juiciness and flavour. In addition, samples in MAP40 increased overall liking scores by 3.9 units compared to MAP80 samples which was consistent for the other eating quality traits. Based on the results of Kirby, the lower oxygen MAP with 40% oxygen, 20% carbon dioxide and 40% nitrogen could provide the industry with an alternative gas mixture that improves consumer sensory scores compared to the currently used high oxygen MAP.

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PHASE 1 New versus old season lambs

1 Background

Eating quality is a major factor that drives consumer acceptability and choice when purchasing meat. Animal age has a considerable influence on eating quality and it is well known that as animal age increases eating quality diminishes (Pethick et al., 2005; Thompson et al., 2005b). This is mostly due to an increase in soluble collagen concentration and an increase in collagen crosslinking, which decreases muscle tenderness (Young and Braggins, 1993; Jeremiah et al., 1997; Thompson et al., 2005b).

Although the age and eating quality relationship is well defined when comparing lamb to mutton, there are limited studies that detail the impact age has on eating quality of multiple cuts within younger animals. In a study conducted by Pethick et al. (2005), lambs aged at 8.5 months had significantly lower shear force than mutton aged between 3 and 4 years old. Though no difference in shear force was demonstrated in the loin when comparing 8.5 month to 20 month old sheep. In the same study, the younger animals (8.5 month) received better eating quality scores in the *M. longissimus lumborum* (loin) and *M. biceps femoris* (outside) than the 3-4 year old animals, yet there was no difference in eating quality scores for both the loin and *M. semimembranosus* (topside) when comparing 8.5 month to the 20 month old sheep (Pethick et al., 2005). Similar results were observed in Pannier et al. (2018) who compared eating quality of lambs (average age 335 days) and yearlings (average age 685 days), with no difference in eating quality scores for the loin between the age groups. However for the topside, eating quality scores did differ between lambs and yearlings. The yearling topside received on average 8 eating quality scores lower for tenderness and 6 eating quality scores lower for overall liking when compared to lamb topside (Pannier et al., 2018). Furthermore, the loin received significantly higher sensory scores than the topside. The difference in quality between these two muscles may impact the effect age has on eating quality. It is possible that increased age has a lesser effect on high quality cuts and more of a detrimental effect to eating quality in low quality cuts.

Retail marketing of “young spring lamb” has shaped an industry wide perception that new season (NS) lamb (approx. 5-8 months old) has better eating quality than old season (OS) lamb (approx. 10-12 months old). This perception has been formed despite a lack of evidence that describes age related eating quality differences within young animals. This study will compare eating quality scores of NS and OS lambs on 8 different cuts across 2 cooking methods. It is hypothesised that for higher quality cuts there will be no difference in eating quality scores between new season and old season lambs, however for low quality cuts old season lamb will receive lower eating quality scores.

2 Project objectives

- Determine the eating quality of ‘new season’ lamb (5-8 month of age at slaughter) and carryover or ‘older’ lambs that reach target slaughter weight at close to 10-12 months.
- Increase the cut x cook combinations for eating quality prediction within the new MSA lamb model.

3 Methodology

3.1 Animals

Animals were sourced from 5 commercial sheep flocks across South Australia (SA) and Victoria (VIC). Each flock is described in Table 1. NS and OS lambs were balanced across each flock (total n=300). Both age groups on each property were kept in the same paddock 3 weeks prior to slaughter, and lambs were generally maintained under pasture grazing conditions with hay or pellet feeding supplied when necessary. Flock 2-5 were commercial grazing systems with lambs from both age groups being genetically related to each other. NS and OS lambs from each of these flocks had common sires and parental lineage. Animals from flock 1 were sourced from a commercial feedlot; lambs were obtained from multiple vendors with potentially no genetic links between the age groups. For this reason flock 1 was excluded from further analysis. Raw eating quality scores are presented in Table 6, Appendix 1. The lambs were weighed prior to being transported to a commercial processing plant, where they were held in lairage overnight and slaughtered the following day. All carcasses were subjected to a medium-voltage electrical stimulation (Pearce et al., 2010) and trimmed according to AUS-MEAT specifications (Anonymous, 2005). Carcasses were chilled overnight (3-4°C) before sampling.

Table 1. Details of new season and old season lambs supplied for this experiment.

		New Season				Old season			
Flock	Location	*n*	Breed	Average Age	Killgroup	*n*	Breed	Average Age	Killgroup
1*	Bordertown, South Australia	30	Merino x	128	1	30	Merino x	360	1
2	Lochabar, South Australia	30	White Suffolk	209[a]	2	30	Merino x White Suffolk	298[b]	2
3	Avenue Range, South Australia	30	Border Leicester Merino x Poll Dorsett	252[a]	3	30	Border Leicester x Merino	308[b]	3
4	Struan, South Australia	30	Border Leicester Merino x Poll Dorsett	250[a]	4	30	Border Leicester x Merino	350[b]	4
5	Greta, Victoria	30	Border Leicester composites	252[a]	4	31	Border Leicester composites	357[b]	4
Total		150				151			

*Flock 1 was not included in further analysis

3.2 Carcass measurements and sample collection

Within 1 hour of slaughter, hot carcass weight and GR tissue depth (11cm from the midline to the lateral surface of the 12th rib) were measured on all carcasses. pH and temperature decline were measured at 3 time points after slaughter on the left portion of the M. *longissimus thoracis* et *lumborum* (LL) as described by Pearce *et al*. (2010). Ultimate pH was measured at 24h post-slaughter in the LL. Eye muscle area was determined by measuring the width, length and depth of the LL muscle cut at the 12th rib. C-site fat depth was measured 45mm from the spine along the LL at the 12th rib. A subset of 217 carcasses had 8 different cuts removed for subsequent eating quality analysis. The remaining 90 carcases had 2 cuts removed used for starter samples during the eating quality sessions. Cuts are described in Table 2. In total 1,008 grill cuts were eaten across 1,680 consumers in 28 eating quality sessions, and 648 roast cuts were eaten across 1,080 consumers in 18 eating quality sessions. All grill cuts were sliced into 5 steaks of 15mm thickness and trimmed for subcutaneous fat and epimysium (silver skin). The leg and shoulder cuts were netted whole and the rack cuts had the cap muscle removed. All cuts were vacuum packed and stored at 2°C for 5 days of aging before being frozen at -20°C. Cuts were later thawed for subsequent sensory testing.

Table 2. Number and type of cuts collected and consumed.

Cut	**AUSmeat code**	**Cook**	***n* eaten**
Grill Eating Quality Cuts			
Loin	5150	Grill	202
Outside	5075	Grill	202
Topside	5077	Grill	200
Knuckle	5072	Grill	202
Rump	5074	Grill	202
Roast Eating Quality Cuts			
Leg	4830	Roast	216
Shoulder	5050	Roast	216
Rack	4748	Roast	216
Starter Eating Quality Cuts			
Topside	5077	Roast	108
Knuckle	5072	Grill	162

3.3 Instrumental meat quality measurements

The remaining loin from each carcases was removed for fresh colour, intramuscular fat (IMF) and shear force measurements. Fresh colour measurement of lightness (L*), redness (a*) and yellowness (b*) was measured with a Minolta Chroma metre (Model CR-300). 40g of loin muscle was collected and freeze-dried in a Cuddon FD 1015 freeze dryer (Cuddon Freeze Dry, Blenheim, New Zealand). A Technicon Infralyser 450 (19 wavelengths) was used for near-infrared analysis to determine IMF (expressed as a percentage), as described by Perry *et al*. (2001). Chemical fat determinations by using solvent extraction (chloroform) was used to validate the near-infrared readings. An additional 65g of loin muscle was collected and aged for 5 days prior to shear force testing. Samples were cooked in a water bath for 35 min at 71°C and cooled in running water for 30 min. Each steak was cut into six cores (~4 cm long, 1 cm^2 in cross-section) and measures for shear force using a Lloyd texture analyser (Model LRX, Lloyd Instruments, Hampshire, UK) with a Warner–Bratzler shear blade fitted as described by Hopkins *et al*. (2010).

3.4 Sensory Testing

The sensory testing protocol for grilled lamb cuts is outlined in Thompson et al (2005). In summary the grilled cuts were cooked on a Silex grill (S-tronic steaker, Silex Elektrogeräte GmbH, Hamburg, Germany), with the top plate set to a temperature of 185°C and the bottom plate set to 190°C. Steaks were removed from the grill with an approximate internal temperature of 65°C, rested for 1.5 minutes and halved before serving.

Leg and shoulder cuts were trimmed into a 15cm x 15cm block, with excess fat removed as well as the neck piece from the shoulder. Cuts were rolled and secured using butchers string prior to cooking. Roast cuts were cooked in a Electrolux 10 tray dry oven (sourced from an independent catering company) and set to a temperature of 160°C. Each roast cut was identified by attaching a laminated oven proof tag with the unique number given to that cut utilising a suitable trussing pin. To achieve an internal temperature of 65°C, roasts were removed from the oven at an internal temperature of 60°C and rested for 10 minutes. Roasts are then sliced across the grain into 4mm pieces using an electric slicer. Ten suitable slices that are representative of the entire cut are selected for consumer testing. Any external fat and gristle seams are removed and slices are trimmed to approximately 50mm wide x 50mm long x 4mm thick. A few surplus slices are placed in a warmed 1/9th bain-marie pan labelled with the unique cut code to keep the test slices above accumulating juice. The 10 consumer samples are then placed in the bain maries on top of the surplus slices, with a further surplus slice placed on top of the test samples to retain moisture. Bain maries are maintained at a temperature of 50°C until serving.

Consumers were recruited by an independent recruitment company and screened to include individuals aged between 18 and 70 years old. Grill and roast samples were assessed using a score from 0 (worse) to 100 (best) by untrained consumers for tenderness, overall liking, juiciness, and liking of flavour. Each consumer commenced with a common starter sample of average quality, followed by six test samples allocated using a Latin square design (Thompson et al., 2005b). Each tasting session consists of 60 consumers that eat a total of 36 cuts to obtain 10 consumer responses per cut. In total 1656 cuts were tested by 2760 consumers.

3.5 Statistical analysis

Linear mixed effects models in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA) were used to analyse the 10 consumer scores for overall liking, tenderness, juiciness and liking of flavour. The base model for each sensory trait included fixed effects for cut (loin, topside, outside, rump, knuckle, rack, shoulder, leg), age class (new season, old season), and killgroup within flock. Animal identification and consumer session within consumer identification were included as random terms. All relevant first-order interactions between fixed effects were tested and non-significant ($P > 0.05$) terms were removed in a stepwise manner. Intramuscular fat percentage (IMF%) was analysed as a covariate within the base models to identify if IMF differences between the age groups accounted for any observed eating quality differences.

In addition, hot standard carcase weight (HCWT), IMF%, shear force (SF), GR fat depth (GR), C-site fat depth, eye muscle area (EMA), lightness (L*), redness (a*) and yellowness (b*) were also analysed as dependant variables to determine the phenotypic variability of each trait between the NS and OS lambs.. These models included fixed effects for ageclass and killgroup within flock. Relevant first-order interactions between fixed effects were included and non-significant ($P > 0.05$) terms were removed in a stepwise manner.

4 Results

4.1 Effect of age on consumer sensory scores

There were significant effects for cut and flock (killgroup) for overall liking, tenderness, juiciness and flavour sensory scores (Table 3). Overall there was no significant difference in sensory scores between NS and OS lambs, however this was not consistent between cuts or flocks (Table 3 and 4).

Table 3. F values and numerator and denominator degrees of freedom for the effects of the base linear mixed effects models of the overall liking, tenderness, juiciness and flavour scores.

Effect	NDF	DDF	Tenderness	Juiciness	Liking of Flavour	Overall Liking
Cut	7	10000	284.59**	155.45**	117**	169.93**
Age class	1	10000	ns	ns	ns	ns
Flock (Killgroup)	2	10000	7.69**	11.82**	11.64**	9.64**
Cut * Age class	7	10000	2.69*	4.14**	2.7*	2.55*
Flock (Killgroup) * Age class	3	10000	2.99*	ns	ns	ns
Cut * Flock (Killgroup)	21	10000	6.37**	7.98**	3.44**	5.1**
Cut * Flock (Killgroup)* Age class	24	10000	1.82*	1.64*	ns	ns

NDF, DDF; numerator and denominator degrees of freedom; ns; non-significant association ($P > 0.05$); *; $P < 0.05$; **; $P < 0.001$.

On average, sensory scores between NS and OS lambs did not differ in the leg, shoulder and rack cuts (roast cook), and the loin cut (grill cook) for all eating quality traits. This was seen across all flocks except for the shoulder cut from flock 2, which had differences of 5.3, 4.9, 5.4 and 6.8 sensory scores for tenderness, juiciness, liking of flavour and overall liking ($P < 0.05$ for all traits) higher in OS lambs compared to NS lambs (Table 4). For the topside, tenderness, liking of flavour and overall liking did not differ between NS and OS lambs in all flocks, and did not differ for juiciness in most flocks. In flock 3 NS topsides scored 4.9 ($P < 0.05$) higher than OS topsides for juiciness. The outside cut had on average no difference in sensory scores for all traits between NS and OS lambs except for liking of flavour. OS lambs had 2.3 scores lower for liking of flavour ($P < 0.05$) compared to NS lambs. This was consistent across all flocks except flock 4 where there were differences between NS and OS outsides for all eating quality traits. In this flock OS lambs had 10, 7.9, 5.4 and 7.8 sensory scores lower for tenderness, juiciness, liking of flavour and overall liking ($P < 0.01$ for all traits) compared to NS lambs.

Sensory scores for all eating quality traits in the knuckle and rump were lower for OS lambs compared to NS lambs. OS lambs had 2.6 to 3.4 scores lower in the knuckle and 2.4 to 4.9 scores lower in the rump across all traits compared to NS lambs. The differences in these cuts were mostly observed in flock 4 for the knuckle, and Flock 3 and 4 for the rump (Table 4). In the knuckle, OS lambs from flock 4 had 8.2 ($P < 0.01$) and 6.6 ($P < 0.01$) scores lower for tenderness and overall liking compared to NS lambs. For the rump, OS lambs from flock 4 had 7.0 ($P < 0.01$) and 6.5 ($P < 0.01$) sensory scores lower for tenderness and juiciness compared to NS lambs. Similarly OS lambs from flock 3 had 6.3 ($P < 0.01$) and 4.7 ($P < 0.05$) sensory scores lower for juiciness and overall liking compared to NS lambs. For all cuts, flock 5 had no significant differences in sensory scores for all traits between NS and OS lambs.

Table 4. Predicted means (± s.e.) of NS and OS lambs of each flock within individual cuts.

		Tenderness		**Juiciness**		**Liking of Flavour**		**Overall Liking**	
Cut	**Flock**	**NS**	**OS**	**NS**	**OS**	**NS**	**OS**	**NS**	**OS**
Knuckle (grill)	2	72.8 ± 1.8	68.7 ± 1.8	68.9 ± 1.7[a]	63.9 ± 1.8[b]	69.3 ± 1.6	66.5 ± 1.7	70.6 ± 1.7	67.6 ± 1.8
	3	67.1 ± 1.8	64.1 ± 1.8	67.1 ± 1.7	64.1 ± 1.7	67.8 ± 1.6	64.6 ± 1.6	68.0 ± 1.7	65.8 ± 1.7
	4	72.2 ± 1.8[a]	64.0 ± 1.8[b]	65.8 ± 1.7	62.0 ± 1.7	67.7 ± 1.7[a]	63.3 ± 1.6[b]	70.0 ± 1.7[a]	63.4 ± 1.7[b]
	5	65.1 ± 1.8	66.9 ± 1.8	64.5 ± 1.7	68.8 ± 1.7	67.3 ± 1.7	67.1 ± 1.7	67.4 ± 1.7	68.5 ± 1.7
Loin	2	64.2 ± 1.8	68.2 ± 1.8	59.1 ± 1.7	62.2 ± 1.8	63.5 ± 1.6	66.6 ± 1.7	63.4 ± 1.7	66.9 ± 1.7
	3	64.3 ± 1.8	67.6 ± 1.8	62.8 ± 1.7	62.8 ± 1.7	65.4 ± 1.6	65.8 ± 1.6	65.6 ± 1.7	66.5 ± 1.7
	4	62.9 ± 1.8	63.1 ± 1.8	61.2 ± 1.7	57.2 ± 1.8	62.7 ± 1.7	62.8 ± 1.7	63.3 ± 1.7	62.5 ± 1.8
	5	64.8 ± 1.8	60.2 ± 1.8	60.8 ± 1.7	59.8 ± 1.7	64.8 ± 1.7	61.3 ± 1.6	65.2 ± 1.7	62.0 ± 1.7
Rump	2	74.4 ± 1.8	72.6 ± 1.8	74.1 ± 1.7[a]	69.3 ± 1.8[b]	71.8 ± 1.6	69.1 ± 1.7	74.2 ± 1.7	71.4 ± 1.7
	3	70.2 ± 1.7	67.1 ± 1.8	71.1 ± 1.7[a]	64.9 ± 1.7[b]	70.3 ± 1.6[a]	66.2 ± 1. 6[b]	70.9 ± 1.7[a]	66.2 ± 1.7[b]
	4	65.8 ± 1.7[a]	58.8 ± 1.8[b]	60.2 ± 1.7[a]	53.7 ± 1.7[b]	61.1 ± 1.7	58.4 ± 1.7	61.8 ± 1.7	58.4 ± 1.7
	5	61.5 ± 1.8	62.8 ± 1.8	63.5 ± 1.7	62.6 ± 1.7	63.7 ± 1.7	63.7 ± 1.7	64.1 ± 1.7	64.4 ± 1.7
Outside	2	57.0 ± 1.7	61.4 ± 1.8	64.3 ± 1.7	65.7 ± 1.8	62.6 ± 1.6	63.2 ± 1.7	61.4 ± 1.7	63.9 ± 1.8
	3	53.4 ± 1.8	51.8 ± 1.8	58.3 ± 1.7	56.2 ± 1.7	59.1 ± 1.7	57.8 ± 1.6	57.9 ± 1.7	56.3 ± 1.7
	4	57.3 ± 1.8[a]	47.4 ± 1.8[b]	60.5 ± 1.7[a]	52.5 ± 1.7[b]	59.1 ± 1.7[a]	53.6 ± 1.7[b]	59.7 ± 1.7[a]	51.9 ± 1.7[b]
	5	56.1 ± 1.7	53.0 ± 1.8	60.1 ± 1.7	59.3 ± 1.7	61.8 ± 1.6	58.9 ± 1.6	60.8 ± 1.7	59.0 ± 1.7
Topside	2	48.7 ± 1.8	49.9 ± 1.8	55.2 ± 1.7	52.9 ± 1.8	54.4 ± 1.6	56.4 ± 1.7	52.8 ± 1.7	54.9 ± 1.8
	3	46.9 ± 1.8	45.5 ± 1.8	55.8 ± 1.7[a]	50.9 ± 1.7[b]	55.6 ± 1.7	54.2 ± 1.6	52.8 ± 1.7	51.9 ± 1.7
	4	42.7 ± 1.8	38.2 ± 1.8	43.7 ± 1.7	42.3 ± 1.7	48.9 ± 1.7	47.0 ± 1.7	46.3 ± 1.7	44.0 ± 1.7
	5	43.9 ± 1.8	42.1 ± 1.8	50.4 ± 1.7	50.4 ± 1.7	52.3 ± 1.7	53.3 ± 1.7	50.3 ± 1.7	50.5 ± 1.7
Rack (roast)	2	71.4 ± 1.8	73.7 ± 1.8	65.6 ± 1.7	69.4 ± 1.7	67.2 ± 1.6	70.4 ± 1.6	67.8 ± 1.7	71.1 ± 1.7
	3	67.3 ± 1.8	68.6 ± 1.8	60.5 ± 1.7	62.7 ± 1.7	64.1 ± 1.6	66.1 ± 1.6	64.8 ± 1.7	67.1 ± 1.7
	4	69.5 ± 1.7	71.0 ± 1.7	63.3 ± 1.6	65.0 ± 1.6	64.3 ± 1.6	64.8 ± 1.6	66.1 ± 1.6	66.7 ± 1.6
	5	69.5 ± 1.7	67.5 ± 1.7	65.4 ± 1.6	64.0 ± 1.6	67.5 ± 1.6	67.6 ± 1.6	68.6 ± 1.6	67.2 ± 1.6
Leg	2	55.3 ± 1.8	58.0 ± 1.8	51.5 ± 1.7	51.7 ± 1.7	57.1 ± 1.6	59.1 ± 1.6	57.1 ± 1.7	58.1 ± 1.7
	3	50.0 ± 1.7	51.6 ± 1.8	46.9 ± 1.7	48.0 ± 1.7	57.0 ± 1.6	54.1 ± 1.6	54.4 ± 1.7	52.3 ± 1.7
	4	54.7 ± 1.7	51.2 ± 1.7	50.1 ± 1.6	46.9 ± 1.6	54.0 ± 1.6	52.7 ± 1.6	54.9 ± 1.6	52.1 ± 1.6
	5	57.8 ± 1.8	58.7 ± 1.7	53.4 ± 1.6	55.0 ± 1.6	58.1 ± 1.6	60.7 ± 1.6	58.5 ± 1.6	60.5 ± 1.6
Shoulder	2	59.7 ± 1.8 [a]	65.0 ± 1.8[b]	57.2 ± 1.7[a]	62.1 ± 1.7[b]	59.2 ± 1.6	64.4 ± 1.6	58.5 ± 1.7[a]	65.3 ± 1.7[b]
	3	67.2 ± 1.8	66.7 ± 1.8	62.9 ± 1.7	64.8 ± 1.7	62.9 ± 1.6	61.3 ± 1.6	64.9 ± 1.7	63.2 ± 1.7
	4	64.7 ± 1.7	60.5 ± 1.7	58.8 ± 1.6	56.5 ± 1.6	56.2 ± 1.6	56.5 ± 1.6	57.6 ± 1.6	56.7 ± 1.6
	5	64.1 ± 1.7	62.6 ± 1.7	62.2 ± 1.6	61.2 ± 1.6	63.9 ± 1.6	62.2 ± 1.6	63.9 ± 1.6	62.7 ± 1.6

4.2 Effect on intramuscular fat on consumer sensory scores

Intramuscular fat had a significant impact on tenderness, juiciness, liking of flavour and overall liking (P < 0.01). Sensory scores increased by 4.5, 4.9, 4.5 and 5.5 across a 3.5% IMF range for tenderness, overall liking, juiciness and liking of flavour. Similarly, the association between IMF and eating quality was observed for each cut tested. The magnitude of the effect of IMF on consumer scores differed slightly for each cut, with IMF having the most impact on the loin and rack cuts (Figure 1).

Within each cut, the impact of IMF on sensory traits varied between NS and OS lambs. For overall liking, the magnitude of IMF effects between NS and OS lambs were similar in the loin, leg, outside, rack, rump and shoulder cuts with an average of 6.3 scores for NS and 4.1 for OS across a 3.5% IMF range. However this effect varied for the two age classes in the knuckle. Overall liking scores increased by 8.1 scores over a 3.5% IMF range for the OS lambs, whereas no effect in the NS lambs was observed. For tenderness, the magnitude of IMF effects between NS and OS lambs were similar in the loin, rack, rump, shoulder and topside, however did significantly differ for the knuckle, leg and outside. IMF had a positive effect for the OS lambs for the knuckle and outside, but there was no effect for the NS lambs, whereas for the leg cuts, there was a positive effect for the NS lambs and no effect for the OS lambs. The impact of IMF on liking of flavour and juiciness scores did not differ for NS and OS lambs within any cuts.

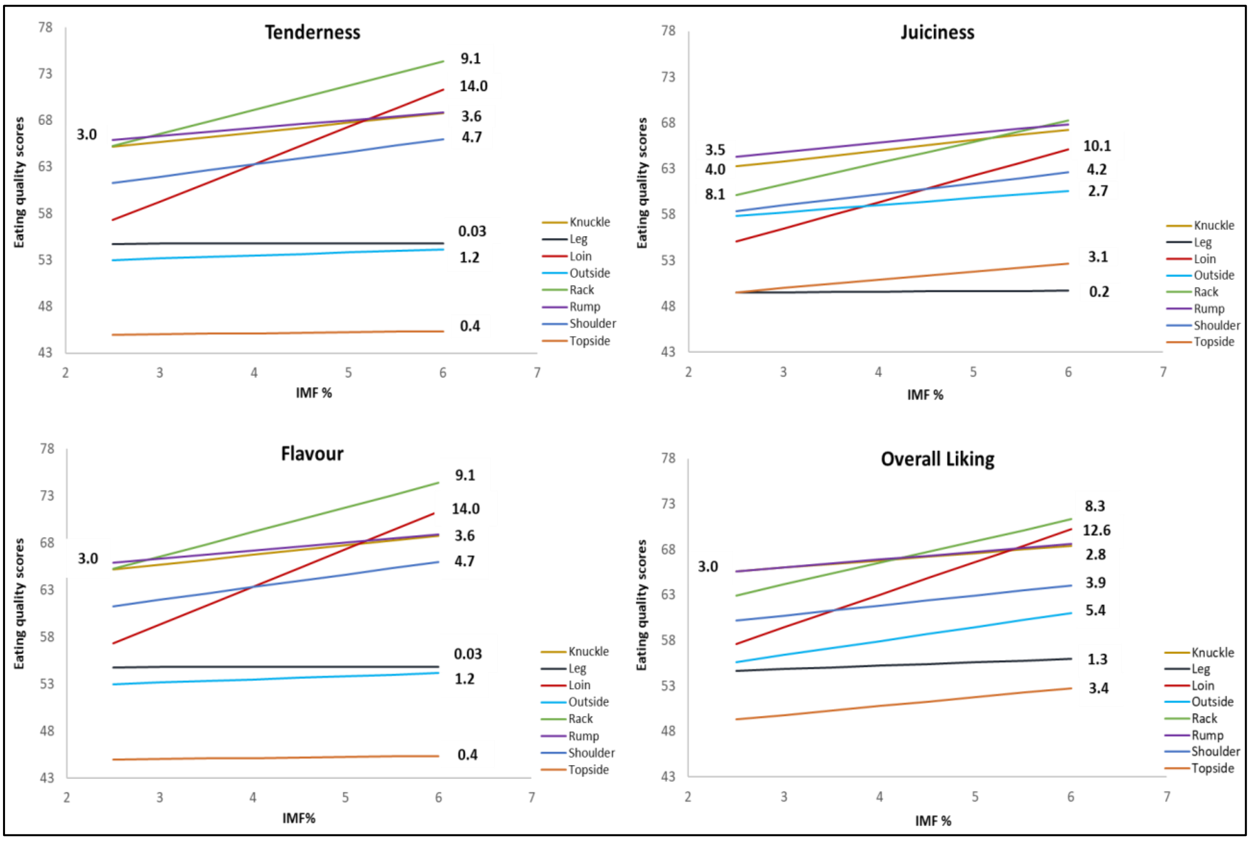

Figure 1. Slope of eating quality scores for all sensory traits across an increasing IMF% range

4.3 Carcase data and instrumental meat quality measurement

Overall, there were significant differences between NS and OS lambs for all meat quality and carcase measurements. OS lambs were 82.5 days older ($P < 0.01$) and were heavier and fatter than NS lambs. OS lambs were 1kg heavier (HCWT 24.5 ± 0.04), had greater GR tissue depth (16.0 ± 0.05), IMF% (4.73 ± 0.01), C-site fat depth (3.4 ± 0.02) and EMA (16.0 ± 0.03) when compared to NS lambs (23.5 ± 0.04 HCWT, 14.5 ± 0.05 GR tissue depth, 4.2 ± 0.01 IMF%, 3.17 ± 0.02 C-site fat depth, 15.1 ± 0.03 EMA ($P < 0.01$ for all measurements). OS lambs were also darker (L* 33.8 ± 0.07), redder (a* 17.2 ± 0.02) and displayed more yellowness (b* 5.7 ± 0.01) than NS lambs (L* 34.8 ± 0.07, a* 16.6 ± 0.02, b* 5.4 ± 0.01). In contrast, NS lambs had higher shear force (4.0 ± 0.01) in comparison to OS lambs (3.66 ± 0.01). These carcass and instrumental measurement differences varied between the different flocks (Table 4). For most traits differences between NS and OS lambs occurred in most flocks, though there was no difference between NS and OS lambs for HCWT, GR tissue depth, shear force and redness for flock 2, 5, 5 and 1. (Table 5). There was no difference in temperature at a pH of 6 between NS and OS lambs in any flock.

Table 5. Predicted means (± s.e.) for carcase and instrumental meat quality measurements for NS and OS lambs from each flock.

Trait	Flock	New Season	Old Season
Hot carcass weight (kg)	2	22.4 ± 0.1[a]	21.7 ± 0.1[b]
	3	23.0 ± 0.1	23.0 ± 0.1
	4	21.4 ± 0.1[a]	27.2 ± 0.1[b]
	5	28.8 ± 0.1[a]	30.4 ± 0.1[b]
GR tissue depth (mm)	2	9.9 ± 0.1[a]	11.8 ± 0.1[b]
	3	15.8 ± 0.1[a]	16.4 ± 0.1[b]
	4	15.0 ± 0.1[a]	18.4 ± 0.1[b]
	5	20.9 ± 0.1	21.1 ± 0.1
C-site fat depth (mm)	2	2.7 ± 0.04[a]	2.2 ± 0.04[b]
	3	2.9 ± 0.04[a]	3.7 ± 0.04[b]
	4	2.8 ± 0.04[a]	3.9 ± 0.04[b]
	5	5.0 ± 0.04[a]	4.5 ± 0.04[b]
Intramuscular fat (%)	2	3.4 ± 0.03[a]	4.3 ± 0.03[b]
	3	4.3 ± 0.03[a]	4.8 ± 0.03[b]
	4	4.1 ± 0.03[a]	5.1 ± 0.03[b]
	5	5.4 ± 0.03[a]	5.2 ± 0.03[b]
Eye muscle area (cm2)	2	13.7 ± 0.05[a]	16.3 ± 0.05[b]
	3	15.1 ± 0.05[a]	13.9 ± 0.05[b]
	4	15.1 ± 0.05[a]	16.7 ± 0.05[b]
	5	17.9 ± 0.05[a]	19.2 ± 0.05[b]

Shear force (KgF)	2	4.4 ± 0.02[a]	3.8 ± 0.02[b]
	3	3.8 ± 0.02[a]	3.5 ± 0.02[b]
	4	4.1 ± 0.02[a]	3.8 ± 0.02[b]
	5	3.5 ± 0.02	3.6 ± 0.02
Lightness (L*)	2	35.2 ± 0.1[a]	32.6 ± 0.1[b]
	3	34.7 ± 0.1[a]	34.0 ± 0.1[b]
	4	35.6 ± 0.1[a]	36.0 ± 0.1[b]
	5	33.3 ± 0.1[a]	33.7 ± 0.1[b]
Redness (a*)	2	16.5 ± 0.04	16.5 ± 0.05
	3	16.3 ± 0.04[a]	17.6 ± 0.04[b]
	4	16.0 ± 0.04[a]	17.0 ± 0.04[b]
	5	18.3 ± 0.04[a]	17.9 ± 0.04[b]
Yellowness (b*)	2	4.8 ± 0.02[a]	4.7 ± 0.02[b]
	3	5.4 ± 0.02[a]	6.3 ± 0.02[b]
	4	5.5 ± 0.02[a]	6.3 ± 0.02[b]
	5	6.3 ± 0.02[a]	6.2 ± 0.02[b]
Temperature at pH 6 (°C)	2	24.5 ± 1.3	26.3 ± 1.3
	3	31.6 ± 2.0	32.8 ± 1.9
	4	27.0 ± 1.8	25.5 ± 1.4
	5	29.2 ± 1.4	29.4 ± 1.4

5 Discussion

5.1 Effect of animal age on eating quality

Overall there was little to no difference between NS and OS lambs for consumer sensory scores. This might not be surprising due to the small age difference between the two age groups. However the differences that were seen in sensory scores between NS and OS lambs varied for each cut and flock. The results support our hypotheses that NS and OS lambs would not differ in sensory scores for high quality cuts, with the exception of the knuckle and rump cooked as grills. For these cuts , consumers generally preferred NS lamb compared to OS lamb although again the difference in consumer scores was small at about 3 consumer points . The lack of an age class difference in the loin is consistent with results from other studies. Loin sensory scores for tenderness, juiciness, liking of flavour and overall liking did not differ in lambs aged from 8.5 to 20 months old (Pethick et al., 2005). Furthermore, there was no difference in loin shear force values when comparing the same lambs (Pethick et al., 2005). This is also consistent with Hopkins et al. (2007) who showed no difference in loin shear force values in lambs aged from 4 to 14 months old. For the knuckle and rump cuts, which were high quality cuts (based on overall sensory scores), the age class effect was not expected. This suggests that the impact of animal age on eating quality cannot simply be explained by a ranking of high or low quality cuts. These differences are more likely caused by muscle characteristics of individual cuts, such as collagen solubility (Cross et al., 1972).

The effect animal age has on collagen solubility and its flow-on effect with tenderness is well described (Young and Braggins, 1993; Weston, 2002; Berge, 2003). As animal age increases collagen solubility decreases. This is due to increased collagen crosslinks (Bailey and Shimokomaki, 1971). More crosslinks cause an increase in the heat resistance of collagen during the cooking process (Young and Braggins, 1993). This in turn results in tougher meat. In lambs ranging from 1 month old to 7 months old, the collagen solubility had a strong correlation with age (-0.67 $P < 0.05$) and with raw compression value (0.40 $P < 0.05$) (Berge, 2003). Cross (1972) identified collagen concentrations of 3 ovine muscles across different age ranges. The topside had a soluble collagen percentage of 6.6% and 6.9% in lambs aged 6 months old and 10 months old. At the same ages the outside had collagen solubility of 8.4% and 7.7%. In comparison, the knuckle had collagen solubility of 9.2% at 6 months old and 6.7% at 10 months old. The knuckle had a collagen solubility decrease of 2.5% in comparison to 0.3% in the topside and 0.7% in the outside between 6 month old and 10 month old lambs. These results suggest that with increasing animal age, collagen solubility decreases more rapidly in the knuckle than the topside and outside. This might potentially explain the differences seen in sensory scores between NS and OS lambs in the knuckle. Furthermore, Girard (2011) found large differences in collagen solubility across cattle ages when comparing the rump to the outside cuts. The calf age group (aged 12-13 months old) had 23.3% soluble collagen in the outside. This decreased to 20.0% in the yearling age group (aged 18-20 months old). In contrast, the rump of the calf group had 52.3% soluble collagen, which decreased to 34.0% in the yearling group. Over the 6-7 month age range soluble collagen of the rump decreased by 18.3% in comparison to a 3.3% decrease in the outside. This shows a muscle difference in the rate of soluble collagen decrease with increased animal age. It is therefore probable that the age class effect seen mostly in the rump and knuckle across all eating quality traits when comparing NS and OS lambs is attributed to the rapid decrease in collagen solubility of those cuts.

The difference in rate of collagen solubility decrease for particular muscles could be due to differences in collagen types, rates of heat insoluble collagen formation or thermal stability of collagen within each muscle. Shimokomaki (1972) pointed out that the relative proportion of thermally labile and thermally stable cross links is most related to tenderness. Horgan (1991) discussed the thermal stability of intramuscular collagen (IMC) in five goat muscles across an age range of 4 months old to 10 years old. There was a significant age by muscle interaction, suggesting that the impact of age on IMC thermal stability was not consistent across the five different muscles. The authors also found that the topside and outside are the most thermally stable. This aligns well with previous work that showed little difference in collagen solubility in these muscles across a range of animal ages (Girard et al., 2011)(Cross 1972). Furthermore, many studies have found no difference in shear force across a range of ages in these muscles (Purchas et al., 2002; Pethick et al., 2005; Hopkins et al., 2007).This also aligns well with our results that showed no difference in sensory scores between NS and OS lambs in the topside and outside cuts.

There was no difference in sensory scores between NS and OS lambs for the leg, shoulder and rack roasts. This is most likely due to the cooking method. Cooking temperature and time has significant effects on the heat solubility of collagen (Vasanthi et al., 2007). As temperature and time increases connective tissue becomes softer (Winegarden et al., 1952; Ritchey et al., 1963). This is attributed to the conversion of collagen to gelatin at high temperatures (Lawrie, 1998). Thus, differences in sensory scores between NS and OS lambs in the grilled leg cuts attributed to decreases in collagen solubility would be mitigated or slowed by the roasting process.

Overall the differences in the eating quality of cuts, whether roasted or grilled were both small and inconsistent confirming the overall statistical conclusion that there is little difference between the new versus old season lambs in this experiment.

5.2 Carcass data and instrumental meat quality measures

NS Lambs were lighter and leaner when compared to OS lambs, which is not surprising due to the age class difference. OS lambs also had higher IMF% values, which agrees with the well documented evidence that IMF% increases with increased animal age (Pethick et al., 2005; Hopkins et al., 2006; Pannier et al., 2014a). An increase in eating quality scores across an increasing IMF % was expected. It has been well documented that IMF has a positive effect on consumer eating quality scores (Thompson; Rymill et al., 1997; Hopkins et al., 2006). Shear force values were higher in NS lambs compared to OS lambs despite no age class difference in overall tenderness. The difference in shear force was small but significant, however values for both age classes are quite low [below 4KgF is considered very tender (Bickerstaffe et al., 2001)]. Despite the positive relationship animal age has on shear force (Jeremiah et al., 1971; Hopkins et al., 2006), there have been some studies that displayed similar results to ours. Kim et al (2012) showed higher shear force value in 3-4 month old lambs compared to 10-11 month old lambs. This was also the case between 8 month old lambs and 20 month old lambs in a similar study by Pethick et al (2005). However in both these studies the differences were non-significant. OS lambs were darker and redder compared to NS lambs, yet still considered acceptable for consumers [L* values of 34 and a* values higher that 14.5 are considered acceptable to consumers (Khliji et al., 2010)]. This is in agreement with Kim (2012) and Pethick (2005) who demonstrated darker and redder meat in older animals, suggesting increased oxidative fibres and aerobicity as animals age (Brandstetter et al., 1998).

6 Conclusions/recommendations

This study has shown little differences in eating quality, according to consumer sensory scores, between NS and OS lambs across several major cuts of the carcase. This is in contrast to the current perception that young lambs, particularly “young spring lambs” have better quality than older, carry over lambs. This study highlights the potential to develop high quality OS or “autumn lamb” products, with the greatest opportunity in roast cuts. OS lambs could therefore receive the same premium price as NS lambs at retail. This study also demonstrates that in lambs, cut type is more significant in the impact of eating quality than animal age. Overall there were instrumental meat quality differences between NS and OS lambs, although neither age group displayed meat quality parameters that would be unacceptable to consumers.

7 Key messages

- Overall there was no age class effect on eating quality.
- NS and OS lamb received the same consumer sensory scores across multiple eating quality traits for most cuts.
- These results were consistent with the hypothesis that NS lamb would not differ to OS lambs for high quality cuts
- The exception was the knuckle and rump cuts whereby NS lambs scored slights higher that OS lambs by about 3 consumer points.

8 Appendix 1

Table 6. Unadjusted means of Flock 1 NS and OS eating quality scores across all cuts

		Tenderness		**Juiciness**		**Liking of Flavour**		**Overall Liking**	
	Cut	New	Old	New	Old	New	Old	New	Old
Grill	Knuckle	68.4	64.8	66.1	63.6	67.2	64.2	68.2	65
	Loin	62.5	63.6	59.6	59.4	62.9	63.1	62.8	63.3
	Outside	55	50.8	60.1	56	59.8	56.2	59	55.3
	Rump	67.4	64.3	66.6	62.1	66.1	63.7	67.4	64.2
	Topside	45.3	42.1	50.9	47.3	52.8	51.1	50.2	48.4
Roast	Rack	69.2	69.2	63	63.1	65.1	65.8	66.2	66.6
	Shoulder	64.3	62.7	60.4	60.2	60.7	60.2	61.5	60.9
	Leg	53.8	52.5	49.7	48.4	55.6	54.7	55.2	53.7

PHASE 2 Packaging

Oxygen concentration required in modified atmosphere packaging to maintain meat colour

1 Background

Meat colour is an important factor impacting the purchasing decisions made by consumers (Faustman and Cassens, 1990). Modified atmosphere packaging (MAP) containing 80% oxygen and 20% carbon dioxide is widely used by retail supermarkets in Australia. The high oxygen concentration promotes a cherry red meat colour that extends shelf life longer than conventional overwrap packaging. Bright red meat colour is generally considered desirable to consumers and seen as an indicator of freshness and quality (Carpenter et al., 2001). The high oxygen content in MAP helps achieve this bright red colour due to the promotion of red oxymyoglobin formation (O'Grady et al., 2000). Including 20-30% carbon dioxide in MAP prolongs the retail shelf life by preventing bacterial growth (McMillin, 2008).

Meat colour changes during retail display as the myoglobin pigment changes from primarily purple deoxymyoglobin, to red oxymyoglobin upon exposure to oxygen, and eventually to brown metmyoglobin with continued exposure to oxygen (AMSA, 2012). The focus of this work was to test the effect of oxygen concentration on the redness of lamb at the meat surface, measured by the ratio of reflectance of light at wavelengths 630 nm and 580 nm, also known as the oxy:met ratio (Jacob et al., 2007). An oxy:met ratio greater than 4 suggests that the majority of the pigment is the red oxymyoglobin, while a ratio approaching 1 suggests mostly brown metmyoglobin. Meat colour was also measured by the proportion of deoxymyoglobin (DMb%), oxymyoglobin (OMb%), metmyoglobin (MMb%), L* (a scale of black 0 to white 100) , a* (a scale of green –a to red +a) and b* (a scale of blue –b to yellow +b) (AMSA, 2012).

Recent evidence has shown that beef and lamb meat displayed under 80% oxygen and 20% carbon dioxide have reduced eating quality, in particular reduced tenderness (Lagerstedt et al., 2011; Frank et al., 2017). Therefore, there is growing interest within the red meat industry on whether reducing the oxygen content in MAP could eliminate the negative impact on tenderness (Zakrys et al., 2008). Studies in beef have shown that reducing oxygen concentration as low as 50% had no adverse effect on meat colour during retail display (Jakobsen and Bertelsen, 2000; Łopacka et al., 2017). Further investigation in lamb meat is needed to determine whether a reduced concentration of oxygen in MAP can still meet the colour requirements for consumer acceptability, before examining the impact on meat tenderness. A range in MAP oxygen concentrations were tested of 0, 20, 40, 60 to 80%. Previous beef studies have shown a reduced oxygen concentration of 50% and 65% (Łopacka et al., 2017) and 55% (Jakobsen & Bertelsen, 2000) in MAP had no adverse effect on meat colour. Therefore, we hypothesise a MAP mixture containing 40% oxygen or higher will have a similar colour measures as the standard 80% oxygen MAP, while oxygen concentrations of 20% or lower will have a poorer meat colour during simulated retail display.

2 Methodology

Lambs (n = 50) were selected from the Meat and Livestock Australia genetic resource flock, Katanning, Western Australia. The lambs were the progeny of 21 Merino sires mated to 47 Merino dams. Lambs ranged from 334 - 349 days of age, 34 were female and 16 were wethers. All carcasses were electrically stimulated with medium voltage (Pearce et al., 2010) and trimmed according to AUS-MEAT specifications (Anonymous, 2005). Hot carcass weight was measured immediately after slaughter, averaging 20.5 kg (StDev = 2.0) and tissue depth at the GR site averaging 10.3 mm (StDev = 3.4). At a pH of 6.0, the carcasses temperatures averaged 11.8 °C (StDev = 6.8), lower than expected indicating the electrical stimulation for this kill group was poorly effective.. Carcasses were chilled overnight at 3-4°C, and at 24 hours post-mortem a M. *longissimus lumborum* (loin) and a M. *semimembranosus* (topside) were removed from each carcass. The loin muscle was excised between the 12th/13th rib and the caudal end of *longissimus*, and subcutaneous fat was removed (AUSMEAT 5150). The topside muscle had the cap removed (AUSMEAT 5077).

Each muscle was sliced into six samples of 50 mm in length, 50 mm in width and 30 mm in depth, after the epimysium (silver skin) was removed. The six loin and six topside samples from each carcass was aged for the same amount of time, either 5 or 20 days at 2°C. The six loin and six topside samples from one animal was then placed into two of the five oxygen concentration MAP treatments 0, 20, 40, 60 or 80% oxygen, with 20% carbon dioxide, and the balance met by nitrogen gas. Loins were butterflied and topsides re-sliced roughly 2mm before samples were placed under MAP. Samples were then placed under simulated retail display for 2, 6 or 10 days at 2°C (see Table 1). After MAP packaging treatment, the surface meat colour was instrumentally measured using a Hunterlab MiniScan EZ. Meat colour was measured using L*, a*, b*, DMb%, OMb%, MMb% and oxy:met ratio.

Each colour measurement was analysed individually using a linear mixed effect models (SAS Version 9.1, SAS Institute Cary, NC, USA) with aging time (5 or 20 days), retail display time (2, 6 or 10 days), and oxygen concentration group as fixed effects, and animal ID within Sire ID was used as random terms.

Table 7. Example of the allocation of samples to treatment groups based on experiment design for the 5 day aging group. The same design was applied to the 20 day aging group.

Loin only (repeated for topside)	5 days aging 0% oxygen			5 days aging 20% oxygen			5 days aging 40% oxygen			5 days aging 60% oxygen			5 days aging 80% oxygen		
Display time	*2*	*6*	*10*	*2*	*6*	*10*	*2*	*6*	*10*	*2*	*6*	*10*	*2*	*6*	*10*

Carcass 1	1	2	3	4	5	6									
Carcass 2	4	5	6				1	2	3						
Carcass 3										1	2	3	4	5	6

3 Results

3.1 Effect of display time and packaging on meat colour

There were significant effects (P < 0.001) between oxygen concentration and retail display time for oxy:met ratio, a*, b*, DMb%, OMb% and MMb%. The least square means (± SE) for oxygen concentration and display time are presented in Table 2.

In general, increasing retail display resulted in reduced colour values. On average across all oxygen concentrations, samples at retail display day 2 to day 6 decreased by 1.7 units for oxy:met ratio and 4.1 units for a*, meaning the samples became less red. Samples also decreased in lightness (L*) from day 2 to 6 by 0.6 units. Samples on display day 2 to day 6 also decreased in 3.1 units in b*, indicating the samples were less yellow and more blue in colour. Likewise, samples on display day 2 to day 6 decreased by 6.8 OMb%, indicating a reduced proportion of red oxymyoglobin. On average across all oxygen concentrations, samples at display day 6 to day 10 reduced by 0.3 units for oxy:met ratio, 1.3 units for a* and 3.7 units for OMb%, meaning the samples became less red over time. Samples also showed reduced lightness from day 6 to 10 by 0.6 units for L*. Samples at display day 6 to day 10 also had reduced DMb% by 1.0 unit, indicating a reduced proportion of purple deoxymyoglobin. The exceptions to this trend was observed for b* at day 6 and 10 which were not significantly different (P > 0.05). Likewise, DMb% at day 2 and day 10 were not significantly different (P > 0.05), and DMb% increased from day 2 to day 6. Increasing retail display showed an increase in MMb% values, indicating the samples became browner over retail display.

When comparing the different oxygen concentrations, samples in 40% oxygen concentration were frequently similar to samples in 80% oxygen concentration for the meat colour measurements (Table 2). At 2 days of retail display the 40% and 80% oxygen concentration samples were similar for L*, b*, DMb% and MMb% (P > 0.05). At 6 days of retail display the 40% and 80% oxygen concentration samples were similar for L* and DMb% (P > 0.05). At 10 days of retail display 40% and 80% oxygen concentration samples were similar for oxy:met ratio, L*, b*, OMb% and MMb% (P > 0.05). The difference in colour between 40% and 80% oxygen concentration was seen at day 2 of retail display for oxy:met ratio, a*, OMb%. At 6 days of retail display 40% and 80% oxygen concentration samples were significantly different for oxy:met ratio, a*, b*, OMb% and MMb%. At 10 days of retail display the 40% and 80% oxygen concentration samples were significantly different for a* and DMb%.

Table 8. Least squared means (± SE) for the effects of oxygen concentration and display time for oxy:met ratio, L*, a*, b*, DMb%, OMb% and MMb%.

	2 days display time				
Oxygen concentration	**0%**	**20%**	**40%**	**60%**	**80%**
oxy:met ratio	5.2 ± 0.2 ^{b}	3.7 ± 0.2 ^{a}	5.4 ± 0.2 ^{bc}	6.1 ± 0.2 ^{cd}	6.4 ± 0.2 ^{d}
L*	33.6 ± 0.5 ^{a}	35.8 ± 0.5 ^{b}	36.6 ± 0.5 ^{b}	36 ± 0.5 ^{b}	37.1 ± 0.5 ^{b}
a*	17 ± 0.4 ^{a}	17.1 ± 0.4 ^{a}	22.3 ± 0.4 ^{b}	24 ± 0.4 ^{bc}	24.9 ± 0.4 ^{c}
b*	14.2 ± 0.4 ^{a}	17.8 ± 0.4 ^{b}	20.8 ± 0.4 ^{bc}	21.1 ± 0.4 ^{c}	21.4 ± 0.4 ^{c}

DMb%	42.1 ± 0.9 [b]	8.4 ± 0.9 [a]	6.8 ± 0.9 [a]	6.8 ± 0.9 [a]	5.9 ± 0.9 [a]
OMb%	33.6 ± 0.6 [a]	58.1 ± 0.6 [b]	66.6 ± 0.6 [c]	68.4 ± 0.6 [cd]	69.7 ± 0.6 [d]
MMb%	24.4 ± 0.8 [a]	33.5 ± 0.8 [c]	26.6 ± 0.8 [b]	24.6 ± 0.8 [ab]	24.5 ± 0.8 [ab]
	6 days display time				
Oxygen concentration	**0%**	**20%**	**40%**	**60%**	**80%**
oxy:met ratio	4.9 ± 0.2 [d]	2.3 ± 0.2 [a]	3.4 ± 0.2 [b]	3.8 ± 0.2 [bc]	4.3 ± 0.2 [cd]
L*	34 ± 0.5 [a]	35 ± 0.5 [ab]	35.5 ± 0.5 [ab]	35.9 ± 0.5 [b]	35.7 ± 0.5 [b]
a*	16.3 ± 0.4 [b]	13.2 ± 0.4 [a]	17.1 ± 0.4 [bc]	18.2 ± 0.4 [c]	20 ± 0.4 [d]
b*	13.5 ± 0.4 [a]	15.3 ± 0.4 [b]	16.7 ± 0.4 [c]	16.4 ± 0.4 [bc]	18.1 ± 0.4 [d]
DMb%	44.5 ± 0.9 [b]	8.1 ± 0.9 [a]	8.1 ± 0.9 [ab]	7.8 ± 0.9 [a]	7.5 ± 0.9 [a]
OMb%	33.6 ± 0.6 [a]	48.1 ± 0.6 [b]	57.3 ± 0.6 [c]	61.1 ± 0.6 [cd]	62.2 ± 0.6 [d]
MMb%	22.1 ± 0.8 [a]	43.8 ± 0.8 [d]	34.6 ± 0.8 [c]	30.8 ± 0.8 [bc]	30.4 ± 0.8 [b]
	10 days display time				
Oxygen concentration	**0%**	**20%**	**40%**	**60%**	**80%**
oxy:met ratio	5.4 ± 0.2 [cd]	2.1 ± 0.2 [a]	2.9 ± 0.2 [ab]	3.3 ± 0.2 [b]	3.3 ± 0.2 [b]
L*	32.8 ± 0.5 [a]	34.3 ± 0.5 [b]	35.3 ± 0.5 [bc]	34.7 ± 0.5 [bc]	35.9 ± 0.5 [c]
a*	17.3 ± 0.4 [c]	11.8 ± 0.4 [a]	15.5 ± 0.4 [b]	16.9 ± 0.4 [bc]	16.9 ± 0.4 [c]
b*	14.6 ± 0.4 [a]	15 ± 0.4 [a]	16.5 ± 0.4 [b]	17.7 ± 0.4 [c]	17.6 ± 0.4 [bc]
DMb%	39.3 ± 0.9 [c]	8.3 ± 0.9 [ab]	9.5 ± 0.9 [b]	6.9 ± 0.9 [ab]	6.9 ± 0.9 [a]
OMb%	37.8 ± 0.6 [a]	43.6 ± 0.6 [b]	51.6 ± 0.6 [c]	55.7 ± 0.6 [d]	55.3 ± 0.6 [cd]
MMb%	23.1 ± 0.8 [a]	48.2 ± 0.8 [c]	38.9 ± 0.8 [bc]	37.1 ± 0.8 [b]	37.9 ± 0.8 [b]

DMb%: deoxymyoglobin percentage, OMb%: oxymyoglobin percentage, MMb%: metmyoglobin percentage. Within a display time, the different letter annotations demonstrate significant differences ($P < 0.05$) between the oxygen concentrations for each colour measurement.

4 Discussion

In partial support of our hypothesis, MAP mixtures containing 40% oxygen or higher had similar colour measures as the standard 80% oxygen MAP, while lower oxygen concentrations had significantly different colour measures. The 80% oxygen concentration in MAP is currently used by Australian retail supermarkets as it promotes a cherry red meat colour and extends shelf life (Carpenter et al., 2001). These results show that 40% and 80% oxygen concentration samples had a majority of similar colour values at different retail display times. These findings are based on the average of loin and topside muscles and aging times of 5 and 20 days prior to retail display under MAP. Therefore, the difference between 40% and 80% oxygen concentration on meat colour may be further impacted on by muscle and aging time. This has been shown previously, as muscle type (M. *longissimus lumborum* or M. *gluteus medius*) influenced beef meat discoloration more significantly than oxygen concentration in the range of 50 to 80% tested (Łopacka et al., 2017). This previous beef study also showed a reduced oxygen concentration of 50% and 65% had no adverse effect on meat colour stability compared to 80% oxygen MAP. However, the beef study only tested 8 cattle, aged for 12 days prior and display times were 4, 8 and 12 which cannot be directly compared to the current lamb meat study. In addition, another beef study showed the average a* values did not markedly increase when oxygen concentrations were increased above 55% in MAP (Jakobsen and Bertelsen, 2000). Interestingly, this beef study showed oxygen concentrations can be reduced without affecting colour stability but this reduction did not impact the lipid oxidation in meat. Therefore, a slightly lower oxygen concentration may be required that still maintains colour stability, but reduces the detrimental effects that high oxygen has on lipid oxidation (Geesink et al., 2015).

A general trend was shown as increasing display time from day 2 to 10 reduced the colour values tested, except for MMb%. However, this was expected as the brown MMb% tends to increase over retail display when exposed to oxygen. This is due to MMb forming at low oxygen concentrations of approximately 1 to 2% oxygen which can be found at the junction of the DMb and OMb layers in the meat (Hunt et al., 2012). The migration of MMb, located between the interior DMb and superficial OMb, thickens and gradually moves towards the meat subsurface and causing the colour change (Hunt et al., 2012).

Two major theories have been suggested for the lack of tenderisation or the toughening of samples from 80% oxygen concentration MAP. The high oxygen environment in 80% oxygen MAP promotes oxidation and inhibits calpain, a protein involved in muscle degradation and the tenderisation process (Koohmaraie and Geesink, 2006; Fu et al., 2015; Geesink et al., 2015). In addition, the high oxygen content in 80% oxygen concentration MAP promotes oxidative protein cross-linking which strengthens myofibrillar structure and thus increases meat toughness (Kim et al., 2010; Geesink et al., 2015). In the current study, the majority of the colour values were similar between the 40% and 80% oxygen concentration samples at different retail display times. At day 2 and day 10 of retail display the most colour values were similar between the 40% and 80% oxygen concentration samples. While at day 6 there were more differences in colour values between the 40% and 80% oxygen concentration samples. The slight colour differences suggests some meat samples were reacting differently within the 40% and 80% oxygen concentration. Therefore, the 40% oxygen concentration MAP may have reduced impacts on oxidation, calpain protein or protein cross-linking, and improving the meat tenderness. This could mean the 40% oxygen concentration has better eating quality compared to samples under 80% oxygen, while still maintaining similar meat colour over retail display.

5 Conclusions/recommendations

The best colour results were achieved by the 80% oxygen concentration MAP mixture, yet importantly 40% oxygen produced similar meat colour within the different display times. This represents an opportunity to reduce oxygen levels within MAP to 40% to counter the negative effects of high oxygen MAP on meat toughness. Further studies will explore the impact of MAP with 40% oxygen on lamb meat tenderness using sensory analysis.

Impact of modified atmosphere packaging (MAP) on lamb meat eating quality

1 Background

Colour is an important attribute influencing consumer acceptability of fresh meat (Mancini and Hunt, 2005). High oxygen modified atmosphere packaging (MAP), containing 80% oxygen (O_2) and 20% carbon dioxide (CO_2), is used in the meat industry as a standard as it extends the bright red colour and shelf life of red meat compared to overwrap packaging in oxygen permeable film (Kim et al., 2012). Bright red meat colour is generally considered desirable to consumers and seen as an indicator of freshness and quality (Carpenter et al., 2001). The high oxygen content in MAP helps achieve this bright red colour due to the promotion of red oxymyoglobin formation (O'Grady et al., 2000). Including 20-30% carbon dioxide in MAP prolongs the retail shelf life by preventing bacterial growth (McMillin, 2008). The significant benefits MAP has on promoting red meat colour and extending the shelf life of meat cannot be dismissed. Recent studies in beef have shown a reduction in the oxygen concentration in MAP can inhibit lipid oxidation (Zakrys et al., 2008), improve flavour (Zakrys et al., 2009) and have no adverse effect on meat colour stability (Łopacka et al., 2017). However, a number of studies have reported reduced eating quality of samples packaged in high oxygen MAP through lower tenderisation, lower sensory traits such as juiciness and tenderness, and the oxidation of lipids and proteins (Lund et al., 2007; Lagerstedt et al., 2011; Geesink et al., 2015; Frank et al., 2017). In addition, a previous study by Corlett et al. (unpublished data) identified MAP containing 40% oxygen, 20% carbon dioxide and 40% nitrogen was the minimum threshold of oxygen required to maintain a similar meat colour to the standard high oxygen MAP with 80% oxygen and 20% carbon dioxide used by the meat industry.

Vacuum skin packaging (VSP) is an increasingly popular alternative form of packaging meat. VSP involves shrink-wrapping meat with a flexible skin polymer with a low oxygen transmission rate. VSP minimises air pockets and wrinkles in the packaging and reduces exudate from occurring, creating a more visually appealing format over conventional vacuum packaging (Nassu et al., 2012). VSP has been found to have higher sensory traits, particularly for tenderness, when compared to high oxygen MAP (Lund et al., 2007; Lagerstedt et al., 2011; Geesink et al., 2015; Frank et al., 2017). These benefits that VSP provides meat are countered by the visual appearance of VSP meat as the anoxic environment causes the meat to retain its dark purple colour (Nassu et al., 2012). Therefore, we hypothesised that lamb meat under a lower oxygen concentration in MAP will have improved overall liking, tenderness, juiciness and flavour scores compared to lamb meat under high oxygen MAP, and VSP will have the highest sensory scores.

2 Project objectives

- Investigate the impact of novel ratios of gas for modified atmosphere packaging on shelf-life and eating quality.

3 Methodology

3.1 Sample collection and experimental design

Lambs (n=144) were selected from the Meat and Livestock Australia's Research Flock across two sites (Katanning, Western Australia; Kirby, New South Wales). The lambs were the progeny of 35 Maternal (Border Lester, Corriedale) and 47 Merino (Dohne Merino, Merino, Poll Merino) sires mated to Merino dams. The majority of sires were represented by minimum of two progeny, up to a maximum of six progeny per sire. Lambs ranged from 294 – 336 days of age and 78 were female and 66 were wethers. Lambs were generally maintained under extensive pasture grazing, with hay, grain or feedlot pellets supplemented when pasture supply was limited. Further information on genetic selection, lamb management and feeding have been described previously (Van der Werf et al., 2010; Ponnampalam et al., 2014). The day prior to slaughter, lambs were held in yards for six hours, weighed and transported to a commercial abattoir where they rested overnight in holding pens and were slaughtered the following day.

All carcasses were electrically stimulated with medium voltage (Pearce et al., 2010) and trimmed according to AUS-MEAT specifications (Anonymous, 2005). Hot carcass weight was measured immediately after slaughter, averaging 23.3 kg (StDev = 2.4) and tissue depth at the GR site averaging 16.7 mm (StDev = 3.9) for the Kirby lambs. The hot carcass weight for the Katanning lambs averaged 21.9 kg (StDev = 2.5) and tissue depth at the GR site averaged 14.7 mm (StDev = 4.8). At a pH of 6.0, the carcasses temperatures averaged 17.9°C (StDev = 8.9) for the Kirby lambs and 20.0°C (StDev = 6.3) for the Katanning lambs. Carcasses were chilled overnight at 3-4°C, and at 24 hours post-mortem, two M. *longissimus lumborum* (loin) and two M. *semimembranosus* (topside) were removed from each carcass. The loin muscle was excised between the 12^{th}/13th rib and the caudal end of *longissimus*, and subcutaneous fat was removed (AUSMEAT 5150). The topside muscle had the cap removed (AUSMEAT 5077). Loin and topside muscles were vacuum packaged and wet aged at 2°C for 7 days at Katanning, and 10 days at Kirby.

Each muscle was sliced into five samples of 15 mm thick for subsequent eating quality testing after the epimysium (silver skin) was removed. The five samples of each muscle were placed into one of six treatment groups comprising out of a combination of four packaging types and two different retail display times. The four packaging types consisted of vacuum skin packaging (VSP), modified atmosphere packaging with 80% oxygen and 20% carbon dioxide (MAP80), and modified atmosphere packaging with 40% oxygen (MAP40) with 20% carbon dioxide and 40% nitrogen for Kirby samples ($MAP40O_220CO_2$), and modified atmosphere packaging with 40% oxygen with 60% carbon dioxide for Katanning samples ($MAP40O_260CO_2$). The lack of nitrogen gas as the 'filler' for Katanning was the result of equipment failure at the MAP packaging facility. The different display times were three and eight days under simulated retail display at 2°C in a cool room fitted with cool white fluorescent lights (OSRAM L36W/20, Germany). Following the allocated display time the five samples were vacuum packed together and frozen at -20°C for subsequent sensory testing.

3.2 Sensory testing

Samples were sensory tested by untrained consumers (total n=960) following the Meat Standards Australia sensory testing protocol previously published by Thompson et al. (2005a) and Watson et al. (2008). In brief, the five samples from each muscle were grilled using a Silex griller to a medium degree of doneness (internal temperature of 65°C). The samples were rested for two minutes, and cut in half to form ten test samples. Untrained consumers assessed each sample for tenderness, juiciness, liking of flavour and overall liking using a 100 score scale, with 100 being the most preferred. All consumers tested one starter sample of average quality, followed by six test samples (3 loin and 3 topside) across the different treatment groups. These six test samples were allocated to the consumers using a Latin square design (Thompson et al., 2005a). Each sensory sessions consisted of 60 unique consumers testing 36 muscles in total, with each muscles being eaten by 10 different consumers, resulting in 10 consumer responses per muscle. A total of 16 consumer sensory session were constructed.

3.3 Statistical analysis

Linear mixed effects models were used in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA) to analyse consumer scores for overall liking, tenderness, juiciness and liking of flavour. The analysis was conducted on the 10 individual scores for each muscle. Base models for each sensory trait included the fixed effects for muscle (loin, topside), site the animals were sourced from (Katanning, Kirby), packaging type within site (Katanning VSP, $MAP40O_260CO_2$, MAP80, and Kirby VSP, $MAP40O_220CO_2$ and MAP80), display time (3, 8 days), sire type (Merino, Maternal) and sex of animal (female, male). Animal identification within sire identification, and consumer within eating quality session were included as random terms. All relevant first-order interactions between fixed effects were tested and non-significant ($P > 0.05$) terms were removed in a stepwise manner.

4 Results

4.1 Effect of display time and packaging on eating quality

The outcomes of the base models are presented in Table 1, with the least square means (± SE) for muscle, display time and packaging within site presented in Table 2.

Samples on retail display for fewer days had higher sensory scores, with day 3 showing increased sensory scores than day 8 samples. On average, samples on display for 3 days had 4.2, 3.3, 3.3 and 4.6 more eating quality scores than day 8 for overall liking, tenderness, juiciness and flavour. This effect was seen for all three packaging types within the Katanning site, whereas at the Kirby site this effect appeared consistent for the MAP40 and MAP80, except for the VSP samples which were not significantly different between day 3 and day 8.

When comparing the different packing types at a given site, generally VSP samples had 3.6 more eating quality scores compared to $MAP40O_260CO_2$ samples, and 3.6 more than MAP80 samples at the Katanning site for overall liking. This was consistent for the other eating quality attributes. The Katanning site $MAP40O_260CO_2$ and MAP80 samples did not differ across all eating quality attributes ($P > 0.05$). At the Kirby site, VSP samples had 5.7 and 9.6 more eating quality scores compared to $MAP40O_220CO_2$ and MAP80 samples for overall liking. This was also consistent for the other eating quality traits. $MAP40O_220CO_2$ samples had 3.9 more eating quality scores compared to MAP80 samples for overall liking and this was consistent for the other eating quality traits.

However, these packaging type differences varied within each muscle and within each display time. At the Kirby site, at both the 3 and 8 days display time for both muscles, VSP samples had increased scores compared to $MAP40O_220CO_2$ samples, except for the loin samples at 3 days which were not significantly different from VSP ($P > 0.05$) for all eating quality attributes. At the Kirby site, at both the 3 and 8 days display time for both muscles, $MAP40O_220CO_2$ samples had increased scores compared to MAP80, except for day 8 topside samples which were not significantly different ($P > 0.05$) for all eating quality attributes. Likewise, $MAP40O_220CO_2$ and MAP80 samples were not significantly different ($P > 0.05$) at day 3 for the loin tenderness scores, and at day 3 for the topside sample tenderness and flavour scores. At Katanning site, at both the 3 and 8 days display time for both muscles, VSP samples had increased scores compared to $MAP40O_260CO_2$ for all eating quality traits, except for day 3 topside samples which were not significantly different ($P > 0.05$) for overall liking and flavour scores, and day 8 topside samples which had reduced overall liking and flavour scores.

4.2 Effect of muscle on eating quality

Across all packaging treatment groups and display days, loin samples were more acceptable than topside samples for all sensory traits and these differed by as much as 10.3 scores for overall liking, 15.9 scores for tenderness, 4.2 scores for juiciness and 8.2 scores for flavour. These differences were consistent in samples from the different packaging treatment groups and the different days on retail display.

4.3 Effect of production effects on eating quality

There were significant effects for site, sex and sire type for overall liking, tenderness, juiciness and flavour sensory scores (Table 1). On average, Kirby samples were more acceptable by 2.7, 4.2, 3.3 and 2.0 scores for overall liking, tenderness, juiciness and flavour, than Katanning samples across both muscles tested and across all packaging treatment groups. On average, samples from males had 3.8, 4.1, 3.7 and 3.3 scores more for overall liking, tenderness, juiciness and flavour than samples from females. Kirby Merino sired lambs had 2.4 more flavour scores to Maternal sired lambs. Whereas, the eating quality attributes did not differ for the Katanning Merino and Maternal sired lambs (P > 0.05).

Table 9. F values and numerator and denominator degrees of freedom for the effects of the base linear mixed effects models of the overall liking, tenderness, juiciness and flavour scores of the loin and topside muscles of lamb.

Effect	NDF	DDF	Overall liking	Tenderness	Juiciness	Flavour
Site	1	4652	8.85*	18.72**	11.83*	6.05*
Muscle	1	4652	432.73**	884.37**	66.92**	312.02**
Packaging(site)	4	4652	35.05**	28.38**	32.30**	33.90**
Display time	1	4652	69.77**	36.79**	40.60**	85.40**
Sire type	1	4652	ns	ns	ns	n.s
Sex	1	4652	17.96**	18.33**	14.69**	16.17**
Site * sire type	1	4652	ns	ns	ns	4.06*
Site * display time	1	4652	ns	4.87*	ns	ns
Muscle * packaging(site)	5	4652	16.30**	16.03**	17.69**	15.3**
Muscle * display time	1	4652	ns	ns	ns	n.s
Display time* packaging(site)	5	4652	3.87*	2.43*	ns	2.81*
Muscle * display time* packaging(site)	6	4652	7.79**	4.89*	3.86*	5.70**

NDF, DDF; numerator and denominator degrees of freedom; ns; non-significant association (P > 0.05); *; P < 0.05; **; P < 0.001.

Table 2. Least squared means (± SE) for the effects of muscle, display time, and packaging within site for overall liking, tenderness, juiciness and flavour sensory scores.

Muscle	Display time	Site	Pack	Overall liking	Difference to VSP	Tenderness	Difference to VSP	Juiciness	Difference to VSP	Flavour	Difference to VSP
Loin	3	Kirby	VSP	69.49 ± 1.56 [ab]		74.42 ± 1.67 [a]		67.90 ± 1.64 [b]		69.48 ± 1.51 [b]	
			MAP40$O_2$20CO_2	70.44 ± 1.50 [a]	0.95	73.27 ± 1.62 [a]	-1.15	68.14 ± 1.58 [b]	0.24	69.36 ± 1.46 [b]	-0.12
			MAP80	66.55 ± 1.53 [b]	-2.94	70.93 ± 1.64 [a]	-3.49	62.60 ± 1.61 [a]	-5.3	64.87 ± 1.48 [a]	-4.61
Loin	8	Kirby	VSP	73.11 ± 1.51 [c]		73.87 ± 1.62 [c]		68.95 ± 1.58 [c]		70.88 ± 1.46 [c]	
			MAP40$O_2$20CO_2	65.00 ± 1.53 [a]	-8.11	68.67 ± 1.64 [b]	-5.2	63.11 ± 1.61 [b]	-5.84	63.88 ± 1.48 [b]	-7
			MAP80	58.16 ± 1.56 [b]	-14.95	61.72 ± 1.67 [a]	-12.15	55.01 ± 1.64 [a]	-13.94	57.52 ± 1.51 [a]	-13.36
Topside	3	Kirby	VSP	64.50 ± 1.53 [c]		61.89 ± 1.65 [b]		67.57 ± 1.61 [c]		64.79 ± 1.49 [b]	
			MAP40$O_2$20CO_2	59.42 ± 1.55 [b]	-5.08	56.15 ± 1.67 [a]	-5.74	63.09 ± 1.63 [b]	-4.48	59.78 ± 1.51 [a]	-5.01
			MAP80	55.68 ± 1.51 [a]	-8.82	52.78 ± 1.62 [a]	-9.11	58.19 ± 1.58 [a]	-9.38	57.54 ± 1.46 [a]	-7.25
Topside	8	Kirby	VSP	61.94 ± 1.51 [b]		60.83 ± 1.62 [b]		64.50 ± 1.58 [b]		61.33 ± 1.46 [b]	
			MAP40$O_2$20CO_2	51.57 ± 1.53 [a]	-10.37	48.82 ± 1.64 [a]	-12.01	56.58 ± 1.61 [a]	-7.92	52.71 ± 1.48 [a]	-8.62
			MAP80	50.44 ± 1.56 [a]	-11.5	48.76 ± 1.67 [a]	-12.07	55.29 ± 1.64 [a]	-9.21	49.78 ± 1.51 [a]	-11.55

Muscle	Display time	Site	Pack	Overall liking	Difference to VSP	Tenderness	Difference to VSP	Juiciness	Difference to VSP	Flavour	Difference to VSP
Topside	3	Katanning	VSP	56.74 ± 1.53 [a]		51.11 ± 1.65 [a]		56.97 ± 1.61 [a]		58.24 ± 1.48 [a]	
			$MAP40O_260CO_2$	56.56 ± 1.53 [a]	-0.18	52.34 ± 1.65 [a]	1.23	60.26 ± 1.61 [a]	3.29	57.96 ± 1.48 [a]	-0.28
			MAP80	56.17 ± 1.53 [a]	-0.57	52.09 ± 1.65 [a]	0.98	59.16 ± 1.61 [a]	2.19	57.46 ± 1.48 [a]	-0.78
Topside	8	Katanning	VSP	46.86 ± 1.53 [a]		44.21 ± 1.65 [a]		51.40 ± 1.61 [a]		48.07 ± 1.48 [a]	
			$MAP40O_260CO_2$	52.95 ± 1.53 [b]	6.09	50.03 ± 1.65 [b]	5.82	55.23 ± 1.61 [b]	3.83	54.59 ± 1.48 [b]	6.52
			MAP80	55.61 ± 1.53 [b]	8.75	52.84 ± 1.64 [b]	8.63	57.72 ± 1.61 [b]	6.32	55.59 ± 1.48 [b]	7.52
Loin	3	Katanning	VSP	70.98 ± 1.52 [b]		72.15 ± 1.64 [b]		67.65 ± 1.61 [b]		70.16 ± 1.48 [b]	
			$MAP40O_260CO_2$	63.86 ± 1.53 [a]	-7.12	63.83 ± 1.65 [a]	-8.32	58.50 ± 1.61 [a]	-9.15	63.25 ± 1.48 [a]	-6.91
			MAP80	65.09 ± 1.53 [a]	-5.89	65.68 ± 1.65 [a]	-6.47	60.93 ± 1.61 [a]	-6.72	64.11 ± 1.48 [a]	-6.05
Loin	8	Katanning	VSP	73.07 ± 1.52 [b]		75.38 ± 1.64 [b]		71.11 ± 1.60 [b]		72.23 ± 1.48 [b]	
			$MAP40O_260CO_2$	59.98 ± 1.53 [a]	-13.09	62.78 ± 1.65 [a]	-12.6	57.13 ± 1.61 [a]	-13.98	58.43 ± 1.48 [a]	-13.8
			MAP80	56.57 ± 1.53 [a]	-16.5	59.52 ± 1.65 [a]	-15.86	55.29 ± 1.61 [a]	-15.82	57.24 ± 1.48 [a]	-14.99

$MAP40O_260CO_2$: modified atmosphere packaging containing 40% oxygen and 60% carbon dioxide; $MAP40O_220CO_2$: modified atmosphere packaging containing 40% oxygen, 20% carbon dioxide and 40% nitrogen; MAP80: modified atmosphere packaging containing 80% oxygen; VSP: vacuum skin packaging. Within a cut, display time and at a given site, the different letter annotations demonstrate significant differences ($P < 0.05$) between the packaging types. Difference to VSP is the difference between VSP and respective MAP treatment least square means.

Table 2. Least squared means (± SE) for the effects of muscle, display time, and packaging within site for overall liking, tenderness, juiciness and flavour sensory scores.

The lamb cuts derived from the Kirby slaughter represent the most relevant data set to base industry conclusions on packaging given the MAP system was able to utilise N_2 gas for the filler as the CO_2 content was reduced to 40%. The difference in overall liking, tenderness, juiciness, and flavour scores of VSP to MAP40$O_2$20CO_2 and MAP80 within a display time, averaged across cut can be seen in Table 3. Compared to the VSP sample, MAP40$O_2$20CO_2 and MAP80 had reduced overall liking by -2.1 and -5.9 points at 3 days of display, and further decreased by -9.2 and -13.2 points at 8 days of display. This summarises the detrimental effect MAP has on eating quality which reduced overall liking scores for MAP40$O_2$20CO_2 samples and further decreased overall liking scores for MAP80 samples. This effect was consistent for all other eating quality attributes.

Table 3. Difference in overall liking, tenderness, juiciness and flavour scores of Kirby MAP40$O_2$20CO_2 and MAP80 from VSP samples within a display time, averaged across cut.

	Day 3 of retail display	Day 8 of retail display
Overall liking		
MAP40$O_2$20CO_2	-2.1	-9.2
MAP80	-5.9	-13.2
Tenderness		
MAP40$O_2$20CO_2	-3.4	-8.6
MAP80	-6.3	-12.2
Juiciness		
MAP40$O_2$20CO_2	-2.1	-6.9
MAP80	-7.3	-11.6
Flavour		
MAP40$O_2$20CO_2	-2.5	-7.8
MAP80	-5.9	-12.5

MAP40$O_2$20CO_2: modified atmosphere packaging containing 40% oxygen, 20% carbon dioxide and 40% nitrogen; MAP80: modified atmosphere packaging containing 80% oxygen; VSP: vacuum skin packaging. Difference is between VSP and respective MAP treatment least square means within a display time and averaged across cut.

5 Discussion

In support of our hypothesis, VSP samples had the highest sensory scores, generally followed by the lower oxygen concentration MAP40, and high oxygen MAP80 samples had the lowest sensory scores. This was likely due to VSP allowing tenderisation to continue in the meat while under retail display (Clausen, 2004; Lagerstedt et al., 2011). Samples packaged in high oxygen MAP80 have previously been well documented to have decreased eating quality scores (Lund et al., 2007; Lagerstedt et al., 2011; Geesink et al., 2015; Frank et al., 2017). The lack of tenderisation or the toughening of samples from high oxygen MAP has been suggested to cause this Fu et al., 2015; Geesink et al., 2015; Kim et al 2010; Koohmaraie & Geesink, 2006). The high oxygen environment in MAP80 promotes oxidation and inhibits calpain, a protein involved in muscle degradation and the tenderisation process (Koohmaraie and Geesink, 2006; Fu et al., 2015; Geesink et al., 2015). In addition, the high oxygen content in MAP80 promotes oxidative protein cross-linking which strengthens myofibrillar structure and thus increases meat toughness (Kim et al., 2010; Geesink et al., 2015). In the current study, the lower oxygen content in MAP40$O_2$20CO_2 (Kirby site) may have reduced the oxidation and calpain activity, thus allowing for increased tenderisation and thus higher sensory scores compared to the MAP80. Conversely, MAP40$O_2$20CO_2 may have reduced the impact on protein cross-linking, reducing the toughening effect and resulting in higher sensory scores compared to the MAP80 samples. For the Kirby site, packaging samples in MAP80 for 8 days retail display resulted in an 11.6 to 13.2 point reduction in all eating quality scores compared to day 8 VSP samples. These findings were consistent with a previous beef study where MAP80 resulted in reduced eating quality scores of 10 to 12 points after 9 days of retail display compared to VSP samples (Polkinghorne et al., 2018). In comparison, packaging samples in MAP40$O_2$20CO_2 rather than VSP for 8 days of retail display had a smaller reduction in eating quality scores, ranging from 6.9 to 9.2 points across all eating quality attributes.

A general trend was shown as increasing display time from day 3 to day 8 reduced all sensory scores for MAP samples. This suggests an increased duration under MAP, regardless of the amount of oxygen content, reduced lamb meat eating quality. Conversely, VSP samples generally showed minimal change in eating quality scores between the different retail display times, regardless of muscle, and thereby maintained a higher eating quality standard than the MAP packaging treatments.

Kirby samples were consistently ranked higher than Katanning sample for all sensory traits. This was likely due to the longer aging time (10 days versus 7 days) of samples in vacuum packaging before being re-packaged into MAP. The lower oxygen content MAP40$O_2$60CO_2 used for Katanning samples also had higher carbon dioxide (40% oxygen, 60% carbon dioxide) than Kirby MAP40$O_2$20CO_2 samples (40% oxygen, 20% carbon dioxide and 40% nitrogen). No studies have investigated the effect of this high carbon dioxide MAP mixture on lamb meat eating quality compared a low oxygen tri-gas MAP or high oxygen MAP (MAP80). However, multiple studies have reported detrimental effects of high carbon dioxide MAP on meat colour (Huffman et al., 1975; Silliker et al., 1977). Therefore, the high carbon dioxide concentration in the Katanning MAP40$O_2$60CO_2 samples could have reduced the eating quality scores compared to the Kirby tri-gas MAP40$O_2$20CO_2 samples. The difference between Katanning and Kirby samples could also be due to environmental factors such as farm management, processing factors, and dietary supplementation (Priolo et al., 2002; Resconi et al., 2009). However the current study was not designed to test these.

Loin samples had more acceptable sensory scores than topsides. This was expected as the loin is a posture muscle with less connective tissue, lower shear force, and thus increased tenderness and overall liking scores than the topside (Pannier et al., 2014a). Whereas, the topside is a muscle used for movement, with more connective tissue, increased shear force and thus reduced tenderness and overall liking scores to the loin (Pannier et al., 2014a). On average, samples from male lambs had more acceptable sensory scores than female lambs. This was unexpected as females have previously been reported to have higher sensory scores as they generally have higher intramuscular fat content (Pannier et al., 2014a; Pannier et al., 2014b).

6 Conclusions/recommendations

Averaged across cut and within a display time, the difference of Kirby VSP samples to MAP40$O_2$20CO_2 and MAP80 reduced overall liking by -2.1 and -5.9 points at 3 days of display, and further reduced by -9.2 and -13.2 points at 8 days of display. Consumer eating quality scores reduced for MAP40$O_2$20CO_2 samples and further reduced for MAP80 samples which was consistently seen for all eating quality attributes.

A desirable packaging system would be able to optimise sensory scores and maintain cherry red meat colour. Utilising VSP packaging for lamb meat is the best system to deliver the highest sensory scores but it does not retain the typical desirable meat colour for consumer appeal in the packaging. The Kirby MAP40$O_2$20CO_2 samples had increased sensory scores to MAP80 samples, but had reduced sensory scores compared to VSP samples which generally scored the highest across all sensory attributes. Therefore, MAP40 (MAP40$O_2$20CO_2) can provide the industry with a packaging format that retains an appealing meat colour and has a lower negative impact on consumer sensory scores compared to the current industry used high oxygen MAP.

7 Key messages

- Vacuum skin packaging resulted in the highest sensory scores, generally followed by MAP containing 40% oxygen and MAP containing 80% oxygen scored lowest.
- This result was consistent with the hypothesis that meat under the lower oxygen MAP (MAP40) would have more acceptable sensory scores than the high oxygen MAP.
- MAP containing 40% oxygen, 20% carbon dioxide and 40% nitrogen may offer an alternative MAP gas mixture to the high oxygen MAP as it has a smaller detrimental effect on lamb meat eating quality compared to high oxygen (80%) MAP.
- Loin samples were rated significantly higher than topside samples for all sensory attributes.
- Loin samples within a packaging type had larger differences over retail display times than topside samples.
- Increasing display time reduced consumer sensory scores for MAP samples, but did not impact VSP samples.

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