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Eating quality assessment of lamb from the Sheep CRC slaughters

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Abstract

The impact of selecting for lean meat yield using breeding values for increased eye muscle depth (PEMD) and decreased fat depth (PFAT) on the consumer acceptance of lamb meat was evaluated. Consumer sensory scores (tenderness, juiciness, flavour, odour, overall liking) were obtained for the *longissimus lumborum* (loin) and *semimembranosus* (topside) muscle of 1471 lambs. On average loin samples were more acceptable for consumers. Sensory scores increased with higher IMF levels, with lower shear force levels, and when animals were younger and less muscular. Increasing PEMD decreased tenderness, overall liking and flavour scores in both muscles, and decreasing PFAT reduced tenderness within the loin samples only. This negative impact of PEMD and PFAT is not solely driven through the phenotypic impact of IMF and shear force on sensory scores. Our results confirm the growing concerns that selecting for lean meat yield would reduce consumer eating quality, and highlights that careful monitoring of selection programs is needed to maintain lamb eating quality.

Executive summary

Understanding genetic interactions between production and meat traits will influence the eating quality of lamb is critical given recent reports from the CRC of strong associations between muscling, intramuscular fatness and shear force.

This project paid for the sensory evaluation of 1500 lambs from the Sheep CRC information nucleus flock (INF) by the company Sensory Solutions Ply Ltd. Loin and topside cuts were collected from 1471 individuals from the 2009/10 and 2010/11 Katanning and Kirby INF lamb drops.

Consumer sensory scores (tenderness, juiciness, flavour, odour, overall liking) were obtained for the longissimus lumborum (loin) and semimembranosus (topside) muscles of 1471 lambs. On average loin samples were more acceptable for consumers. Sensory scores increased with higher IMF levels, with lower shear force levels, and when animals were younger and less muscular. Increasing PEMD decreased tenderness, overall liking and flavour scores in both muscles, and decreasing PFAT reduced tenderness within the loin samples only. This negative impact of PEMD and PFAT is not solely driven through the phenotypic impact of IMF and shear force on sensory scores. Our results confirm the growing concerns that selecting for lean meat yield would reduce consumer eating quality, and highlight that careful monitoring of selection programmes is needed to maintain lamb eating quality.

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Pannier, L., Gardner, G. E., Pearce, K. L., McDonagh, M., Ball, A. J., Jacob, R. H., & Pethick, D. W. (2014). Associations of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb. *Meat Science, 96*(2), 1076-1087.

Table of Contents

Abstract 2
Executive summary 3
Table of Contents 4
1 Background..... 5
2 Project objectives..... 6
3 Methodology 7
3.1 Experimental design and slaughter details 7
3.2 Carcass measurements and sample collection 7
3.3 Sensory testing 8
3.4 Intramuscular fat and shear force measurements 8
3.5 Statistical analysis..... 9
4 Results..... 10
4.1 Effect of genetic and non-genetic factors on consumer sensory scores..... 11
4.2 Effect of intramuscular fat on sensory scores..... 12
4.3 Effect of shear force at day 5 on sensory scores..... 12
4.4 Effect of pH at 24 h on sensory scores..... 12
4.5 Effect of carcass composition traits on sensory scores 13
4.6 Effect of sire breeding values on sensory scores 13
5 Discussion..... 14
5.1 Associations of sire breeding values with sensory scores 14
5.2 Association of IMF with sensory scores..... 17
5.3 Association of shear force and sensory scores 18
5.4 Association of pH at 24 h with sensory scores 18
5.5 Production and management effects on sensory scores 19
5.6 Comparison of effects on sensory scores..... 21
6 Conclusions 21
7 Acknowledgements..... 22
8 Table and Figures..... 23
9 References 32

1 Background

Tenderness, juiciness, flavour, odour and overall liking are all important quality determinants of sensory enjoyment of lamb meat. Sensory enjoyment is a key driver strongly influencing the demand of lamb in Australia, and the purchase and willingness to pay decisions of consumers (Pethick, Banks, Hales, & Ross, 2006a). Consumers also demand lamb that is lean and has good nutritional attributes (Pethick et al., 2006a). Whilst the nutritional content of lamb has been shown to be sufficient to claim lamb as a good source of key nutrients (Pannier et al., 2013a; Pannier et al., 2010), there is concern regarding the high focus of lean meat yield selection throughout the supply chain on the eating quality attributes, as Australian lambs have become larger, leaner and more muscular (Gardner et al., 2010).

Palatability of meat can be described in terms of tenderness, juiciness and flavour scores (Forrest, Aberle, Hendrick, Judge, & Merkel, 1975), and some studies in lamb have described the influences of nutritional, environmental and production factors on these attributes. For example, palatability is influenced by animal age, with older animals having lower sensory scores (Hopkins, Hegarty, Walker, & Pethick, 2006; Pethick, Hopkins, D'Souza, Thompson, & Walker, 2005b). Other studies have shown that there are some effects of nutritional treatments on some sensory traits of lambs, particularly of animals fed pasture versus concentrate diets (Font et al., 2009; Priolo, Micol, Agabriel, Prache, & Dransfield, 2002; Resconi, Campo, Furnols, Montossi, & Sanudo, 2009). However in contrast, consumers could not discriminate between the different sensory traits from lambs fed different dietary treatments (Pethick et al., 2005a). Sex has shown no or a small influence on sensory scores (Arsenos et al., 2002; Navajas et al., 2008; Teixeira, Batista, Delfa, & Cadavez, 2005; Tejeda, Peña, & Andrés, 2008). Conflicting results have been published regarding the influence of different genotypes on sensory scores. Safari, Fogarty, Ferrier, Hopkins and Gilmour (2001) found no significant differences between Maternal, Merino and Terminal genotypes, whereas Hopkins, Walker, Thompson and Pethick (2005b) found several genotypic differences with a general trend for Merino lambs to have lower sensory scores and Terminal first cross lambs having higher sensory scores. However these studies were based on the analysis of small sample numbers, providing little confidence regarding the impact of production and genetic effects on these sensory scores.

An alternative approach for determining meat eating quality is through the use of objective meat quality measurements such as intramuscular fat (IMF) and Warner Bratzler shear force. These measurements have shown associations with sensory scores. Increasing shear force has been associated with lower tenderness, flavour, juiciness and overall liking scores (Hopkins et al., 2006; Safari et al., 2001), and reduced IMF levels have been associated with reduced juiciness (Shorthose & Harris, 1991; Thompson, 2004), flavour (Rymill, Thompson,

& Ferguson, 1997; Thompson, 2004) and overall liking scores (Hopkins et al., 2006).

Data from the Cooperative Research Centre (CRC) for Sheep Industry Innovation (Fogarty, Banks, van der Werf, Ball, & Gibson, 2007) has shown a positive phenotypic correlation (+0.14) between shear force and lean meat yield, and a negative phenotypic correlation (-0.28) between IMF and lean meat yield (Mortimer, unpublished data). Selection for lean meat yield is carried out through the use of Australian Sheep Breeding Values (ASBVs) for post-weaning eye muscle depth (PEMD), post-weaning c-site fat depth (PFAT) and post-weaning weight (PWWT). Lambs from sires with reduced PFAT breeding values have reduced whole carcass fatness and increased loin muscle weight, whereas lambs from sires with higher PEMD breeding values have increased muscling in high valued cuts mainly located in the animal's saddle region (Gardner et al., 2010). It is likely that these ASBV impacts on lean growth will reduce the consumer sensory scores and studies have shown that increasing PEMD and reducing PFAT has been linked with a decline in IMF (Hopkins, Hegarty, & Farrell, 2005a; Hopkins et al., 2007b; Pannier et al., 2013b), and with detrimental effects on meat eating quality (Hopkins et al., 2005a; Hopkins et al., 2007b).

Given the limited number of studies published that have examined the impact of breeding values on sensory scores, and the small sample numbers previously used, untrained consumer testing of sensory eating quality attributes was carried out on the *longissimus lumborum* (loin) and *semimembranosus* (topside) muscles of 1471 lambs. We hypothesised that lambs from sires with reduced PFAT and increased PEMD breeding values will have reduced sensory scores for eating quality, and that this would be reflected through the correlation between sensory scores and the phenotypic expression of leanness (shortloin fat weight) and muscling (shortloin and topside muscle weight) that these ASBVs deliver. In addition, we hypothesised that Merino sired lambs will have lower sensory scores, that sensory score would not be different between female and wether lambs, and that objective eating quality traits IMF and tenderness will have a positive association with the sensory eating quality scores.

2 Project objectives

The relationship between carcase and objective meat quality traits with consumer sensory assessment of eating quality will be determined on 2 muscles from 1500 INF flock progeny.

3 Methodology

3.1 Experimental design and slaughter details

The design of the Sheep CRC Information Nucleus Flock (INF) was presented elsewhere (Fogarty et al., 2007; van der Werf, Kinghorn, & Banks, 2010). Briefly, about 2000 lambs each year, starting in 2007, were produced from artificially inseminated matings to Merino and crossbred ewes located at 8 research sites across Australia (Katanning WA, Cowra NSW, Trangie NSW, Kirby NSW, Struan SA, Turretfield SA, Hamilton VIC, and Rutherglen VIC), which represent a broad cross-section of Australian production systems. The lambs were progeny of industry Terminal (Poll Dorset, Suffolk, Texel, White Suffolk), Maternal (Bond, Border Leicester, Coopworth, Corriedale, Dohne Merino, Prime SAMM) or Merino (Merino, Poll Merino) sires, representing the major production types in the Australian sheep industry. These sires were chosen to represent the full range of ASBVs for key traits within each sire type. Lambs were mainly maintained under extensive pasture grazing conditions, but were fed grain, hay or feedlot pellets when feed supply was limited at some sites (Ponnampalam et al., 2013). For each site lambs were assigned to smaller groups (kill groups) to be killed at the same day to enable carcass weight targets to be achieved. Lambs were yarded the day before slaughter, held for 6 hours and then weighed and transported to one of five commercial abattoirs, where they were held in lairage overnight and slaughtered the following day at an average carcass weight of 22.9 kg (StDev = 3.87). 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. All lambs were measured and sampled for a wide range of live animal, carcass, meat and growth traits.

For this study, a subset of 1471 animals from 2009 and 2010 were selected from the Kirby and Katanning sites for sensory testing. Across the two sites, the selection of progeny was balanced for sire (n = 175), with each sire represented by a minimum of at least six progeny.

3.2 Carcass measurements and sample collection

Hot carcass weight was measured straight after slaughter. At 24 h post-mortem, the pH was measured on the left portion of the *longissimus thoracis e*t *lumborum* muscle and pH measurements are described by Pearce et al. (2010).

From the carcass saddle region (cut between the 12th and 13th ribs), the shortloin (AUS-MEAT 4880) (Anonymous, 2005) component was removed. From this, the entire *longissimus lumborum* muscle without subcutaneous fat (shortloin muscle; referred in this paper as 'loin' muscle) (up to the 12^{th} rib) was prepared. The topside muscle, cap off, was also excised from the carcass as a whole. Both muscles were weighed (shortloin muscle weight, topside muscle weight), vacuum packed, and stored at 2°C to age for 5 days. The trimmed subcutaneous loin fat was also weighed (shortloin fat weight), and the epimysium (silver skin) was removed. Five steaks from each muscle of 15 mm thick were cut, vacuum packed and frozen at -20°C for subsequent sensory testing. The other loin and topside of the carcass were also excised and used for subsequent objective meat quality measurements of IMF and shear force.

3.3 Sensory testing

Details of the sensory testing protocol were presented by Thompson et al. (2005a) and Watson, Gee, Polkinghorne and Porter (2008) and was based on the Meat Standards Australia sensory system which uses untrained consumers. Briefly, 5 steaks from each muscle were halved to form ten test samples and where grilled using a Silex griller to a medium degree of doneness (internal temperature of 65°C). Samples were rested for 2 min before being tasted. Untrained consumers assessed the steaks for tenderness, overall liking, juiciness, liking of flavour and liking of odour using a 100 score scale (100 being most preferred). Consumers also graded the samples to the following categories; unsatisfactory, good every day (3 star), better than every day (4 star), or premium (5 star). Each taste panel member consumed 7 steaks, commencing with a starter steak of average quality (based on overall liking score of 72; (Pethick, Pleasants, Gee, Hopkins, & Ross 2006b)) followed by 6 test steaks (3 loin and 3 topside) allocated by using a latin square design (Thompson et al., 2005a) such that each sensory session consisted of 60 unique consumers testing 36 samples, finally to obtain 10 consumer responses per sample. Position and carryover effects were completely balanced by using the Latin square design to allocate products to consumers. In total 5640 consumers were recruited, divided over 94 consumer sessions, to test the loin and topside samples.

3.4 Intramuscular fat and shear force measurements

About 40 g of diced loin muscle sample was collected and stored at -20°C until subsequent freeze drying using a Cuddon FD 1015 freeze dryer (Cuddon Freeze Dry**,** NZ). IMF was measured on the loin samples using a near infrared procedure (NIR) in a Technicon Infralyser 450 (19 wavelengths), as described by Perry, Shorthose, Ferguson and Thompson (2001). NIR readings were validated with chemical fat determinations using solvent extraction (chloroform). IMF was expressed as percentage fat.

Approximately 65 g loin and topside muscle was used for shear force testing. Samples were vacuum packed and frozen at -20°C after 5 days till subsequent testing. Frozen samples were cooked in plastic bags in a water bath for 35 min at 71°C, and were cooled in running water for 30 min after cooking. Six cores (~3 - 4 cm long, 1 cm^2 cross sectional) from each loin sample were cut and shear force was measured using a Lloyd texture analyser (Model LRX, Lloyd Instruments, Hampshire, UK) with a Warner-Bratzler shear blade fitted as described by Hopkins, Toohey, Warner, Kerr and van de Ven (2010).

3.5 Statistical analysis

The analyses were conducted on the mean of 10 consumer answers for each sample. Tenderness, overall liking, juiciness, flavour and odour, were analysed using linear mixed effects models in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). The base model for each sensory trait included fixed effects of site (Kirby, Katanning), year (2009, 2010), cut (loin, topside), sire type (Merino, Maternal, Terminal), sex within sire type (wether Maternal, wether Merino, wether Terminal, and female Terminal, there being no Merino or Maternal female lambs), birth-rearing type (term representing animals born as single, twin or triplet and reared as single, twin or triplet; 11, 21, 22, 31, 32, 33), dam breed within sire type (Merino x Merino, Maternal x Merino, Terminal x Merino, Terminal x Border Leicester-Merino) and kill group within site by year. Sire identification, dam identification by year, animal identification, as well as the consumer session when samples were tasted, 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.

Several phenotypic covariates were tested individually in the base model described above to determine their association with sensory measures of tenderness, overall liking, juiciness, flavour and odour. These were; IMF, loin pH at 24 h, shear force at 5 days of aging for the loin and topside, muscle weight of the loin (shortloin muscle weight) and topside (topside muscle weight), shortloin fat weight and age at slaughter. When measurements were only taken on the loin (ie. IMF and loin pH at 24 h), associations with sensory scores were still tested within the topside muscle using the loin IMF or loin pH at 24 h values. The muscle weight and shortloin fat weight models also included hot carcass weight as an extra covariate to assess whether the observed effects were merely reflecting their correlation with hot carcass weight. When age at slaughter was included as a covariate, the kill group within site by year term was included as a random term rather than a fixed effect term. Within each site by year, age was confounded by kill group (i.e. there were no lambs of the same age within a separate kill group, and the variation in age within each kill group was less than 10 days). Thus kill group accounted for the slaughter-age affect, and removing this term as a fixed effect enabled the impact of age at slaughter to be estimated. All covariate models included all relevant first order interactions between fixed effects and covariate, and the covariate quadratic effect. Non-significant (*P* > 0.05) terms were removed in a stepwise manner.

The associations between the sensory traits and sire ASBVs for PWWT, PEMD and PFAT were also tested in the base model. The mean and range for these ASBVs is summarised in Table 1. Initially, all 3 ASBVs were present in the model as both linear and quadratic covariates, as well as their first order interactions with other terms, with non-significant (*P* > 0.05) terms removed in a stepwise manner. Due to the correlations that exist between these ASBVs in this data set (PWWT vs PEMD = 0.3; PWWT vs PFAT = -0.4; PFAT vs PEMD = 0.2) this process was repeated with the ASBVs included one at a time to test the independence of their effects. In addition the 3 ASBV model was also tested with, shortloin and topside muscle weight, shortloin fat weight, IMF and shear force at day 5 as covariates (included one at the time) to assess whether the impact of ASBVs on sensory scores were associated with their correlated impacts on these carcass measurements. These models also included all relevant interactions and covariate quadratic effects, and were stepwise regressed to remove non-significant (*P* > 0.05) terms.

Phenotypic partial correlation coefficients within the loin and topside samples between all sensory traits were calculated in a Multivariate Analysis of Variance in SAS. This model contained all sensory scores as dependent variables, and all significant fixed effects and fixed effects interactions for each sensory trait.

4 Results

Of the total 1471 lambs with sensory data available, the base models used 1434 lambs which had all other production data available (after dropping animals with missing data). For each lamb, the loin and topside muscle were tasted resulting in a total of 2868 samples included in our analysis. The number of lambs for each category, and the raw data for the sensory traits and objective quality measures have been summarised in Table 2 and 3. Phenotypic partial correlation coefficients within the loin and topside samples between all sensory traits are presented in Table 4. All results and differences are expressed as the change in sensory scores (1 - 100), and when covariates were included in the models these magnitudes were expressed across the observed range of the covariate.

4.1 Effect of genetic and non-genetic factors on consumer sensory scores

Outcomes of the base models are presented in Table 5, and least square means (± SE) for the significant effects of site by year, sex within sire type, and dam breed within sire type between the loin and the topside are presented in Table 6. The base models described 79%, 76%, 75%, 71% and 55% of the total variance in tenderness, overall liking, juiciness, flavour and odour sensory scores. There were significant ($P < 0.05$) effects for cut, site, year and sire type for the tenderness, overall liking, juiciness and flavour sensory scores (Table 5). On average, loin samples were more acceptable than topside samples and these differed with 25.9, 20.5, 19.9, 16.2 and 3.8 units for tenderness, overall liking, juiciness, flavour and odour. These muscle differences, varied between sites and years with lambs from Kirby having higher ($P < 0.01$) sensory scores for tenderness, overall liking, juiciness and flavour by 3.9, 3.3, 3.4 and 2.5 units respectively, when compared to lambs from the Katanning site. Lambs from year 2009 were 4.2, 3.1, 4.2 and 2.5 units higher ($P < 0.01$) for tenderness, overall liking, juiciness and flavour, compared to lambs from year 2010.

The male Terminal sired lambs had lower sensory scores ($P < 0.01$; Table 5) when compared to the male Maternal and Merino sired lambs. These differences were 5.0, 4.0, 3.7 and 2.9 lower tenderness, overall liking, juiciness and flavour scores when compared to the Maternal sired lambs and 5.2, 3.9, 3.3 and 2.9 lower sensory scores when compared to the Merino sired lambs. The difference in juiciness varied between the two cuts ($P < 0.01$; Table 5 and 6) with the effect being greater in the loin (where male Terminal sired lambs had 4.4 and 5.4 less sensory scores compared to the male Maternal and Merino sired lambs) than in the topside (where male Terminal sired lambs had 3.1 and 1.2 less sensory scores compared to the Maternal and Merino sired lambs).

Kill group within site by year also caused variation for the tenderness, overall liking, juiciness and flavour scores ($P < 0.05$; Table 5), and when comparing the most extreme differences, they varied by as much as 4.6, 3.6, 4.1 and 3.3 units for tenderness, overall liking, juiciness and flavour respectively (individual data not shown). These kill group differences were greater ($P < 0.01$) in the topside than in the loin samples for all sensory traits. Furthermore, there was a tendency for the older kill groups to have lower sensory scores (Fig. 1 for tenderness and overall liking), however this was only evident in the loin samples for tenderness, overall liking, juiciness and flavour. This result is supported by the effect of age at slaughter as a covariate. The average age at slaughter was 299.0 ± 59.6 (mean ± SD) however between kill groups this varied from 214 – 434 days. Thus with the kill group within site by year term removed as a fixed effect, the effect of age ($P < 0.01$) decreased sensory scores by 4.7, 3.2, 3.7 and 2.8 units across the 220 day age range for tenderness, overall liking, juiciness and flavour respectively. The only variation to this theme was for tenderness within the topside, where sensory scores increased by 4.5 units across the 220 day age range.

Within the Terminal sired lambs, females had better sensory scores than male lambs (P < 0.05; Table 5 and 6). However this effect was small, and only evident within the loin which had 1.8, 1.5, 1.6, 0.9 and 0.9 units higher for tenderness, overall liking, juiciness, flavour and odour, when compared to the wether lambs.

Dam breeds also differed for tenderness, overall liking, juiciness and flavour scores however these differences were only evident in the loin (P < 0.01; Table 5 and 6). Lambs from Merino dams had higher sensory scores compared to lambs from Border Leicester x Merino dams, with these differences being 1.9, 1.2, 1.5 and 1.4 units for tenderness overall liking, juiciness and flavour scores.

4.2 Effect of intramuscular fat on sensory scores

For all sensory traits, increasing levels of loin IMF were associated with increasing sensory scores (P < 0.01) within both the loin (Fig. 2) and topside samples. Across the 4.5% IMF range, the sensory scores for the loin samples increased by 10.7, 10.0, 9.1, 5.9 and 2.7 units for juiciness, overall liking, flavour, tenderness and odour. The magnitude of these responses changed for the topside samples for juiciness, overall liking and flavour scores and were 6.7, 6.6 and 5.4, respectively.

4.3 Effect of shear force at day 5 on sensory scores

Shear force at 5 days of aging for both the loin and topside samples had a negative relationship (P < 0.01) with the sensory scores (Fig. 3). Within the loin most shear force values ranged between 12 - 49 Newtons, and across this range sensory scores decreased by 11.6, 8.5, 7.6, 7.4 and 2.5 for tenderness, overall liking, juiciness, flavour and odour. Within the topside samples shear force values ranged between 22 - 65 Newtons, and across this range sensory scores decreased by 17.4, 13.5, 10.9, 9.8 and 1.4 units for tenderness, overall liking, juiciness, flavour and odour.

4.4 Effect of pH at 24 h on sensory scores

pH in the loin at 24 h post-mortem had a positive association (P < 0.05) with tenderness, juiciness and flavour scores within the loin samples. However these differences were small, with sensory scores increasing by 1.9, 0.9, 3.4 and 2.1 units for tenderness, overall liking, juiciness and flavour between pH 5.2 – 6.0. For the topside samples there was relatively little association between loin pH at 24 h and sensory scores, with the effects varying between kill groups, sites, and years with no consistent pattern evident (data not shown). There were no significant effects of pH at 24 h on odour scores.

4.5 Effect of carcass composition traits on sensory scores

The phenotypic measures of muscling (shortloin muscle weight and topside muscle weight) adjusted for hot carcass weight (23.7 ± 3.9 (mean ± SD); range 15.0 - 40.0), had a negative relationship with tenderness, overall liking, juiciness and flavour scores ($P < 0.05$; Fig. 4). Increasing the shortloin muscle weight from 200 to 560 g was associated with a decrease in sensory scores of 7.0, 6.0, 4.8 and 3.4 units for tenderness, overall liking, juiciness and flavour within the loin samples. Likewise, increasing the topside weight from 400 to 880 g was associated with a decrease in sensory scores of 9.3, 7.9, 6.5 and 4.5 within the topside samples. Odour scores had no association with muscle weight.

Compared to the muscle measurements, the opposite relationship was seen for shortloin fat weight which had a positive curvilinear relationship with the sensory scores within both muscles for tenderness, overall liking and flavour ($P < 0.05$). Increasing shortloin fat weight from 60 to 450 g was associated with an increase in sensory scores of about 3.0, 2.3 and 1.6 units within both the loin and topside samples, reaching a plateau beyond this point.

4.6 Effect of sire breeding values on sensory scores

In the base models, sire as a random term was significant ($P < 0.01$) for all sensory scores except for odour. Sire estimate ranges within each cut for each sire type, are shown for all the sensory traits in Table 7. Sire accounted for 6.0, 4.4, 4.2 and 2.6% of the total variance for tenderness, overall liking, juiciness and flavour.

When the sire ASBVs for PWWT, PEMD and PFAT were included simultaneously as covariates in the base linear mixed effects models, each ASBV demonstrated some association with sensory scores. PEMD affected ($P < 0.01$) tenderness, overall liking and flavour, reducing these sensory scores across all sire types by 5.3, 3.6 and 3.1 units across the 6.5 mm PEMD range within both the loin and topside samples (Fig. 5a,b for tenderness and overall liking). The magnitude of the PEMD effects were only slightly diminished when PEMD was included alone as covariate in the base model. Similarly, when IMF measured in the loin, shortloin muscle weight or shortloin fat weight was included in the 3 ASBV model, the magnitudes of the PEMD effects remained. When shear force at 5 days of aging for both the loin and topside samples was included in the 3 ASBV model, the magnitude of the PEMD effect for both cuts slightly increased for tenderness, whereas for overall liking and flavour it remained unchanged.

Decreasing PFAT was associated with a reduction in tenderness scores of 3.6 units across the 4 mm PFAT range within the loin samples ($P < 0.05$) (Fig. 6). This effect was halved when PFAT was included in the base model alone, and remained unchanged when IMF, shear force at 5 days of aging, shortloin muscle weight or shortloin fat weight was included in the 3 ASBV model.

PWWT had a significant effect on the tenderness scores ($P < 0.05$) across all sire types, which decreased by 4.0, 5.3 and 4.9 units within the topside samples only across the 9, 12 and 11 kg PWWT range for the Maternal, Merino and Terminal sire type respectively . PWWT also varied significantly ($P < 0.01$) between the sites for tenderness, overall liking, juiciness and flavour scores. These PWWT associations were apparent within samples of the Kirby site, which decreased the sensory scores by 10.1, 6.3, 5.5 and 4.9 units for tenderness, overall liking, juiciness and flavour scores. When PWWT was included in the model alone, the above described effects remained similar but the magnitudes were slightly diminished. The magnitude of the PWWT effect on tenderness within the topside samples remained the same, and the magnitude of the PWWT effect for the Kirby samples remained similar for the tenderness scores but was slightly decreased for the overall liking, juiciness and flavour scores when IMF, shear force at 5 days of aging, or shortloin muscle weight were included in the 3 ASBV model. None of the effects changed when shortloin fat weight was included. None of the ASBVs demonstrated significant effects for the odour sensory scores.

5 Discussion

5.1 Associations of sire breeding values with sensory scores

As hypothesised, increased PEMD values were associated with reduced sensory scores, but only for tenderness, overall liking and flavour (Fig. 5a,b), indicating that sires selected for muscling are more likely to produce progeny with less tender, less flavoursome and less overall acceptable meat. Our findings align well with the study of Hopkins et al. (2005a), in which reduced tenderness, overall liking, juiciness and flavour scores were observed with increasing PEMD values. However, in contrast to that study where the effect was only observed in the loin, in this study the PEMD effect was observed in both the loin and topside muscles, having a similar impact in each. This result was unexpected given that the PEMD breeding value is derived from a muscle depth measurement taken on the loin (C site, 45 mm from the midline, over the 12^{th} rib) and therefore it would be reasonable to assume that its effect would be focused at this location only. However, on the strength of this result, and considering the independence of these different cuts, effects of similar magnitude may be expected in other muscles in the carcass. Studies assessing the impact of sire breeding values on the weight and distribution of muscle tissue in lamb showed that selection for increased sire PEMD resulted in an increased loin weight (7.3%) and depth (4.2%) (Gardner et al., 2010), and an 8.1% increased muscling in the whole carcass (Anderson, Williams, Pannier, Pethick, & Gardner, 2013). This impact on whole carcass muscling may explain the broader impact of PEMD on both the loin and topside muscles. Contrasting to our results, Navajas et al. (2008) found that lambs from high and low muscling sires had similar eating quality scores of both the loin and topside muscle. The authors concluded that although they observed differences in muscularity (high versus low) within both muscles, selection for muscling would not impact on the eating quality traits (Navajas et al., 2008).

Decreasing PFAT was associated with reduced tenderness scores for the loin samples only (Fig. 6), supporting our hypothesis that selection for sires with reduced PFAT would produce lambs with lower sensory scores. Our results demonstrated a 3.6 unit reduction in tenderness across the PFAT range (4 mm) which is similar to the findings of Hopkins et al. (2007b), who reported a 4 unit reduction across their PFAT range (3 mm). There was no impact of PFAT within the topside samples with this contrasting effect between the two cuts possible due to the different IMF levels. Evidence in beef shows that the topside muscle has a lower IMF percentage compared to the loin muscle (Brackebusch, Mckeith, Carr, & Mclaren, 1991) and when selecting for reduced PFAT, which reduces IMF (Pannier et al., 2013b), these topside IMF levels might have been too low for PFAT to impact on.

Progeny of sires with decreased PFAT and increased PEMD breeding values have been associated with reduced IMF values (Hegarty, Warner, & Pethick, 2006; Hopkins et al., 2005a; Hopkins et al., 2007b; Pannier et al., 2013b). Hence, it has been speculated before that the negative impact of PFAT, and also PEMD breeding values on sensory scores is driven through the amount of IMF within the muscle (Hopkins et al., 2005a; Hopkins et al., 2007b). This was not evident in our study as the magnitude of the association between PFAT and tenderness scores within the loin samples remained unaffected with inclusion of IMF in the 3 ASBV model. This suggests that IMF does not entirely reflect the association seen by PFAT within the loin samples for the tenderness score. However contradictory to our results, Hopkins et al. (2007b), concluded that IMF was responsible for the PFAT effect on the tenderness scores, as when IMF was analysed simultaneously with the PFAT ASBV, it eliminated its effect. However, the Hopkins et al. (2007b) study was far smaller, using only 314 animals from 20 sires with a PFAT range of -2.0 – 1.0 mm. The PEMD impact on sensory scores remained similar when IMF was included, again illustrating that IMF is not solely responsible for the PEMD effect. Furthermore, inclusion of shear force at day 5 in the model as a covariate did not greatly alter the effects of PFAT or PEMD on sensory scores.

This illustrates that the observed ASBV effects are not fully driven through the phenotypic association of shear force and sensory scores.

It is conceivable that the association of the PFAT and PEMD ASBV with the sensory scores is delivered entirely through their correlated impacts on whole body muscling and adiposity. Both shortloin muscle weight and shortloin fat weight are good indicators of whole carcass muscling and total carcase adiposity as data has shown a strong correlation of shortloin muscle weight with whole carcass muscle weight (0.84), and shortloin fat weight with whole carcass fat weight (0.83) (Anderson, unpublished data). Additionally, previous studies have indicated the relationship of these carcass composition traits with PEMD and PFAT ASBV (Gardner et al., 2010). As hypothesised, shortloin muscle weight and shortloin fat weight (corrected for hot carcass weight) were strongly associated with tenderness, overall liking, juiciness and flavour scores. Thus, when compared at the same hot carcass weight, the sensory scores decreased with increasing shortloin muscle weight, and with decreasing shortloin fat weight. These phenotypic associations had some alignment with more muscular, leaner animals as selected via increased PEMD and decreased PFAT breeding values. However, the inclusion of shortloin muscle weight and shortloin fat weight (one at the time) within the 3 ASBV model, only slightly reduced the PFAT and PEMD effects, suggesting that the impact of PFAT and PEMD upon sensory scores is delivered through mechanisms other than just the correlated impact on whole body adiposity and muscling.

Increasing PWWT breeding values decreased the tenderness, overall liking, juiciness and flavour scores within both cuts at the Kirby site and also decreased on average the tenderness scores within the topside samples only at both sites. Increasing PWWT at a constant slaughter age (i.e. kill group corrects for age – see Fig. 1) reflects maturity within our study, hence the negative association between PWWT and some sensory scores might suggest that less mature and leaner lambs at the same age will be less acceptable to consumers. However why this was only evident within the topside samples for tenderness and samples from the Kirby site is unclear. When IMF was included as a covariate in the ASBV model, the association between PWWT and tenderness within the topside samples remained the same, but because IMF was only measured on the loin samples, a valid comparison cannot be made here. The PWWT effect within the Kirby samples also remained when IMF or shear force were included, suggesting that the PWWT effects were not driven through the phenotypic association of shear force or IMF with sensory scores.

5.2 Association of IMF with sensory scores

Aligning with our hypothesis, IMF was a strong driver of sensory scores, increasing all sensory traits (Fig. 2). As such, animals with higher IMF levels will produce meat which is more acceptable for consumers. The strongest association with IMF was observed for juiciness and flavour. This was not unexpected given that previous studies have shown that reduced IMF levels reduce juiciness (Shorthose & Harris, 1991; Thompson, 2004) and flavour (Rymill et al., 1997; Thompson, 2004) in cattle. It has been stated that IMF directly affects juiciness and flavour (Hocquette et al., 2010), however indirectly affects tenderness (Miller, 2002), and hence this might explain the different magnitudes of the IMF effect on these sensory traits. IMF will affect juiciness by lubricating the muscle fibres during cooking, or by stimulating the salivary glands during mastication (Savell & Cross, 1988), whereas flavour depends on the composition of the IMF lipids (Savell & Cross, 1988) involved in the Maillard reactions which form flavour compounds upon cooking (Shahidi, 2002). Tenderness on the other hand, tends to increase with increasing IMF levels and various studies have confirmed this effect in cattle and sheep (Hopkins et al., 2005a; Pethick et al., 2005b; Thompson et al., 2005b; Wheeler, Cundiff, & Koch, 1994), but there is conflicting evidence regarding the precise nature of this relationship. It has been stated that IMF separates and dilutes the perimysial collagen fibres and disorganises the structure of intramuscular connective tissue that increases meat toughness (Hocquette et al., 2010). Hence IMF affects lamb tenderness by altering the meat structure rather than through influencing the meat aging process (Warner, Greenwood, Pethick, & Ferguson, 2010a). Indeed, Warner et al. (2010b) showed that the effect of change in IMF percentage on shear force at 1 day post-mortem aging, was the same as 5 days ageing.

In this study, we demonstrated a 2.2 unit increase in overall liking per 1% IMF increase. In comparison, Hopkins, Hegarty, Walker and Pethick (2006) found a 13 unit increase in overall liking between 2 and 18% IMF in the loin muscle. This equates to a 1.23 score increase per 1% IMF increase, an effect almost half that evidenced in this study, even though it was modelled across almost 3 times the IMF range. The authors stated that an IMF level of 5% was required to achieve an overall liking score of 63 (Hopkins et al., 2006). Yet in contrast, this study suggests that an IMF level lower than 5% may in fact be adequate. For example, the average overall liking score within our dataset was 72.3, which would equate to a predicted IMF level of 3.9%. Sensory scores at this level exceed the threshold (< 70) for consumer ratings of better than every day quality (Pleasants, Thompson, & Pethick, 2005), and such cut offs are a goal for the current lamb industry. The smaller number of animals (n = 471), the greater age range (5 to 68.5 months), the larger IMF range and lower overall sensory scores used in the study of Hopkins et al. (2006), contribute to the disparity between the relationships observed for IMF and overall liking between the studies.

5.3 Association of shear force and sensory scores

Supporting our hypothesis, there was a negative association between all sensory traits and the objective eating quality trait of shear force at 5 days of aging for the loin muscle (Fig. 3). As expected, this association was the strongest for the tenderness scores, increasing by 11.6 units between 12 and 49 N but was also present for overall liking, juiciness and flavour. It is well known and agreed that if shear force increases, meat tenderness decreases, and hence the sensory quality scores decrease. Several other studies in lamb have also reported lower sensory scores when shear force increased (Hopkins et al., 2006; Safari et al., 2001) and this association occurred not only with tenderness scores, but also with overall liking, juiciness and flavour. Mechanistically it is difficult to explain why shear force would be associated with juiciness and flavour, with this more likely to be a reflection of the untrained panelists used in this study who are less able to differentiate the sensory traits of meat. In untrained consumers this has been called the 'halo' effect (carry-over effect) (Kunert, 1998; Shorthose & Harris, 1991) and results in the high correlations seen between the sensory traits in this study (Table 4). Thus there were high correlation coefficients between tenderness, overall liking, juiciness and flavour scores within both muscles ($r > 0.77$), with the highest correlation being 0.94 and 0.91 between overall liking and flavour both within the loin and topside samples. This dependent scoring of the consumers has previously been identified and the sensory traits were found to be highly correlated with each other (Font et al., 2009; Thompson et al., 2005a).

Part of the Sheep CRC objectives was to estimate new ASBVs for traits such as shear force. Estimates of heritability in a recent study have shown that shear force at day 5 in lamb has a moderate heritability, which was estimated at 0.28 ± 0.04 (Mortimer et al., 2013). This indicates that there is sufficient genetic variation in this trait to allow genetic manipulation through selection via these ASBVs to improve the eating quality of lamb.

5.4 Association of pH at 24 h with sensory scores

The relationship between pH at 24 h and sensory scores were variable and small in magnitude. As such there appeared to be no consistent effect on consumer perceptions of eating quality. This was an unexpected finding given that previous studies have demonstrated a negative association between pH and sensory scores in lamb (Hopkins et al., 2005a; Young, Reid, & Scales, 1993). The reason for this poor association is difficult to explain.

5.5 Production and management effects on sensory scores

The difference between loin and topside accounted for the largest proportion of variance in sensory scores with the loin consistently ranking higher for all sensory traits. This difference varied significantly between the two research sites, and between years that lambs were born. Lambs from Kirby and lambs born in 2009 had consistently higher sensory scores compared to lambs from the Katanning site and lambs from year 2010. These differences could be due to environmental factors, such as dietary supplementation which may have had an impact on the sensory scores (Font et al., 2009; Priolo et al., 2002; Resconi et al., 2009). However in a study in which lambs were finished either on pasture or concentrate rations, the authors concluded that the nutritional treatment of the lambs on the sensory scores of grilled steaks was very small and that Australian consumers cannot discriminate sensory traits from lambs fed different diets (Pethick et al., 2005a). This implies that other environmental factors (e.g. on-farm management, processing factors) might have impacted on these sensory scores. It is also important to note that whilst site and year do impact on the sensory scores, these effects were small, suggesting that the impact of these production effects on eating quality would not be very unfavourable.

The differences between kill groups within each year at each site reflect to a small extent animal slaughter age, with a general trend for sensory scores to decrease in older kill groups. However this age effect was mainly observed within the loin samples and agrees with the findings of Hopkins et al. (2006) who found that all sensory traits (tenderness, flavour, juiciness and overall liking) of loin samples declined when animal age increased. Moreover, it has been shown before that consumers rate meat from lamb more tender compared to meat from older sheep (Pethick et al., 2005b), and this has also been reflected in higher shear force values of older animals (Hopkins, Stanley, Martin, Toohey, & Gilmour, 2007a). Paradoxically, the opposite was seen within the topside samples for the tenderness score only, however this may also have been a kill group effect. Given that there were only 14 kill groups, any interpretation should be carefully weighted as we cannot differentiate between age and kill group. This was further demonstrated by removing the last kill group (age > 410 days), which eliminated this effect for tenderness within the topside. In addition, the kill group effect would also reflect other environmental variables such as different seasons, feed types at different times of the year, and processing variation within the abattoir, all of which are beyond the control of this study.

Contrasting with our hypothesis, the progeny of Terminal sires (males) had the lowest sensory scores for tenderness, overall liking, juiciness and flavour. This response probably reflects the intense selection pressure within this sire line for more muscular and leaner animals, with subsequent detrimental effects on eating quality. These eating quality differences between the sire types may be linked to differences in IMF as Terminal sired lambs have been shown to have less IMF compared to Merino and Maternal sired lambs (Pannier et al., 2013b) and this IMF difference may be associated with the lower scores for tenderness, overall liking, juiciness and flavour in Terminal progeny. However, when including IMF into the statistical model, the magnitude of these sire type differences remained, suggesting that the effect is not only related to differences in IMF. Our results contrast with a previous study in which progeny of male Terminal sired lambs (first cross) had generally higher sensory scores compared to male Merino lambs, and female and male Maternal lambs (Hopkins et al., 2005b). However in the study of Safari, et al. (2001), no difference between Terminal, Maternal and Merino genotypes were observed, though this study used lambs with cryptorchidism, the samples set was smaller, and trained panelist were used as opposed to the untrained consumers used in our study.

Sensory scores differed between wethers and female lambs contrasting with our initial hypothesis. These effects were small and only observed within the loin, and may be due to differences in IMF levels. Females deposit 0.15% more IMF in the loin than wether lambs (Pannier et al., 2013b), and are therefore likely to be more tender, flavoursome, juicier and have overall a better liking score. However, when the model was corrected for IMF the magnitude of the difference between sexes (within Terminals) remained for tenderness, overall liking and juiciness, indicating that their effect is not solely explained by differences in IMF. In addition, the small IMF difference between the sexes would only have accounted for a small eating quality improvement (e.g. 0.15 IMF% would only result in 0.33 more sensory scores for overall liking). For flavour on the other hand, when IMF was included the sex difference disappeared, suggesting the variation in flavour scores between the female and wether lambs is driven by IMF. This further confirmed that IMF plays a key role in regulating flavour. Our observed sex differences are in agreement with some other studies, in which lamb sex had a small and weak impact on sensory scores (Arsenos et al., 2002; Dransfield, Nute, Hogg, & Walters, 1990; Navajas et al., 2008; Sañudo, Sánchez, & Alfonso, 1998; Teixeira et al., 2005; Tejeda et al., 2008). Contrasting to our results, no sex differences were observed in the studies of Tejeda et al. (2008) and Teixeira et al. (2005). However it should be noted that our much bigger dataset (n = 1434) compared to the latter two studies (e.g. n = 48, Tejeda et al., 2008; n = 72, Teixeira et al., 2005) might have caused this discrepancy in the results, and the fact that our study used wethers instead of uncastrated lambs.

5.6 Comparison of effects on sensory scores

Given its size, this dataset provides the opportunity to compare the magnitudes of factors impacting on sensory traits with a good degree of precision. Shear force explained the largest amount of variation in tenderness scores with a magnitude (11.6) that was at least double or even three times more compared to any other phenotypic effect on tenderness. For juiciness (10.7) and flavour (9.1) scores, it was IMF that had the largest non-genetic effect with a magnitude that was 50% and 30% more than their magnitude described by shear force. For overall liking scores, IMF also had the largest effect with a magnitude (10.0) one third more than the shear force magnitude (8.5), and about double or more than the other production effects of site, kill group, sex, and sire type. Thus, the effects of shear force and IMF were the largest and when compared to the ASBV effects, their impact on the sensory score is much more profound.

6 Conclusions

Both non-genetic and genetic factors demonstrated significant relationships with all sensory scores. For both the loin and topside muscle, the sensory scores as assessed by untrained consumers, illustrated a large amount of variation despite all carcasses being electrically stimulated and both muscles aged for 5 days. This variation could partly be explained by IMF, shear force at day 5, carcass composition traits and production and management effects. Shear force at day 5 was the best indicator of variation for tenderness, whereas IMF explained the largest amount of variation in flavour and juiciness. To reach optimal eating quality, lambs would have to need high IMF levels, low shear force levels, should be less muscular and be slaughtered at a younger age. Furthermore, selection for increased lean meat yield through reduced PFAT, and increased PEMD and PWWT breeding values, reduced the consumer sensory scores in lamb meat. This negative effect on sensory traits emphasises the current concerns of selecting for leaner, more muscular and faster growing animals and its impact on meat quality and consumer perception of eating quality, and should be monitored when selecting for lean meat yield. The variation in IMF and shear force did not appear to explain the impact of these breeding values, suggesting that the associations seen between these breeding values and sensory scores are not solely driven through their phenotypic impact of IMF and shear force. Our data confirms the growing concerns that selecting for lean meat yield would reduce consumer eating quality and highlights the need for careful monitoring of selection programs to maintain consumer satisfaction.

7 Acknowledgements

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8 Table and Figures

Table 1

Number of sires, number of lambs, and mean (min, max) of Australian Sheep Breeding Values for each sire type. Data are presented for 1434 animals.

Sire type	No. of sires	No. of lambs	PFAT (mm)	PEMD (mm)	PWWT (kg)
Maternal	49	348	-0.06 (-1.61, 0.90)	0.33 (-1.44, 1.28)	5.63 (0.94, 9.88)
Merino	61	197	-0.16 (-1.39, 1.50)	0.11 (-1.67, 2.69)	2.60 (-3.68, 8.39)
Terminal	65	889	-0.86 (-2.44, 0.33)	0.99 (-2.90, 4.23)	12.5 (7.13, 18.1)

PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: c-site fat depth.

Table 2

Number of lambs analysed in the base models (n = 1434) according to site, year, sex, birth-rearing type, sire type, dam breed within sire type.

Effects	Number of lambs
Site	
Kirby	710
Katanning	724
Year	
2009	726
2010	708
Sex	
Female	458
Male	976
Birth-rearing type	
11	632
12	169
22	587
31	17
32	15
33	14
Siretype	
Maternal	348
Merino	197
Terminal	889
Dam breed (sire type)	
Merino (Maternal)	336
Merino (Merino)	197
BLM (Terminal)	440
Merino (Terminal)	461

BLM: Border Leicester-Merino.

Table 3

Mean (± s.d.) and range for tenderness, overall liking, juiciness, flavour and odour sensory scores, and covariates of intramuscular fat, shear force at day 5 for loin and topside, pH at 24 h of the loin, muscle weight for loin and topside, and shortloin fat weight. Data are presented for 1434 animals.

	Loin		Topside	
Traits	**Mean ± s.d.**	**Range**	**Mean ± s.d.**	**Range**
Tenderness	73.2 ± 9.3	32.4 - 92.7	47.6 ± 11.9	12.9 - 83.9
Overall liking	72.3 ± 8.4	40.6 - 93.9	52.1 ± 10.3	20.8 - 84.2
Juiciness	67.3 ± 9.4	30.3 - 94.8	48.1 ± 10.3	20.9 - 78.9
Flavour	71.1 ± 7.9	40.5 - 91.2	55.1 ± 9.3	27.8 - 86.7
Odour	69.9 ± 6.4	46.1 - 87.0	66.2 ± 6.8	44.6 - 84.5
Intramuscular fat (%)	4.5 ± 1.1	2.0 - 9.8		
Shear force at day 5 (N)	25.4 ± 7.8	11.9 - 70.2	39.9 ± 11.1	19.2 - 87.2
pH at 24 h	5.6 ± 0.2	5.2 - 6.8		
Muscle weight (g)	367.1 ± 68.0	170.0 - 635.0	616.8 ± 96.9	350.0 - 1010.0
Shortloin fat weight (g)	248.8 ± 115.5	40.0 - 880.0		

Table 4

Phenotypic partial correlation coefficients for the different sensory traits within the loin (above diagonal) and within the topside samples (below diagonal).

Sensory traits					
	Tenderness	**Overall liking**	**Juiciness**	**Flavour**	**Odour**
Tenderness		0.867	0.808	0.798	0.486
Overall liking	0.888		0.853	0.941	0.587
Juiciness	0.830	0.861		0.805	0.492
Flavour	0.776	0.911	0.814		0.601
Odour	0.402	0.495	0.467	0.568	

Table 5

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

Effect	NDF	DDF	Tenderness	Ov. Liking	Juiciness	Flavour	Odour
Site	1	1415	54.11**	30.57**	29.21**	19.00**	na
Year	1	1415	21.97**	13.66**	20.68**	9.15**	0.23
Sex (sire type)	1	1415	2.63	1.82	1.02	0.15	1.38
Cut	1	1415	7031.74**	5453.95**	4525.34**	3862.37**	411.44**
Sire type	2	1415	28.56**	24.28**	19.75**	20.32**	na
Dam breed (sire type)	1	1415	1.45	0.03	0.28	0.74	na
Kill group (Site*year)	10	1415	4.51**	3.07**	2.90**	1.83*	0.39
Site*year			0.07	na	3.32	na	na
Site*year*cut			10.48**	na	3.90*	na	na
Site*cut			7.54**	na	4.99*	na	na
Year*cut			10.82**	51.44**	57.56**	50.78**	37.54**
Site*sex (sire type)			na	3.39**	3.29*	2.7*	na
Sex (sire type)*cut			6.21*	6.67**	11.81**	5.75*	3.2*
Sire type*cut			na	na	6.39**	na	na
Dam breed (sire type) *cut			6.72**	9.23**	9.40**	6.80**	na
Kill group(site*year) *cut			17.06**	10.62**	13.94**	6.74**	2.27**

NDF, DDF: numerator and denominator degrees of freedom; Ov. Liking: overall liking; na: not applicable; *: $P < 0.05$; **: $P < 0.01$.

Table 6

Least square means (± SE) for the effects of site by year, sex within sire type, and dam breed within sire type between the loin and topside muscles for the tenderness, overall liking, juiciness, flavour and odour sensory scores.

Effect	Cut	Category	Tenderness	Ov. Liking	Juiciness	Flavour	Odour
Site*year*cut	Loin	Kirby 2009	77.48 ± 0.83	75.33 ± 0.77	71.05 ± 0.85	73.43 ± 0.75	69.68 ± 0.66
	Loin	Kirby 2010	75.05 ± 0.78	74.90 ± 0.71	70.28 ± 0.78	73.44 ± 0.68	70.44 ± 0.58
	Topside	Kirby 2009	54.38 ± 0.83	57.21 ± 0.77	53.05 ± 0.85	59.05 ± 0.75	66.71 ± 0.66
	Topside	Kirby 2010	48.13 ± 0.78	52.21 ± 0.71	47.22 ± 0.78	54.97 ± 0.68	65.34 ± 0.58
	Loin	Katanning 2009	75.22 ± 0.88	72.97 ± 0.81	68.48 ± 0.90	71.45 ± 0.79	69.73 ± 0.68
	Loin	Katanning 2010	71.13 ± 0.73	70.86 ± 0.67	64.78 ± 0.73	69.92 ± 0.64	70.24 ± 0.55
	Topside	Katanning 2009	48.48 ± 0.88	53.83 ± 0.81	50.67 ± 0.90	56.92 ± 0.79	67.17 ± 0.68
	Topside	Katanning 2010	44.44 ± 0.73	48.98 ± 0.67	44.01 ± 0.73	52.58 ± 0.64	65.48 ± 0.55
Sex(siretype)*cut	Loin	Male Maternal	75.70 ± 0.70	74.30 ± 0.62	69.49 ± 0.66	72.67 ± 0.57	69.94 ± 0.46
	Loin	Male Merino	76.97 ± 0.86	75.27 ± 0.76	70.52 ± 0.81	73.46 ± 0.71	70.49 ± 0.57
	Loin	Male Terminal	70.61 ± 0.66	70.24 ± 0.58	65.11 ± 0.63	69.59 ± 0.55	69.17 ± 0.45
	Loin	Female Terminal	72.37 ± 0.64	71.73 ± 0.56	66.75 ± 0.61	70.50 ± 0.53	70.10 ± 0.44
	Topside	Male Maternal	50.73 ± 0.70	54.72 ± 0.62	50.49 ± 0.66	57.15 ± 0.57	66.72 ± 0.46
	Topside	Male Merino	50.00 ± 0.86	53.69 ± 0.76	48.64 ± 0.81	56.40 ± 0.71	65.82 ± 0.57
	Topside	Male Terminal	45.89 ± 0.66	50.87 ± 0.58	47.42 ± 0.63	54.38 ± 0.55	65.99 ± 0.45
	Topside	Female Terminal	45.80 ± 0.64	50.66 ± 0.56	46.76 ± 0.61	53.81 ± 0.53	66.00 ± 0.44
Dam breed (sire type)*cut	Loin	BLM (Terminal)	70.55 ± 0.68	70.36 ± 0.61	65.19 ± 0.65	69.35 ± 0.57	69.78 ± 0.46
	Loin	Merino (Terminal)	72.43 ± 0.68	71.61 ± 0.60	66.67 ± 0.65	70.73 ± 0.56	69.50 ± 0.46
	Topside	BLM (Terminal)	46.01 ± 0.68	51.28 ± 0.61	47.51 ± 0.65	54.32 ± 0.57	66.31 ± 0.46
	Topside	Merino (Terminal)	45.68 ± 0.68	50.25 ± 0.60	46.66 ± 0.65	53.86 ± 0.56	65.67 ± 0.46

Ov. Liking: overall liking; BLM: Border Leicester-Merino.

Table 7

Sire estimate ranges of the base linear mixed effects models of tenderness, overall liking, juiciness and flavour scores of the loin and topside muscles of lamb for the Maternal, Merino and Terminal sired progeny.

Sire type (n)	Tenderness	Ov. Liking	Juiciness	Flavour
Maternal (49)				
Loin	72.9 – 76.9	73.0 – 74.9	68.5 – 70.7	72.2 – 73.0
Topside	48.3 – 53.2	53.2 – 55.9	49.3 – 51.4	56.7 – 57.6
Merino (61)				
Loin	75.4 – 77.8	74.7 – 75.9	69.9 – 70.9	73.2 – 73.6
Topside	48.1 – 51.8	53.0 – 54.6	47.9 – 49.2	56.2 – 56.7
Terminal (65)				
Loin	67.8 – 73.8	69.0 – 72.2	64.5 – 67.2	69.4 – 70.5
Topside	43.3 – 49.9	49.4 – 52.6	45.5 – 48.5	53.7 – 54.7

Ov. Liking: overall liking.

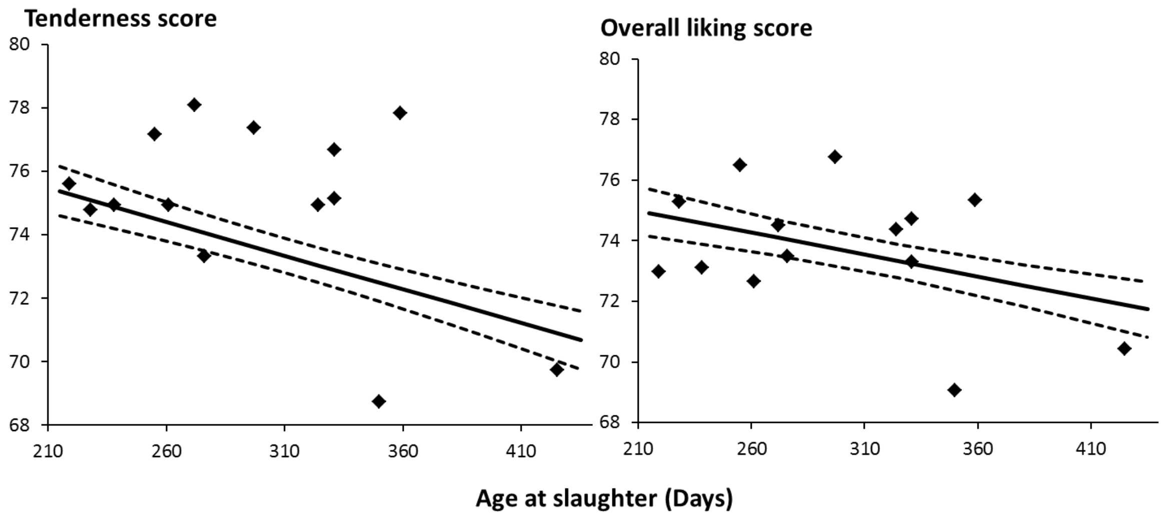

Fig. 1. Relationship between sensory scores for tenderness and overall liking of the loin muscle with slaughter age (days). Symbols (♦) represent kill group least squares means. Lines represent least squares means for slaughter-age (± SE) from base model with kill group within site by flock term removed.

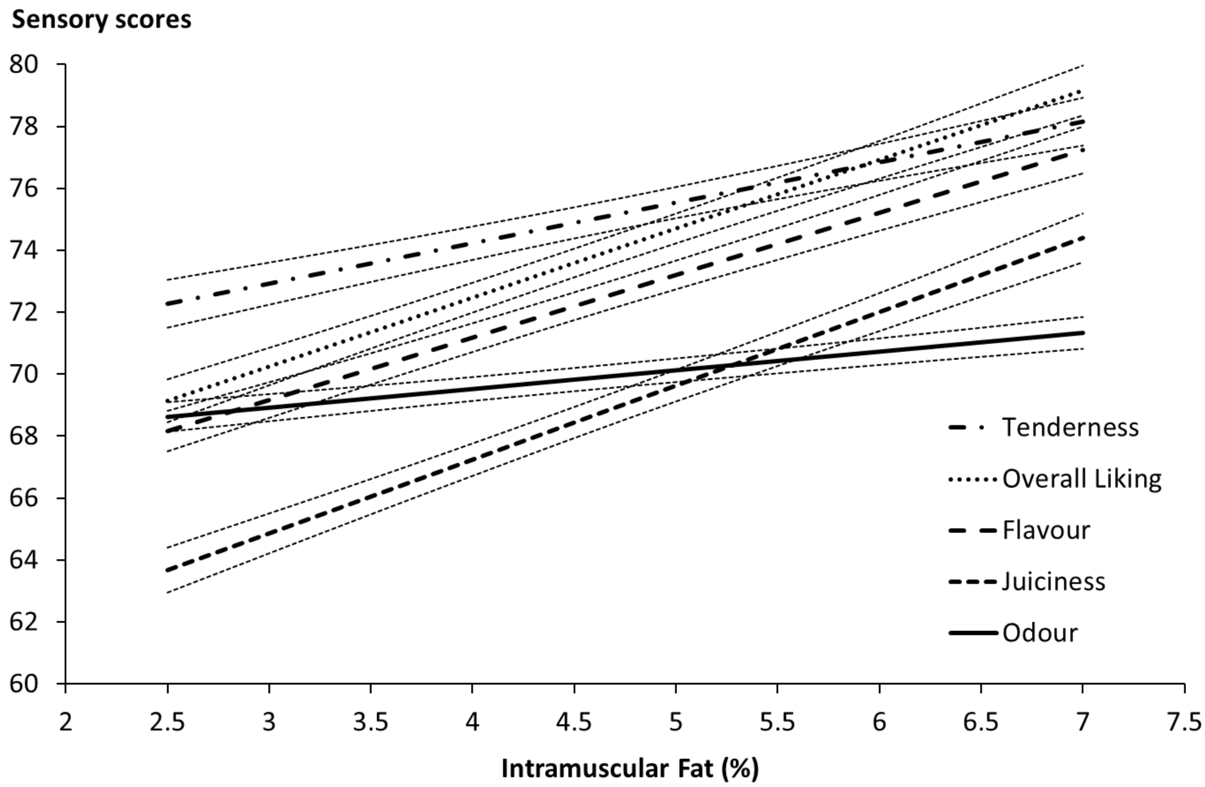

Fig. 2. Relationship between IMF (%) and tenderness, overall liking, juiciness, flavour and odour sensory scores of the loin muscle of lamb. Lines represent least squares means (± SE) for IMF from the base model with IMF tested as covariate.

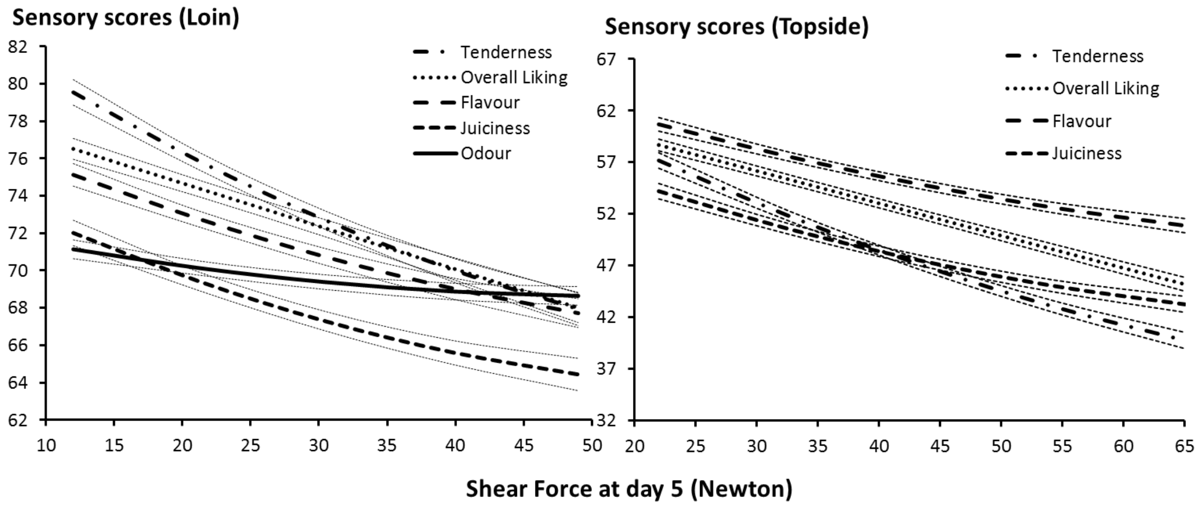

Fig. 3. Relationship between shear force at 5 days of aging (Newton) and tenderness, overall liking, juiciness, flavour and odour sensory scores of the loin and topside muscle of lamb. Lines represent least squares means (± SE) for shear force at day 5 from the base model with shear force tested as covariate.

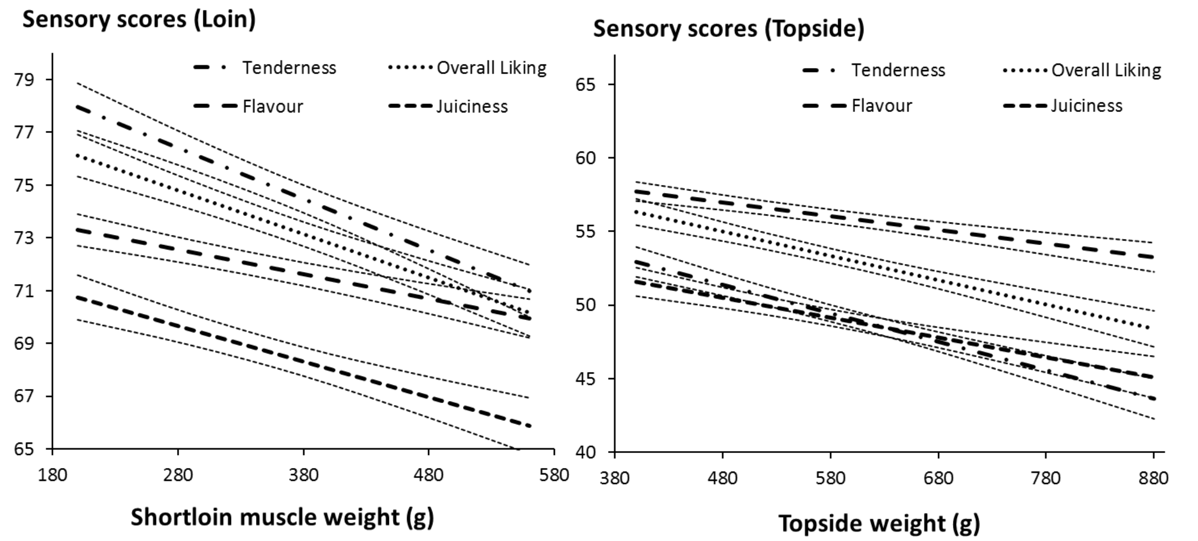

Fig. 4. Relationship between shortloin muscle weight (g) and topside weight (g) with tenderness, overall liking, juiciness and flavour sensory scores of the loin and topside muscles, respectively, of lamb. Lines represent least squares means (± SE) for shortloin muscle weight and topside weight from the covariate models.

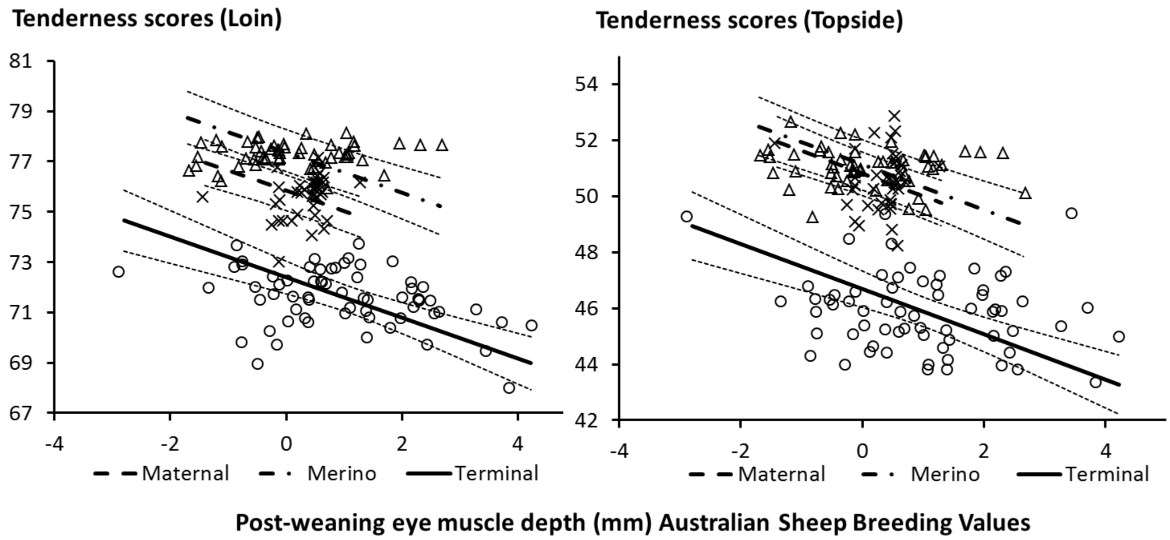

Fig. 5a. Relationship between sire estimates for the tenderness scores and post weaning eye muscle depth (PEMD). Icons represent sire estimates as (×) Maternal, (Δ) Merino and (○) Terminal sires plus the least squares means for their respective sire type, and are obtained from the ASBV model in which PEMD was removed. Lines represent least squares means for PEMD (± SE) from the ASBV model for tenderness sensory scores.

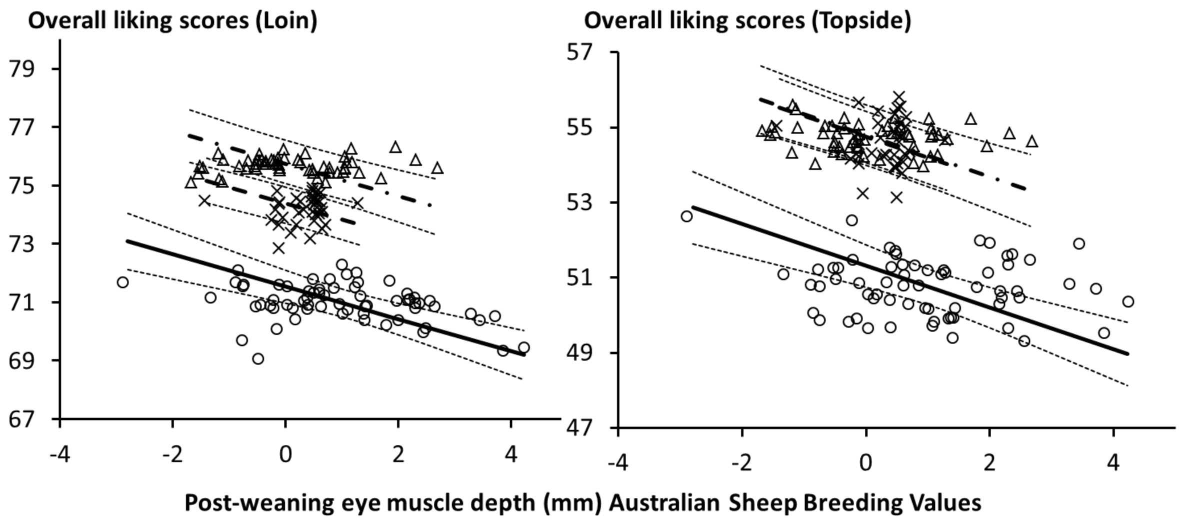

Fig. 5b. Relationship between sire estimates for the overall liking scores and post weaning eye muscle depth (PEMD). Icons represent sire estimates as (×) Maternal, (Δ) Merino and (○) Terminal sires plus the least squares means for their respective sire type, and are obtained from the ASBV model in which PEMD was removed. Lines represent least squares means for PEMD (± SE) from the ASBV model for overall liking sensory scores.

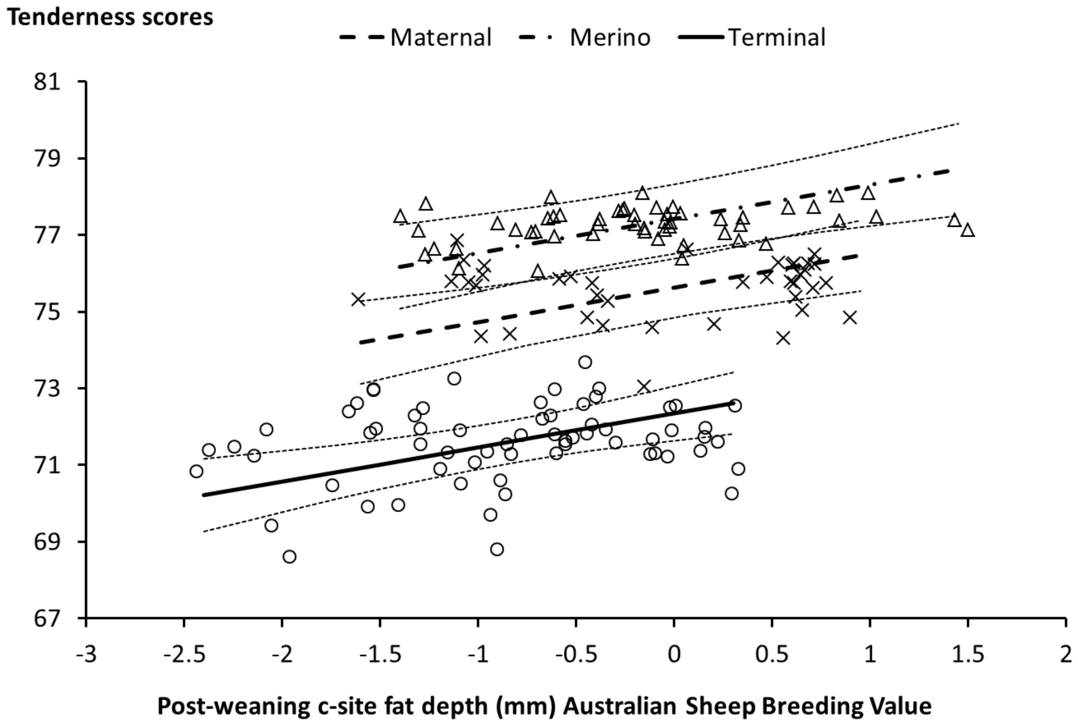

Fig. 6. Relationship between sire estimates for the tenderness scores and subcutaneous post-weaning fat depth (PFAT). Icons represent sire estimates as (×) Maternal, (Δ) Merino and (○) Terminal sires plus the least squares means for their respective sire type, and are obtained from the ASBV model in which PFAT was removed. Lines represent least squares means for PFAT (± SE) from the ASBV model for tenderness sensory scores.

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