



Associations of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb[☆]

L. Pannier^{a,b,*}, G.E. Gardner^{a,b}, K.L. Pearce^{a,b}, M. McDonagh^{a,c}, A.J. Ball^{a,d}, R.H. Jacob^{a,e}, D.W. Pethick^{a,b}

^a Australian Cooperative Research Centre for Sheep Industry Innovation, Australia

^b Murdoch University, School of Veterinary & Life Sciences, Western Australia 6150, Australia

^c Department of Primary Industries, New South Wales 2351, Australia

^d University of New England, Meat & Livestock Australia, New South Wales 2351, Australia

^e Department of Agriculture and Food, Western Australia 6151, Australia

ARTICLE INFO

Article history:

Received 15 May 2013

Received in revised form 29 July 2013

Accepted 30 July 2013

Keywords:

Lamb

Tenderness

Juiciness

Flavour

Odour

Overall liking

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) 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.

© 2013 The Authors. Published by Elsevier Ltd. All rights reserved.

1. Introduction

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, 2006). Consumers also demand lamb that is lean and has good nutritional attributes (Pethick, Banks, Hales, & Ross, 2006). Whilst the nutritional content of lamb has been shown to be sufficient to claim lamb as a good source of key nutrients (Pannier, Pethick, Boyce, et al., 2014a, 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., 2005). 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 (2005) 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

[☆] This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-No Derivative Works License, which permits non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.

* Corresponding author at: Murdoch University, School of Veterinary & Life Sciences, Western Australia 6150, Australia. Tel.: +61 401398257.

E-mail address: lpannier@murdoch.edu.au (L. Pannier).

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 et al., 2014). 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 have been linked with a decline in IMF (Hopkins, Hegarty, & Farrell, 2005; Hopkins et al., 2007; Pannier, Pethick, Geesink, et al., 2014b), and with detrimental effects on meat eating quality (Hopkins, Hegarty, & Farrell, 2005; Hopkins, Walker, Thompson, & Pethick, 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. Material and methods

2.1. 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., 2014). 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 h 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 to 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.

2.2. 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 et 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 12th 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.

2.3. Sensory testing

Details of the sensory testing protocol were presented by Thompson et al. (2005a) and Watson, Gee, Polkinghorne, and Porter (2008) and were 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 everyday (3 stars), better than everyday (4 stars), or premium (5 stars). 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, Gee, 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.

2.4. 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 muscles were 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 cm² 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).

2.5. 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 * Merino, Maternal * Merino, Terminal * Merino, Terminal * Border Leicester–Merino) and kill group within site by year. Sire identification, dam identification by year, and 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 ageing 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 (i.e. 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 are 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

Table 2

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

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

BLM: Border Leicester–Merino.

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 was 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.

3. 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 muscles 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 Tables 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

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: post-weaning c-site fat depth.

Table 3

Mean (\pm SD) 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.

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

included in the models these magnitudes were expressed across the observed range of the covariate.

3.1. 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 (\pm 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

Table 5

F-values and 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; *: $P < 0.05$; **: $P < 0.01$.

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 ($P < 0.01$; Tables 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 \pm SD) however between kill groups this varied from 214 to 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 ($P < 0.05$; Tables 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 ($P < 0.01$; Tables 5 and 6). Lambs from Merino dams had higher sensory

Table 6
Least square means (\pm 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 \pm 0.83 | 75.33 \pm 0.77 | 71.05 \pm 0.85 | 73.43 \pm 0.75 | 69.68 \pm 0.66 |
| | Loin | Kirby 2010 | 75.05 \pm 0.78 | 74.90 \pm 0.71 | 70.28 \pm 0.78 | 73.44 \pm 0.68 | 70.44 \pm 0.58 |
| | Topside | Kirby 2009 | 54.38 \pm 0.83 | 57.21 \pm 0.77 | 53.05 \pm 0.85 | 59.05 \pm 0.75 | 66.71 \pm 0.66 |
| | Topside | Kirby 2010 | 48.13 \pm 0.78 | 52.21 \pm 0.71 | 47.22 \pm 0.78 | 54.97 \pm 0.68 | 65.34 \pm 0.58 |
| | Loin | Katanning 2009 | 75.22 \pm 0.88 | 72.97 \pm 0.81 | 68.48 \pm 0.90 | 71.45 \pm 0.79 | 69.73 \pm 0.68 |
| | Loin | Katanning 2010 | 71.13 \pm 0.73 | 70.86 \pm 0.67 | 64.78 \pm 0.73 | 69.92 \pm 0.64 | 70.24 \pm 0.55 |
| | Topside | Katanning 2009 | 48.48 \pm 0.88 | 53.83 \pm 0.81 | 50.67 \pm 0.90 | 56.92 \pm 0.79 | 67.17 \pm 0.68 |
| | Topside | Katanning 2010 | 44.44 \pm 0.73 | 48.98 \pm 0.67 | 44.01 \pm 0.73 | 52.58 \pm 0.64 | 65.48 \pm 0.55 |
| | Sex (sire type) * cut | Loin | Male Maternal | 75.70 \pm 0.70 | 74.30 \pm 0.62 | 69.49 \pm 0.66 | 72.67 \pm 0.57 |
| Loin | | Male Merino | 76.97 \pm 0.86 | 75.27 \pm 0.76 | 70.52 \pm 0.81 | 73.46 \pm 0.71 | 70.49 \pm 0.57 |
| Loin | | Male Terminal | 70.61 \pm 0.66 | 70.24 \pm 0.58 | 65.11 \pm 0.63 | 69.59 \pm 0.55 | 69.17 \pm 0.45 |
| Loin | | Female Terminal | 72.37 \pm 0.64 | 71.73 \pm 0.56 | 66.75 \pm 0.61 | 70.50 \pm 0.53 | 70.10 \pm 0.44 |
| Topside | | Male Maternal | 50.73 \pm 0.70 | 54.72 \pm 0.62 | 50.49 \pm 0.66 | 57.15 \pm 0.57 | 66.72 \pm 0.46 |
| Topside | | Male Merino | 50.00 \pm 0.86 | 53.69 \pm 0.76 | 48.64 \pm 0.81 | 56.40 \pm 0.71 | 65.82 \pm 0.57 |
| Topside | | Male Terminal | 45.89 \pm 0.66 | 50.87 \pm 0.58 | 47.42 \pm 0.63 | 54.38 \pm 0.55 | 65.99 \pm 0.45 |
| Topside | | Female Terminal | 45.80 \pm 0.64 | 50.66 \pm 0.56 | 46.76 \pm 0.61 | 53.81 \pm 0.53 | 66.00 \pm 0.44 |
| Dam breed (sire type) * cut | | Loin | BLM (Terminal) | 70.55 \pm 0.68 | 70.36 \pm 0.61 | 65.19 \pm 0.65 | 69.35 \pm 0.57 |
| | Loin | Merino (Terminal) | 72.43 \pm 0.68 | 71.61 \pm 0.60 | 66.67 \pm 0.65 | 70.73 \pm 0.56 | 69.50 \pm 0.46 |
| | Topside | BLM (Terminal) | 46.01 \pm 0.68 | 51.28 \pm 0.61 | 47.51 \pm 0.65 | 54.32 \pm 0.57 | 66.31 \pm 0.46 |
| | Topside | Merino (Terminal) | 45.68 \pm 0.68 | 50.25 \pm 0.60 | 46.66 \pm 0.65 | 53.86 \pm 0.56 | 65.67 \pm 0.46 |

Ov. liking: overall liking; BLM: Border Leicester–Merino.

scores compared to lambs from Border Leicester * Merino dams, with these differences being 1.9, 1.2, 1.5 and 1.4 units for tenderness, overall liking, juiciness and flavour scores.

3.2. 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 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 was 6.7, 6.6 and 5.4, respectively.

3.3. Effect of shear force at day 5 on sensory scores

Shear force at 5 days of ageing for both 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 and 49 N, 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 and 65 N, 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.

3.4. 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 and 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.

3.5. 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 \pm SD); range 15.0–40.0), had a negative relationship with

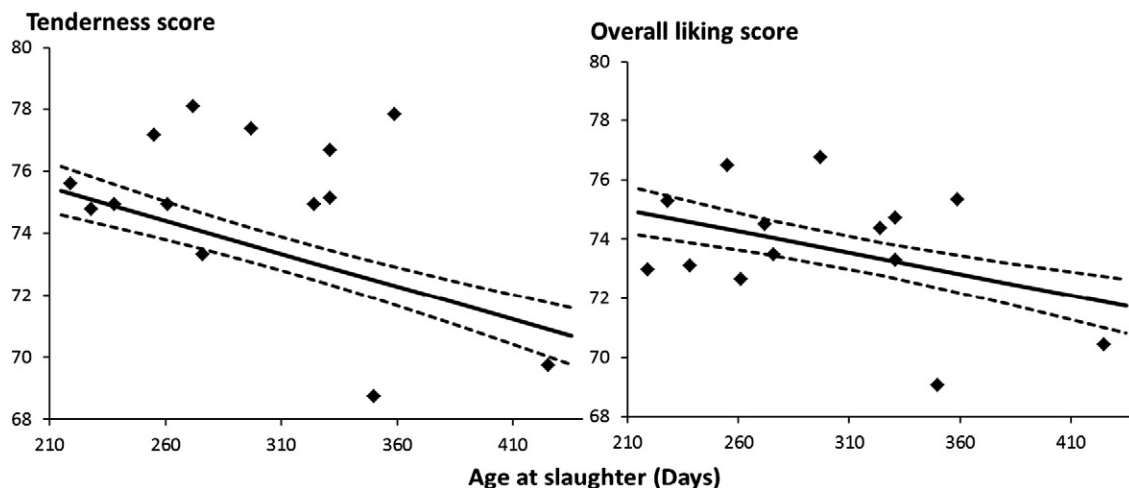


Fig. 1. Relationship between sensory scores for tenderness and overall liking of the loin muscle with slaughter age (days). Symbols (\blacklozenge) represent kill group least squares means. Lines represent least squares means for the sensory scores across the slaughter-age range (\pm SE) from base model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

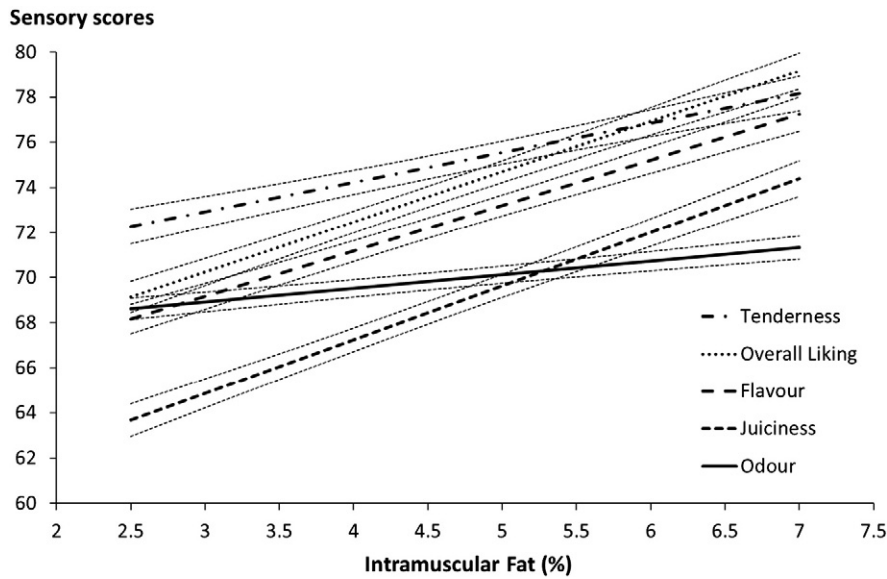


Fig. 2. Relationship between IMF (%) and tenderness, overall liking, juiciness, flavour and odour sensory scores of the loin muscle of lamb. Lines represent least squares means (\pm SE) for the sensory scores across the IMF range from the base model with IMF tested as covariate.

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 loin and topside samples, reaching a plateau beyond this point.

3.6. 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 loin and topside samples (Fig. 5A, B for tenderness and overall liking). The magnitude of the PEMD effects was 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 ageing for both 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

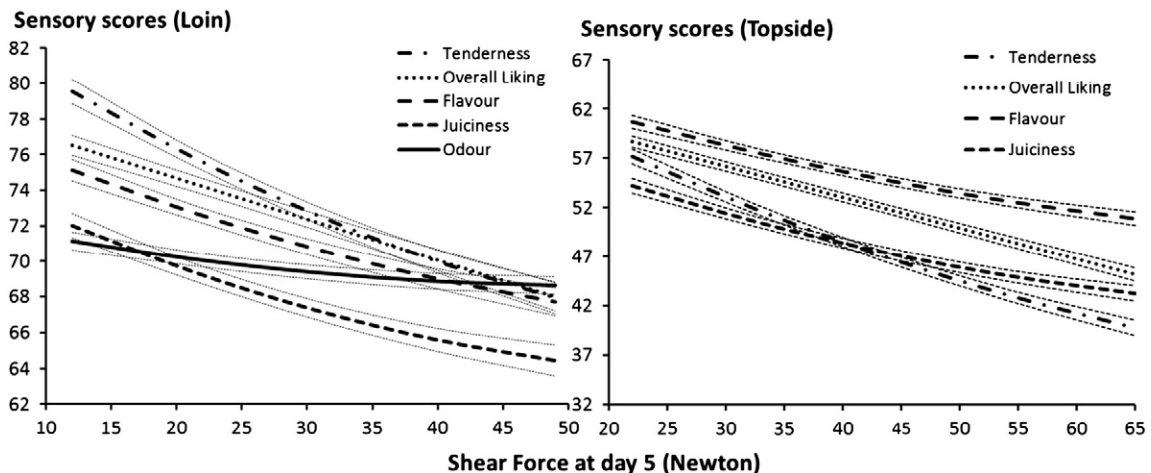


Fig. 3. Relationship between shear force at 5 days of ageing (N) and tenderness, overall liking, juiciness, flavour and odour sensory scores of the loin and topside muscles of lamb. Lines represent least squares means (\pm SE) for the sensory scores across the shear force range at day 5 from the base model with shear force tested as covariate.

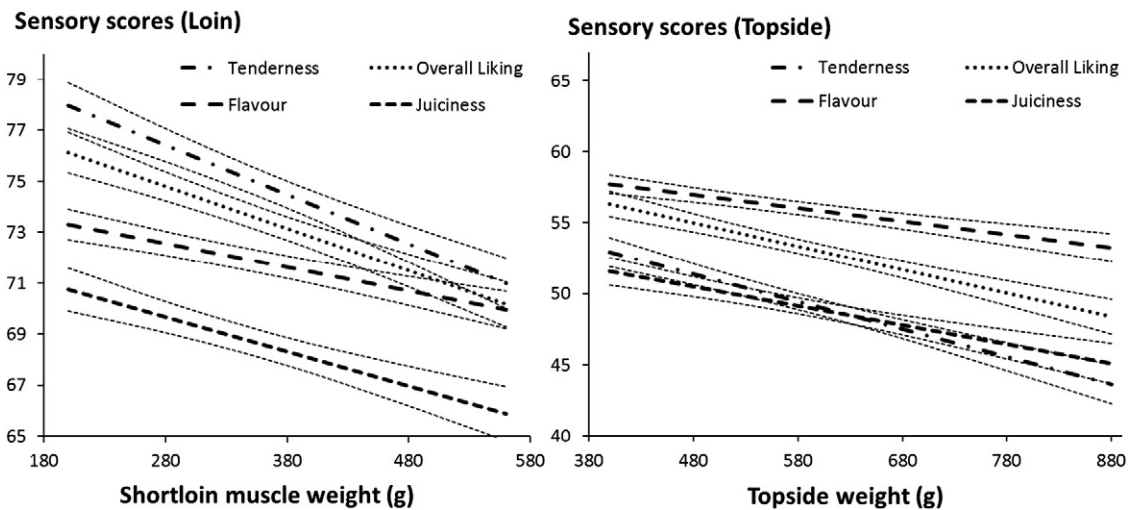


Fig. 4. Relationship between shortloin muscle weight (g) and topside weight (g) with tenderness, overall liking, juiciness and flavour sensory scores of the loin and topside muscles, respectively, of lamb. Lines represent least squares means (\pm SE) for the sensory scores across the shortloin muscle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

at 5 days of ageing, 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 types 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 ageing, or shortloin muscle weight was 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.

4. Discussion

4.1. 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

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. 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, Hegarty, and Farrell (2005), 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 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 12th 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 et al., submitted for publication). This impact on whole carcass muscling may explain the broader impact of PEMD on both 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 loin and topside muscles. 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, Stanley, Martin, Toohey, and Gilmour (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, Pethick, Geesink, et al., 2014b), 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 has been associated with reduced IMF values (Hegarty, Warner,

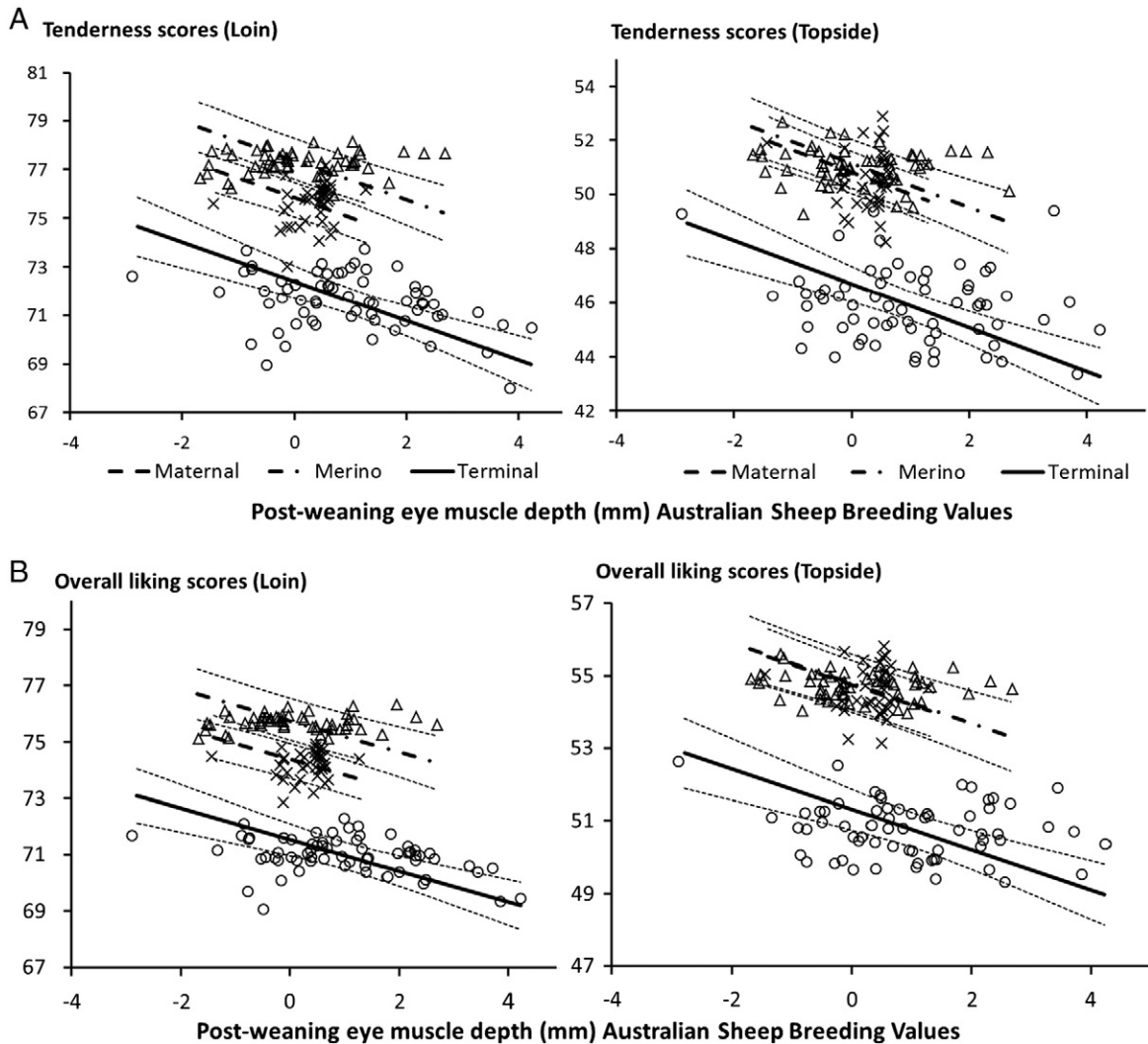


Fig. 5. A. Relationship between sire estimates for the tenderness scores and post-weaning eye muscle depth (PEMD). Icons represent sire estimates as (x) Maternal, (Δ) Merino and (○) Terminal sires plus the least squares means for their respective sire type, and are obtained from the ASBV model in which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

& Pethick, 2006; Hopkins, Hegarty, & Farrell, 2005; Hopkins, Stanley, Toohey, et al., 2007b; Pannier, Pethick, Geesink, et al., 2014b). 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, Hegarty, & Farrell, 2005; Hopkins, Stanley, Toohey, 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, Stanley, Toohey, 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, Stanley, Toohey, 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 carcass 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 et al., submitted for publication). 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)

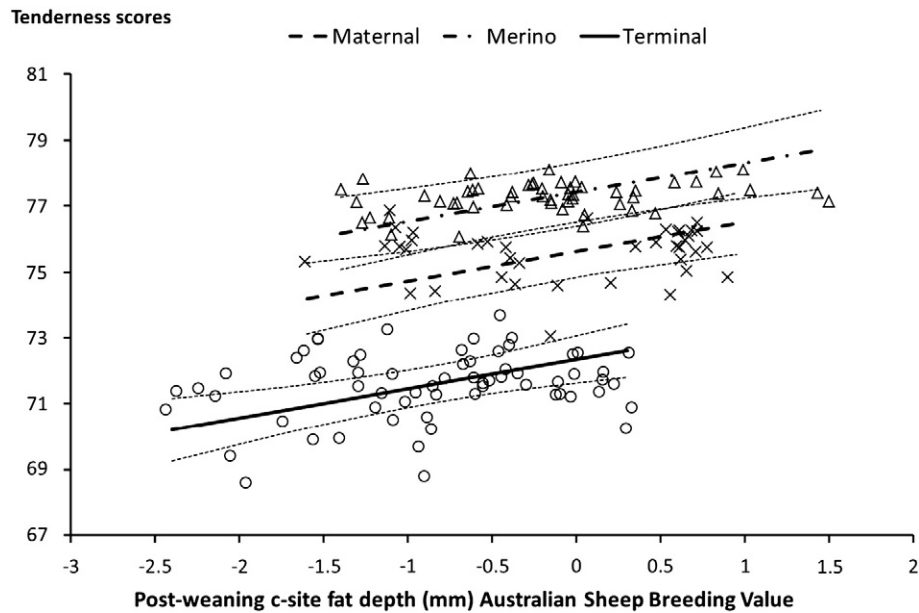


Fig. 6. Relationship between sire estimates for the tenderness scores and subcutaneous post-weaning fat depth (PFAT). Icons represent sire estimates as (×) Maternal, (Δ) Merino and (○) Terminal sires plus the least squares means for their respective sire type, and are obtained from the ASBV model in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

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 was included, suggesting that the PWWT effects were not driven through the phenotypic association of shear force or IMF with sensory scores.

4.2. 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, Hegarty, & Farrell, 2005; Pethick, Hopkins, D'Souza, Thompson, & Walker, 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 ageing 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 ageing was the same as at 5 days ageing.

In this study, we demonstrated a 2.2 unit increase in overall liking per 1% IMF increase. In comparison, Hopkins et al. (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 everyday quality (Pleasant, 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 the 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.

4.3. 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 ageing 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 panellists 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, Gee, 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.

4.4. Association of pH at 24 h with sensory scores

The relationship between pH at 24 h and sensory scores was 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, Hegarty, & Farrell, 2005; Young, Reid, & Scales, 1993). The reason for this poor association is difficult to explain.

4.5. 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, Davidson, 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, Hopkins, D'Souza, Thompson, & Walker, 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, Pethick, Geesink, et al., 2014b) 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, Walker, Thompson, & Pethick, 2005). However in the study of Safari et al. (2001), no difference between Terminal, Maternal and Merino genotypes was observed, though this study used lambs with cryptorchidism, the sample set was smaller, and trained panellists were used as opposed to the untrained consumers used in our study.

Sensory scores differed between wether 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, Pethick, Geesink, et al., 2014b), and are therefore likely to be more tender, flavoursome, and juicy 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 that 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; Tejada et al., 2008). Contrasting to our results, no sex differences were observed in the studies of Tejada 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. $n = 48$, Tejada et al., 2008; $n = 72$, Teixeira et al., 2005) might have caused this discrepancy in the results, and the fact that our study used wether instead of uncastrated lambs.

4.6. 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.

5. Conclusions

Both non-genetic and genetic factors demonstrated significant relationships with all sensory scores. For both loin and topside muscles, 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 programmes to maintain consumer satisfaction.

Acknowledgements

The CRC for Sheep Industry Innovation is supported by the Australian Government's Cooperative Research Centre Program, Australian Wool Innovation Ltd. and Meat & Livestock Australia. The authors gratefully acknowledge the contributions of staff and resources provided at each site for the INF: NSW Department of Primary Industries, University of New England, Department of Primary Industries Victoria, SA Research & Development Institute and Department of Agriculture and Food WA. The Meat programme also benefits from the contribution of staff employed by CSIRO and Murdoch University.

References

Anderson, F., Williams, A., Pannier, L., Pethick, D. W., & Gardner, G. E. (2013). Australian Sheep Breeding Values increase % carcass lean and redistribute lean tissue to the saddle region. *59th International Congress of Meat Science and Technology Turkey* (submitted for publication).

Anonymous (2005). *Handbook of Australian meat International red meat manual* (7th ed.). Sydney, Australia: AUS-MEAT.

Arsenos, G., Banos, G., Fortomaris, P., Katsaounis, N., Stamatari, C., Tsaras, L., & Zygoyiannis, D. (2002). Eating quality of lamb meat: effects of breed, sex, degree of maturity and nutritional management. *Meat Science*, *60*(4), 379–387.

Brackebusch, S. A., Mckeith, F. K., Carr, T. R., & McLaren, D. G. (1991). Relationship between longissimus composition and the composition of other major muscles of the beef carcass. *Journal of Animal Science*, *69*(2), 631–640.

Dransfield, E., Nute, G. R., Hogg, B. W., & Walters, B. R. (1990). Carcass and eating quality of ram, castrated ram and ewe lambs. *Animal Production*, *50*, 291–299.

Fogarty, N. M., Banks, R. G., van der Werf, J. H. J., Ball, A. J., & Gibson, J. P. (2007). The information nucleus – A new concept to enhance sheep industry genetic improvement. *Proceedings of the Association for Advancement of Animal Breeding and Genetics*, Vol. 17. (pp. 29–32).

Font, I. F. M., Realini, C. E., Guerrero, L., Oliver, M. A., Sanudo, C., Campo, M. M., Nute, G. R., Caneque, V., Alvarez, I., San Julian, R., Luzardo, S., Brito, G., & Montossi, F. (2009). Acceptability of lamb fed on pasture, concentrate or combinations of both systems by European consumers. *Meat Science*, *81*(1), 196–202.

Forrest, J. C., Aberle, E. D., Hendrick, H. B., Judge, M. D., & Merkel, R. A. (1975). *Principles of meat science*. W. H. Freeman and Co.

Gardner, G. E., Williams, A., Siddell, J., Ball, A. J., Mortimer, S., Jacob, R. H., Pearce, K. L., Edwards, J. E. H., Rowe, J. B., & Pethick, D. W. (2010). Using Australian Sheep Breeding Values to increase lean meat yield percentage. *Animal Production Science*, *50*(11–12), 1098–1106.

Hegarty, R. S., Warner, R. D., & Pethick, D. W. (2006). Genetic and nutritional regulation of lamb growth and muscle characteristics. *Australian Journal of Agricultural Research*, *57*(6), 721–730.

Hocquette, J. F., Gondret, F., Baeza, E., Medale, F., Jurie, C., & Pethick, D. W. (2010). Intramuscular fat content in meat-producing animals: Development, genetic and nutritional control, and identification of putative markers. *Animal*, *4*(2), 303–319.

Hopkins, D. L., Hegarty, R. S., & Farrell, T. C. (2005). Relationship between sire estimated breeding values and the meat and eating quality of meat from their progeny grown on two planes of nutrition. *Australian Journal of Experimental Agriculture*, *45*(5), 525–533.

Hopkins, D. L., Hegarty, R. S., Walker, P. J., & Pethick, D. W. (2006). Relationship between animal age, intramuscular fat, cooking loss, pH, shear force and eating quality of aged meat from sheep. *Australian Journal of Experimental Agriculture*, *46*(6–7), 879–884.

Hopkins, D. L., Stanley, D. F., Martin, L. C., Toohey, E. S., & Gilmour, A. R. (2007). Genotype and age effects on sheep meat production. 3. Meat quality. *Australian Journal of Experimental Agriculture*, *47*, 1155–1164.

Hopkins, D. L., Stanley, D. F., Toohey, E. S., Gardner, G. E., Pethick, D. W., & van de Ven, R. (2007). Sire and growth path effects on sheep meat production. 2. Meat and eating quality. *Australian Journal of Experimental Agriculture*, *47*(10), 1219–1228.

Hopkins, D. L., Toohey, E. S., Warner, R. D., Kerr, M. J., & van de Ven, R. (2010). Measuring the shear force of lamb meat cooked from frozen samples: A comparison of two laboratories. *Animal Production Science*, *50*, 382–385.

Hopkins, D. L., Walker, P. J., Thompson, J. M., & Pethick, D. W. (2005). Effect of sheep type on meat and eating quality of sheep meat. *Australian Journal of Experimental Agriculture*, *45*(5), 499–507.

Kunert, J. (1998). Sensory experiments as crossover studies. *Food Quality and Preference*, *9*(4), 243–253.

Miller, R. K. (2002). Factors affecting the quality of raw meat. In J. Kerry, J. Kerry, & D. Ledward (Eds.), *Meat processing: Improving meat quality* (pp. 27–63). Cambridge: Woodhead Publishing Limited.

Mortimer, S. I., van der Werf, J. H. J., Jacob, R. H., Hopkins, D. L., Pannier, L., Pearce, K. L., Gardner, G. E., Warner, R. D., Geesink, G. H., Hocking-Edwards, J. E., Ponnampalam, E. N., Ball, A. J., Gilmour, A. R., & Pethick, D. W. (2014). Genetic parameters for meat quality traits of Australian lamb meat. *Meat Science*, *96*, 1016–1024.

Navajas, E. A., Lambe, N. R., Fisher, A. V., Nute, G. R., Bungler, L., & Simm, G. (2008). Muscularity and eating quality of lambs: Effects of breed, sex and selection of sires using muscularity measurements by computed tomography. *Meat Science*, *79*(1), 105–112.

Pannier, L., Pethick, D. W., Boyce, M. D., Ball, A. J., Jacob, R. H., & Gardner, G. E. (2014a). Associations of genetic and non-genetic factors with concentrations of iron and zinc in the longissimus muscle of lamb. *Meat Science*, *96*, 1111–1119.

Pannier, L., Pethick, D. W., Geesink, G. H., Ball, A. J., Jacob, R. H., & Gardner, G. E. (2014b). Intramuscular fat in the longissimus muscle is reduced in lambs from sires selected for leanness. *Meat Science*, *96*, 1068–1075.

Pannier, L., Ponnampalam, E. N., Gardner, G. E., Hopkins, D. L., Ball, A. J., Jacob, R. H., Pearce, K. L., & Pethick, D. W. (2010). Prime Australian lamb supplies key nutrients for human health. *Animal Production Science*, *50*(11–12), 1115–1122.

Pearce, K. L., Van de Ven, R., Mudford, C., Warner, R. D., Hocking-Edwards, J. E., Jacob, R., Pethick, D. W., & Hopkins, D. L. (2010). Case studies demonstrating the benefits on pH and temperature decline of optimising medium-voltage electrical stimulation of lamb carcasses. *Animal Production Science*, *50*, 1107–1114.

Perry, D., Shorthose, W. R., Ferguson, D. M., & Thompson, J. M. (2001). Methods used in the CRC program for the determination of carcass yield and beef quality. *Australian Journal of Experimental Agriculture*, *41*(7), 953–957.

Pethick, D. W., Banks, R. G., Hales, J., & Ross, I. R. (2006). Australian prime lamb – A vision for 2020. *International Journal of Sheep & Wool Science*, *54*, 66–73.

Pethick, D. W., Davidson, R., Hopkins, D. L., Jacob, R. H., D'Souza, D. N., Thompson, J. M., & Walker, P. J. (2005). The effect of dietary treatment on meat quality and on consumer perception of sheep meat eating quality. *Australian Journal of Experimental Agriculture*, *45*(5), 517–524.

Pethick, D. W., Hopkins, D. L., D'Souza, D. N., Thompson, J. M., & Walker, P. J. (2005). Effects of animal age on the eating quality of sheep meat. *Australian Journal of Experimental Agriculture*, *45*(5), 491–498.

- Pethick, D. W., Pleasants, A.B., Gee, A.M., Hopkins, D. L., & Ross, I. R. (2006b). Eating quality of commercial meat cuts from Australian lambs and sheep. *Proceedings of the New Zealand Society of Animal Production*, Vol. 66. (pp. 363–367).
- Pleasants, A.B., Thompson, J. M., & Pethick, D. W. (2005). A model relating a function of tenderness, juiciness, flavour and overall liking to the eating quality of sheep meat. *Australian Journal of Experimental Agriculture*, 45(5), 483–489.
- Ponnampalam, E. N., Butler, K. L., Jacob, R. H., Pethick, D. W., Ball, A. L., Hocking Edwards, J. E., Geesink, G., & Hopkins, D. L. (2014). Health beneficial long chain omega-3 fatty acid levels in Australian lamb managed under extensive finishing systems. *Meat Science*, 96, 1104–1110.
- Priolo, A., Micol, D., Agabriel, J., Prache, S., & Dransfield, E. (2002). Effect of grass or concentrate feeding systems on lamb carcass and meat quality. *Meat Science*, 62(2), 179–185.
- Resconi, V. C., Campo, M. M., Fumols, M. F., Montossi, F., & Sanudo, C. (2009). Sensory evaluation of castrated lambs finished on different proportions of pasture and concentrate feeding systems. *Meat Science*, 83(1), 31–37.
- Rymill, S. R., Thompson, J. M., & Ferguson, D.M. (1997). The effect of intramuscular fat percentage on the sensory evaluation of beef cooked by different methods to two degrees of doneness. *Proceedings of the 43rd International Congress of Meat Science and Technology* (pp. 212–213) (Auckland, New Zealand).
- Safari, E., Fogarty, N. M., Ferrier, G. R., Hopkins, D. L., & Gilmour, A. (2001). Diverse lamb genotypes. 3. Eating quality and the relationship between its objective measurement and sensory assessment. *Meat Science*, 57(2), 153–159.
- Sañudo, C., Sánchez, A., & Alfonso, M. (1998). Small ruminant production systems and factors affecting lamb meat quality. *Meat Science*, 49, S29–S64.
- Savell, J. W., & Cross, H. R. (1988). The role of fat in the palatability of beef, pork, and lamb. In G. J. Robbins (Ed.), *Designing foods, animal product options in the marketplace* (pp. 345–355). Washington D.C.: National Academic Press.
- Shahidi, F. (2002). Lipid-derived flavors in meat products. In J. Kerry, J. Kerry, & D. Ledward (Eds.), *Meat processing: Improving meat quality* (pp. 105–121). Cambridge: Woodhead Publishing Limited.
- Shorthose, W. R., & Harris, P. V. (1991). Effects of growth and composition on meat quality. *Meat Science*(7), 515–549.
- Teixeira, A., Batista, S., Delfa, R., & Cadavez, V. (2005). Lamb meat quality of two breeds with protected origin designation. Influence of breed, sex and live weight. *Meat Science*, 71(3), 530–536.
- Tejeda, J. F., Peña, R. E., & Andrés, A. I. (2008). Effect of live weight and sex on physico-chemical and sensorial characteristics of Merino lamb meat. *Meat Science*, 80, 1061–1067.
- Thompson, J. M. (2004). The effects of marbling on flavour and juiciness scores of cooked beef, after adjusting to a constant tenderness. *Australian Journal of Experimental Agriculture*, 44(7), 645–652.
- Thompson, J. M., Gee, A., Hopkins, D. L., Pethick, D. W., Baud, S. R., & O'Halloran, W. J. (2005). Development of a sensory protocol for testing palatability of sheep meats. *Australian Journal of Experimental Agriculture*, 45(5), 469–476.
- Thompson, J. M., Hopkins, D. L., D'Souza, D. N., Walker, P. J., Baud, S. R., & Pethick, D. W. (2005). The impact of processing on sensory and objective measurements of sheep meat eating quality. *Australian Journal of Experimental Agriculture*, 45(5), 561–573.
- van der Werf, J. H. J., Kinghorn, B. P., & Banks, R. G. (2010). Design and role of an information nucleus in sheep breeding programs. *Animal Production Science*, 50(11–12), 998–1003.
- Warner, R. D., Greenwood, P. L., Pethick, D. W., & Ferguson, D.M. (2010). Genetic and environmental effects on meat quality. *Meat Science*, 86(1), 171–183.
- Warner, R. D., Jacob, R. H., Edwards, J. E. H., McDonagh, M., Pearce, K., Geesink, G., Kearney, G., Allingham, P., Hopkins, D. L., & Pethick, D. W. (2010). Quality of lamb meat from the Information Nucleus Flock. *Animal Production Science*, 50(11–12), 1123–1134.
- Watson, R., Gee, A., Polkinghorne, R., & Porter, M. (2008). Consumer assessment of eating quality – Development of protocols for Meat Standards Australia (MSA) testing. *Australian Journal of Experimental Agriculture*, 48, 1360–1367.
- Wheeler, T. L., Cundiff, L. V., & Koch, R. M. (1994). Effect of marbling degree on beef palatability in *Bos taurus* and *Bos indicus* cattle. *Journal of Animal Science*, 72(12), 3145–3151.
- Young, O. A., Reid, D. H., & Scales, G. H. (1993). Effect of breed and ultimate pH on the odor and flavor of sheep meat. *New Zealand Journal of Agricultural Research*, 36(3), 363–370.