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Carcase weight and dressing percentage are increased using Australian Sheep Breeding Values for increased weight and muscling and reduced fat depth.

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Abstract

Pre-slaughter live weight, dressing percentage, and hot standard carcase weight (HCWT) from the 2007, 2008, 2009 and 2010 birth-years of the Information Nucleus Flock Lambs (n=7325) were analysed using linear mixed effects models. Increasing the sire breeding value for post-weaning weight (PWWT), and c-site eye muscle depth (PEMD), and reducing the sire breeding value for fat depth (PFAT) all had positive impacts on HCWT. The magnitude of the PWWT effect was greater in pure bred Merinos compared to Maternal and Terminal sired progeny. The improved HCWT resulting from increased PEMD was entirely due to its impact on improving dressing percentage, given that it had no impact on pre-slaughter live weight. There were marked differences between sire types and dam breeds, with pure-bred Merinos having lower pre-slaughter weight, reduced dressing percentage, and lower HCWT than progeny from Terminal and Maternal sired lambs or progeny from Maternal (1st cross) dams.

Keywords: Lamb; Live weight; Genetic; Maturity; Sire Breed.

1. Introduction

Dressing percentage is the proportion of hot standard carcase weight (HCWT) relative to pre-slaughter weight, expressed as a percentage. This parameter is of particular importance to producers selling on the basis of HCWT as the live weight prior to dispatch combined with dressing percentage and some measure of fatness enables them to more accurately target the carcase specifications of a price grid. However, there is currently no direct method for Australian prime-lamb producers to select for this trait, with the emphasis of selection for carcase traits targeted towards rapid lean growth.

Dressing percentage for sheep can vary markedly, and is impacted upon by a range of factors including nutrition, maturity, wool growth, and breed. Nutrition is of particular importance, leading to variation in gut-fill that can markedly influence visceral weight and therefore dressing percentage. Thus Sheridan et al. (2003) demonstrated that the greater the roughage component of a diet, the greater the associated gut-fill, and the lower the dressing percentage. The effect of maturity on dressing percentage is due to the visceral portion of sheep maturing earlier than the carcase component (Butterfield, 1988). Therefore, older larger lambs will have higher dressing percentages than younger smaller lambs (Hawkins, et al., 1985; Sheridan et al., 2003). Alternatively, when compared at the same weight large mature size lambs will be less mature and therefore have a lower dressing percentage than smaller mature size lambs.

In Australian Merinos, mature size is positively correlated (0.56) with the Australian Sheep Breeding Value (ASBV) for post weaning weight (PWWT) (Huisman & Brown, 2008). Thus it seems likely that the progeny of high PWWT sires will have lower dressing percentages than the progeny of low PWWT sires when compared at the same live weight.

Selection for leanness has also been shown to reduce dressing percentage in pigs (Cliplef & Mckay, 1993; McPhee, 1981). Likewise, Kremer et al. (2004) demonstrated higher dressing percentage in the progeny of Texel sires compared to Corriedale sires, with the Texel breed noted for producing lambs with increased muscling and reduced fatness. However, these studies have compared genotypes that have been concurrently selected for rapid growth, confounding the interpretation of this effect. Within the Australian lamb industry, leanness can be selected for using the

ASBV for post weaning fat depth (PFAT) (Gardner et al., 2010). Thus, if selection for leanness were to affect dressing percentage, we could assume that the progeny of low PFAT sires would have reduced dressing percentage compared to the progeny of high PFAT sires.

Breeds have also been shown to differ in dressing percentage - particularly Merino's which demonstrate consistently lower dressing percentage than first and second cross lambs (Gardner, Kennedy, Milton, & Pethick, 1999; Ponnampalam, Hopkins, Butler, Dunshea, & Warner, 2007). Due to the relatively slow growth of Merino lambs, these studies are often confounded by live weight when the breeds are compared at the same age. Therefore it is possible that this difference merely reflects the smaller and less mature status of the Merino lambs. Fogarty et al. (2000) attempted to overcome this by correcting for carcase weight in an analysis of 2400 lambs. While they were able to demonstrate lower dressing percentage in Merino lambs compared to first cross lambs, there were relatively few lambs at the same weight between the different sire groups creating some uncertainty regarding this comparison. Hence, to confirm that this difference is not merely a reflection of live weight and maturity, research is required where Merino lambs are compared to other breeds at the same weight and the same nutritional history.

This paper analyses data from the Information Nucleus Flock (INF) experiment which has been run by the Australian Cooperative Research Centre for Sheep Industry Innovation (Sheep CRC). We describe the impact of genetic and non-genetic factors on dressing percentage and its components, live weight and carcase weight. We hypothesise that dressing percentage will be higher with increasing pre-slaughter live weight, but will be lower in the progeny of sires with high PWWT breeding values and low PFAT breeding values. Independent of these effects dressing percentages will be lowest in Merinos when compared to other breeds at the same weight.

2. Materials and methods

2.1 Experimental design and slaughter details

The design of the Sheep CRC INF is detailed elsewhere (Fogarty, Banks, van der Werf, Ball, & Gibson, 2007; van der Werf, Kinghorn, & Banks, 2010). Briefly, about 10,000 lambs were produced from artificial insemination of Merino or Border Leicester-Merino dams over a 5 year period (year 2007-2011). The breeding program was undertaken at eight 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 lamb production systems. Lambs born in 4 years (2007-2010) were used for this study. The lambs (Merino, Maternal x Merino, Terminal x Merino and Terminal x Border Leicester-Merino) were the progeny of 363 industry sires, representing the major sheep breeds used in the Australian industry. The sires types included Terminal sires (Hampshire Down, Ile De France, Poll Dorset, Southdown, Suffolk, Texel, White Suffolk), Maternal sires (Bond, Booroola Leicester, Border Leicester, Coopworth, Corriedale, Dohne Merino, East Friesian, Prime South African Meat Merino, White Dorper), and Merino sires (Merino, Poll Merino). After weaning at 90 days of age the lambs were grazed under extensive pasture conditions and supplemented with grain, hay or pellets when pasture was limited, the frequency of which varied between sites (Ponnampalam et al., 2013). All male lambs were castrated.

2.2 Slaughter protocol and HCWT and dressing percentage measurement

At each INF site lambs were consigned to smaller groups on the basis of live weight, with each group killed separately (kill groups) to enable a target carcass weight of 21.5 kg to be achieved. Within a year, we attempted to represent each sire with progeny in each kill group, although due to the slower growth rates in Merinos this was not always possible. Hence of the 112 kill groups in this experiment, 14 consisted entirely of Merino sired progeny, 38 consisted of only Maternal and Terminal sired progeny, and a further 60 consisted of lambs from all three sire types.

At all INF sites, lambs were yarded within 48 hours before slaughter, maintained off-feed for at least 6 hours, and then weighed to determine pre-slaughter live weight. They were then transported for 0.5-6 hours via truck to one of 6 commercial abattoirs, held in lairage at the abattoir for between 1 and 12 hours, and then slaughtered.

All carcasses were electrically stimulated and trimmed according to AUSMEAT standards (Anon, 1992), and hot standard carcase weight (HCWT) was then measured within 40 minutes of slaughter. Dressing percentage was calculated as HCWT divided by pre-slaughter live weight and expressed as a percentage. All lambs were measured and sampled for a wide range of carcass, meat and growth traits including GR tissue depth, loin weight, shortloin fat weight and wool length. GR tissue depth was measured 12 cm from the midline over the 12th rib, and was taken as the total tissue depth above the surface of this rib. To prepare the shortloin (4880), the hind quarter was separated from the carcase by a cut through the mid-length of the sixth lumbar vertebrae. A second cut was then made between the 12th and 13th rib to separate the lumbar section of the saddle which was then split down the midline. Lastly the flaps were removed by a single cut 25 mm from the lateral edge of the *m.longissimus lumborum*. The subcutaneous fat from the shortloin was then dissected and weighed. Then the *m.longissimus lumborum* was dissected from the shortloin and also weighed and recorded as “loin weight”. Wool length of the skin was measured after skin removal and within 6 hours of slaughter, prior to salting (mean±STDEV, min-max; 48.3±25.8mm, 10-150mm).

2.3 Data Analysed

A total of 7849 lambs were slaughtered, with data from 7439 available for analysis of pre-slaughter weight, 7516 available for analysis of HCWT, and 7325 available for analysis of dressing percentage after removing animals with missing data. In particular, data was excluded from analysis of carcase weights and dressing percentage when the carcase was damaged during hide removal or trimmed beyond AUSMEAT standards for HCWT, usually due to grass-seed damage or faecal/urine contamination. Using the trait with the least observations (dressing percentage), the total number of animals recorded at each site are shown in Table 1 as well as their breakdown into subgroups of year, sex, sire type, birth-rearing type, and dam breed within sire type. In addition, Table 2 shows the raw data means, standard deviation, minimum, and maximum values for pre-slaughter weight, HCWT, dressing percentage, and slaughter age within sub-groupings of site, year, sex, sire type, birth-rear type, and dam breed within sire type.

Of the 363 sires used within this study, 76 Maternal, 127 Merino, and 135 Terminal sires had ASBVs for PWWT, PEMD (c-site eye muscle depth), and PFAT, as well as Carcase Plus Index values. The breeding values for PEMD and PFAT are based upon live ultrasound measurement, and PWWT is based upon live weight, all measured at the post weaning time point (about 240 days of age). These values are combined into a single index value (Carcase Plus Index) which is based upon weightings for positive PWWT (0.26), weaning weight breeding value (0.39), and PEMD (0.30), and negative PFAT (0.05). These values were all sourced from Sheep Genetics, which is Australia's national genetic evaluation database for sheep (Brown et al., 2007). The sire breeding values and index estimates were generated within 3 separate data-bases for Terminal, Maternal, and Merino sired progeny. This was from an analysis completed in April 2012, and excluded progeny from the Information Nucleus Flock. Some of the youngest sires used in this experiment lacked industry records and therefore did not have ASBVs available. The ranges for these ASBVs varied within sire types as shown in Table 3.

2.4 Statistical Analysis

Pre-slaughter weight, dressing percentage and HCWT were analysed using linear mixed effects models (SAS Version 9.2, SAS Institute, Cary, NC, USA). The base model included fixed effects and first order interactions for site, year, sex, birth and rearing type (combined term representing animals born as single, twin or triplet and reared as single, twin or triplet resulting in 6 combinations – 11, 21, 22, 31, 32, 33), sire type, dam breed within sire type (all sire types were crossed with Merino dams, but only Terminal sires were crossed with Border Leicester–Merino dams, hence the dam breed contrast was only relevant within Terminal sire types), and kill group within site by year (n=114 kill groups). Sire identification, and dam by year identification were included as random terms, and non-significant terms were removed in a step-wise manner ($P > 0.05$).

To test the association between lamb age at slaughter with pre-slaughter weight, dressing percentage and HCWT this term was included as a covariate in the base model, however in this case the kill group within site by year term was removed as a fixed effect and included as a random term. This is because within each site by year age was confounded by kill group (ie there were no lambs of the same age within separate kill groups, 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 association of slaughter-age to be estimated. All relevant first order interactions between fixed effects and covariate were tested, as was the covariate quadratic effect, and non-significant ($P > 0.05$) terms were removed in a stepwise manner.

Sire Australian Sheep Breeding Values for post weaning weight (PWWT), eye muscle depth (PEMD) and c-site fat depth (PFAT) were also tested for their associations with pre-slaughter weight, dressing percentage and HCWT. Initially, all 3 breeding values were included simultaneously as covariates in the base model, as well as their first order interactions with other fixed terms. Non-significant ($P > 0.05$) terms were removed in a stepwise manner. Due to the correlations that exist between these breeding values in this data set (PWWT vs PEMD = 0.3; PWWT vs PFAT = 0.3; PEMD vs PFAT = 0.1) this process was repeated with the breeding values included one at a time to test the independence of their effects. Furthermore the Carcase Plus index was also tested as a covariate in a separate analysis. This index value was included in the base model, along with its relevant first order interactions with other terms, and non-significant ($P > 0.05$) terms were removed in a stepwise manner.

In order to further explain some of the factors affecting dressing percentage, additional analyses were performed. Given that dressing percentage is known to change with maturity (Butterfield, 1988) the dressing percentage models were also corrected for pre-slaughter live weight to determine whether this explained any of the effects seen. The pre-slaughter live weight and dressing percentage models were also corrected for wool length at the time of slaughter to determine whether the sire type, dam breed, sex, and birth type-rear type effects were simply a reflection of differences in wool growth. Furthermore, given the correlations between yearling greasy-fleece weight breeding value and the carcase ASBVs (+0.16 with PWWT; -0.19 with PFAT; and -0.14 with PEMD), this breeding value was also included in the pre-slaughter live weight and dressing percentage models that included these three carcase ASBVs. Sire yearling greasy-fleece weight breeding values ranged between -31 to 39, and were generated in the same run as the PWWT, PFAT, and PEMD sire breeding values. In all cases, these additional terms were included separately as covariates, along with their first order interactions with fixed effects, and non-significant ($P>0.05$) terms were removed in a step-wise manner.

The residuals from the models for pre-slaughter weight, dressing percentage and HCWT demonstrated no obvious skewing or kurtosis, and thus data was not transformed.

3. Results

3.1 Production effects on pre-slaughter weight – base model

The base linear mixed effects model (Table 4) used 7439 observations of the total 7849 available (after dropping animals with missing data), and described about 70% of the total variance in the data set.

Pre-slaughter live weight of females (46.0±0.18kg) was about 5% lower ($P <$ 0.01; *Table 4*) than males (48.2±0.14kg), although this difference varied between flocks and years by as little as 0.2kg at Struan in 2010, and by as much as 4.8kg for Cowra in 2009. Lamb birth type-rear types differed (P <0.01; *Table 4*), with lambs born and raised as singles being the heaviest (49.1±0.13kg), about 2% heavier than lambs born as a twin but raised as a single (48.0±0.20kg), between 4-6% heavier than lambs raised as twins (47.0±0.13kg for twin born; 46.2±0.29kg for triplet born), and about 9% heavier than lambs born and raised as triplets (45.0±0.30kg). Within the sire types Merino lambs (43.2±0.28kg) were 8% lighter ($P < 0.01$; *Table 4*) than Maternal (46.7±0.23kg) and 16% lighter than Terminal sired lambs (51.4±0.18kg). Likewise within Terminal sired lambs the progeny of Merino dams (49.5±0.20kg) were 7% lighter ($P < 0.01$) pre-slaughter than the progeny of Border-Leicester x Merino dams (53.3±0.20kg).

Pre-slaughter live weights differed markedly between sites (P <0.01; *Table 4*). Lambs at Kirby (50.3±0.21kg) and Katanning (50.0±0.20kg) were on average about 4% heavier, than lambs at Trangie (48.3±0.24kg) and Turretfield (48.2±0.22kg), 9% heavier than lambs at Rutherglen (46.1±0.22kg), and Cowra (46.2±0.24kg), and 14% heavier than lambs at Hamilton (43.7±0.23kg), and Struan (44.2±0.24kg), although these differences varied between years (data not shown). Pre-slaughter weights also differed between years (P <0.01; *Table 4*), with lambs in 2008 (47.4±0.23kg) and 2010 (47.4±0.23kg) 1% heavier than lambs in 2009 (47.0±0.23kg), and 2% heavier than lambs in 2007 (46.5±0.22kg). Within each year at each site there were differences between kill groups (P <0.01; *Table 4*). The average magnitude of these differences was 7.2kg, a magnitude that represented 14% of the mean pre-slaughter live weight. The smallest difference between kill groups at any site for any year was 1.48kg and the greatest difference was 21.5kg (data not shown). As a general trend the older kill groups tended to be heavier, aligning well with the impact of age at slaughter which was associated with a 12kg increase in pre-slaughter weight across the age range (Figure **1**). Wool length at slaughter increased (P <0.05) pre-slaughter live weight by 0.015±0.007kg per mm of wool, but had little impact on any of the differences described above apart from slightly diminishing the difference in weight between kill groups.

3.2 Sire and sire carcase breeding value effects on pre-slaughter weight

Within the base model, sire had a significant impact on pre-slaughter weight (P <0.01), with sire estimates ranging from 49.0 – 54.1kg for Terminal sires, 44.1 – 49.4kg for Maternal sires, and 39.6 – 46.8kg for Merino sires.

When sire PWWT, PFAT, and PEMD ASBV were simultaneously incorporated into the base model only PWWT and PFAT were found to impact pre-slaughter weight (P <0.01). As expected the effect was clearly the strongest for PWWT ASBV which was associated with a pre-slaughter weight increase of 0.46kg per unit increase in PWWT, equivalent to a live weight increase of 10.7kg across the 23 unit PWWT range. The magnitude of this effect varied between sire types (slope of 0.68kg/PWWT for Merino sires compared to 0.37kg and 0.34kg/PWWT for Maternal and Terminal sires), sites (slope range 0.37kg-0.56kg/PWWT), and sexes (slope of 0.41kg/PWWT for wethers, and 0.52kg/PWWT for ewes). Decreasing sire PFAT ASBV also increased pre-slaughter weight by about 2.22kg across the 5 unit PFAT range (0.44 kg/unit PFAT). Incorporating these into the model one at a time made no difference to the magnitude of any of their effects on HCWT.

The Carcase Plus index also demonstrated a positive relationship with pre-slaughter weight (P <0.01) which increased by 0.055kg per Carcase Plus index unit. Similar to the PWWT ASBV effects, this response varied between Sire types (P <0.05) and dam breeds (P <0.05). In the case of sire types, Merinos demonstrated a 7.14kg increase in pre-slaughter weight across their 95 unit range in Carcase Plus values (0.075kg/ Carcase Plus index unit), and Maternal sires increased by 3.71kg across a 60 unit Index range (0.062kg/ Carcase Plus index unit). In contrast the Terminal sires only increased by 2.24kg across their 80 unit Index range (0.028kg/Carcase Plus index unit).

The yearling greasy-fleece weight breeding value had no impact on pre-slaughter live weight when included in the model containing all three carcase ASBVs (ie PWWT, PFAT, and PEMD), or when included in the model containing the Carcase Plus index.

3.3 Production effects on dressing percentage – base model

The base linear mixed effects model (*Table 4*) used 7325 observations of the total 7849 available (after excluding animals with missing data), and described about 73% of the total variance in the data set.

Dressing percentage of females (44.9±0.10%) was about 0.2 dressing percentage units lower ($P < 0.01$) than males (45.1±0.09%). Lambs raised as twins (44.9±0.11%) or triplets (44.7±0.23%) had the lowest dressing percentage ($P < 0.01$), being at most 0.4 of a dressing percentage unit lower than single raised lambs (45.1±0.17%). Within the sire types Merino's (42.7±0.20%) were between 3-4 dressing percentage units lower ($P < 0.01$) than Maternal (45.5±0.16%) and Terminal sires (46.8±0.10%). Likewise within Terminal sired lambs the progeny of Merino dams (46.2±0.13%) were 1.2 dressing percentage units lower than the progeny of Border-Leicester x Merino dams (47.4±0.12%).

Compared to the effects described above, the differences between sites ($P < 0.01$), years ($P < 0.01$), and kill groups ($P < 0.01$) were comparatively larger. The Cowra site (47.1±0.13%) had the highest dressing percentage, followed by Trangie, Hamilton, Struan, and Rutherglen (all between 45.3±0.13% to 46.7±0.2%), Kirby and Turretfield (both at 44.5±0.11%), with Katanning (41.3±0.11%) having the lowest dressing percentage. At each of these sites the dressing percentage differed between years by as little as 0.22 at the Kirby site to as much as 5.92 dressing percentage units at the Struan site.

There was variation between kill groups within all sites ($P <0.01$). On average the maximum difference between kill groups at a site within a year was 3.2 dressing percentage units, with these differences varying by as little as 1.0 dressing percentage units, to as much as 9.5 dressing percentage units (data not shown). As a general trend the older kill groups tended to have higher dressing percentages, aligning well with the impact of age at slaughter ($P <0.05$) which was associated with a 6.0 dressing percentage unit increase across the age range (Figure 2).

When pre-slaughter weight was included in the base model as a covariate it had a marked effect on dressing percentage ($P <0.01$; *Table 4*), particularly in Merino sired lambs which increased by about 0.09±0.012 dressing percentage units per kilogram increase in pre-slaughter weight. This was equivalent to an increase of 3.41

percentage units between 32 and 70kg pre-slaughter weight (Figure 3). This impact was markedly less in Terminal and Maternal sired lambs, increasing by only 0.03±0.010 dressing percentage units per kilogram increase in pre-slaughter weight (Figure 3). The impact of pre-slaughter weight on dressing percentage also differed between dam breeds (P <0.01), and similar to the sire type interaction the effect was greatest in the progeny of Merino dams (0.05±0.009 dressing percentage units per kilogram increase in pre-slaughter weight), and least in the progeny of Border-Leicester x Merino dams (0.01±0.009 dressing percentage units per kilogram increase in pre-slaughter weight). Lastly, the effect of pre-slaughter weight also differed (results not shown) between sites (P < 0.01), years (P < 0.01) and kill groups (P < 0.01).

The inclusion of pre-slaughter weight in the base model had little impact on the effects described above. The only exceptions to this were for the differences between sire types, and birth type- rear type which were reduced by about 30% (for sire type) or eliminated entirely (for birth type- rear type).

The inclusion of wool length at slaughter in the base model also had little impact on the production effects described above, although it marginally diminished the differences between kill groups. For each millimetre increase in wool length, dressing percentage reduced (P <0.05) by 0.008±0.004 dressing percentage units.

3.4 Sire and sire carcase breeding value effects on dressing percentage

Within the base model, sire had a significant impact on dressing percentage (P <0.01), with sire estimates ranging from 45.5 – 47.9% for Terminal sires, 43.5 – 47.2% for Maternal sires, and 42.6 – 44.7% for Merino sires (Figure 4).

When the ASBVs for the sire were incorporated into the base model, all 3 were found to impact. Decreasing PFAT ASBV was associated with a reduction in dressing percentage (P <0.01) in Merino sired lambs which decreased by about 1.4 dressing percentage units across the 3.5 unit PFAT range (Figure 4). This effect was non-existent in Terminal sired lambs, and in Maternal sired lambs the opposite effect was seen with a 3 unit decrease in PFAT associated with an increase of 1.3 dressing percentage units (Figure 4). There was also a positive association (P <0.01) between increasing PEMD ASBV and dressing percentage (coefficient = 0.245±0.047%), which increased by about 1.72 dressing percentage units across the seven unit PEMD range. Lastly there was a positive association (P <0.01) between increasing PWWT

ASBV and dressing percentage, the magnitude of which was greatest in Merino sired lambs (coefficient = 0.127±0.029%), much smaller in terminal sired lambs (coefficient = 0.039±0.025%), and not significant in maternal sired lambs (coefficient = -0.042±0.040%). Across the sire PWWT ranges for Merino (14 unit PWWT range), Terminal (17 unit PWWT range), and Maternal (9 unit PWWT range) sired lambs, this corresponded to changes in dressing percentage of 1.8, 0.66, and -0.38 units. Incorporating these ASBVs into the model individually, made no difference to the effects described above.

When the model containing the 3 ASBVs was corrected for pre-slaughter weight the PEMD and PFAT effects were relatively unchanged, except the PFAT effect within the Maternal sired progeny in which the magnitude was halved. In contrast, the PWWT effect was strongly influenced by the pre-slaughter weight correction. Where previously the PWWT effect had differed between sire types, this was no longer the case with PWWT increasing dressing percentage by the same magnitude (coefficient = 0.038 ±0.017%) across all sire types.

When loin weight (not significant), shortloin fat weight (*P* <0.01), or GR tissue depth (*P* <0.01) were included in the ASBV model, none of these covariates changed the magnitude of the ASBV effects. Shortloin fat weight varied between 10-750g, and GR tissue depth varied between 0-32mm, and across their increasing range were associated with 1.1 and 2.6 units higher dressing percentage.

Similar to PWWT the Carcase Plus Index showed a strong positive effect (*P* <0.01) on dressing percentage particularly for lambs from Merino sires, with much smaller effects in the progeny of Terminal and Maternal sires. Across the range in carcase plus values dressing percentage increased within these sire types by 3.1 dressing percentage units in Merino sired lambs (Carcase Plus range = 70-165), 1.3 dressing percentage units in Terminal sired lambs (Carcase Plus range = 130-210), and 1.1 dressing percentage units in Maternal sired lambs (Carcase Plus range = 90-155). When this model was corrected for pre-slaughter weight the Carcase Plus Index effect on dressing percentage no longer differed between sire types, increasing dressing percentage by 0.021±0.008 per unit increase in Carcase Plus Index value.

The breeding value and Carcase Plus Index effects described above were not affected by the inclusion of wool length at slaughter in the model. Likewise, including the sire breeding value for the yearling greasy-fleece weight also had relatively little effect on the other breeding values, the only effect being to increase the magnitude of the PWWT effect by about 50% in the Merino sired lambs only. The sire breeding value for the yearling greasy-fleece weight was itself significant, with each unit increase reducing dressing percentage (*P* <0.05) by 0.023±0.006 dressing percentage units.

3.5 Production effects on hot standard carcase weight – base model

The phenotypic linear mixed effects model (*Table 4*) used 7516 observations of the total 7849 available (after dropping animals with missing data), and described about 75% of the total variance in the data set.

Within this dataset, HSCW of the males (21.9±0.10kg) was about 1.1kg heavier (*P* <0.01;*Table 4*) than females (20.7±0.11kg), Terminal sired lambs (24.0±0.11kg) were about 2.7kg heavier than the Maternal (21.3±0.18kg) and 5.5kg heavier than the Merino (18.5±0.22kg) sired lambs (*P* <0.01; *Table 4*), and within the Terminal sired group the lambs from Border-Leicester x Merino dams (25.2±0.13kg) were about 2.3kg heavier (*P* <0.01; *Table 4*) than the lambs from Merino dams (22.9±0.14kg).

The HSCW of the single born and reared lambs (22.1±0.08kg) was about 0.5kg heavier than twin born and single reared lambs (21.6±0.12kg), and between 1.0-1.2kg heavier than twin born and reared or triplet lambs (*P* <0.01; *Table 4*). The magnitude of these differences varied between sire types and dam types (*P* <0.01; *Table 4*). In Terminal sired lambs the difference between singles and other birth type-rear types was double that of Merino and Maternal sired lambs, and in lambs from Maternal dams the difference between singles and other birth type-rear types was 50% greater than lambs from Merino dams.

With respect to site, the HCWT for Kirby (22.8±0.12kg), Trangie (22.8±0.08kg), and Cowra (22.1±0.13kg) were on average about 7% heavier (*P* <0.01; *Table 4*) than Rutherglen (21.0±0.13kg), Turretfield (21.4±0.13kg), and Katanning (20.9±0.12kg), and 13% heavier than Hamilton (19.9±0.14kg), and Struan (20.0±0.14kg), although these differences varied between years (data not shown). The HCWT for the 2008 (21.4±0.14kg) and 2009 (21.2±0.14kg) years were about 2% heavier than the 2007 (20.85±0.14kg) year lambs, and 2% lighter than the 2010 (21.7±0.14kg) year lambs (*P* <0.01; *Table 4*). Within each year at each site there were differences between kill groups (*P* <0.01; *Table 4*). The average magnitude of these differences was 4.11kg, a magnitude that represented 20% of the mean carcase weight. The smallest difference between kill groups at any site for any year was 0.79kg and the greatest difference was 14kg (data not shown). As a general trend the older kill groups tended to be heavier, aligning well with the impact of age at slaughter which was associated with a 7.8kg increase in HCWT across the age range (Figure **5**).

3.6 Sire and sire carcase breeding value effects on hot standard carcase weight

Within the base model, sire had a significant impact on HCWT (*P* <0.01), with sire estimates ranging from 22.55 – 25.64kg for Terminal sires, 19.78 – 23.21kg for Maternal sires, and 16.67 – 21.21kg for Merino sires (Figure 6).

When sire PWWT, PFAT, and PEMD ASBV were simultaneously incorporated into the base model all three were found to impact HCWT (*P* <0.01). As expected the effect was clearly the strongest for PWWT ASBV which increased HCWT by 0.24kg per unit increase in PWWT, equivalent to a HCWT increase of 5.52kg across the 23 unit PWWT range. The magnitude of this effect varied between Sire types (slope of 0.35kg/PWWT for Merino sires compared to 0.18kg/PWWT for Maternal and Terminal sires), sites (slope range 0.18-0.30kg), and at some of these sites the magnitude also varied between years (Cowra, Katanning, and Turretfield). Decreasing sire PFAT ASBV increased HCWT by about 1.04kg across the 5 unit PFAT range, and similarly sire PEMD ASBV increased HCWT by about 1.09kg across the 7 unit PEMD range. Incorporating these into the model one at a time made no difference to the magnitude of any of their effects on HCWT.

The Carcase Plus index also demonstrated a positive relationship with HCWT (*P* <0.01), increasing weight by 0.038kg per Carcase Plus index unit (Figure 6). Similar to the PWWT ASBV effects, this response varied between sites (*P* <0.05; slope range 0.030-0.046kg), years (*P* <0.05), and Sire types (*P* <0.05). In the case of Sire types, Merino's demonstrated a 4.15kg increase in HCWT across their 95 unit range in Carcase Plus values, and Maternal sires increased by 3.2kg across a 60 unit Index range. In contrast the Terminal sires only increased by 2.0kg across their 80 unit Index range.

4. Discussion

4.1 Impact of sire Post Weaning Weight breeding value

Contrary to our hypothesis lambs from high PWWT sires had an increased dressing percentage. This effect was particularly marked in Merino lambs, with the magnitude being 3 times that of terminal lambs. The differential effect of PWWT between sire types appeared to be related to pre-slaughter weight. As previously demonstrated (Butterfield, 1988) the visceral portion of a sheep is relatively early maturing, and thus it was not surprising that dressing percentage increased with increasing pre-slaughter weight in this study. However this relationship was particularly strong in Merino’s, the effect being 3 times the magnitude of the Terminal sire type. As would be expected, pre-slaughter weight itself was increased by the PWWT breeding value, however for the Merino sired progeny the magnitude of this effect was double that of Terminal and Maternal sired progeny. Thus the greater change in pre-slaughter weight per unit PWWT combined with the corresponding stronger relationship between pre-slaughter weight and dressing percentage appears to drive the greater impact of PWWT on dressing percentage in Merino lambs. In support of this notion, correcting the ASBV model for pre-slaughter weight removed all differences in PWWT effects between sire types. The stronger association between pre-slaughter weight and dressing percentage, and the generally lower dressing percentage of Merino lambs may suggest that Merino lambs are less mature and therefore at a different stage of their allometric growth at the same age compared to Terminal and Maternal sired progeny. Thus, equivalent changes in weight in a less mature animal are eliciting greater changes in proportional composition compared to a more mature animal. Alternatively, differences in wool growth may explain the greater effect of the PWWT breeding value within Merino sired lambs. However, when these models were corrected for either phenotypic wool length or the breeding value for yearling greasy-weight of fleece, neither diminished the impact of PWWT within Merino sired lambs. Irrespective of the biology explaining these differences, it was the combination of PWWT effects on pre-slaughter weight and dressing percentage that delivered the particularly strong impact of PWWT on carcass weight in Merino lambs, the magnitude of this effect double that seen in Terminal and Maternal lambs. This highlights excellent potential within the Merino breed to increase carcass weight by using high PWWT sires.

In an earlier analysis using data from the first year (2007) of the INF (Gardner et al., 2010) we highlighted a strong negative association between PWWT and dressing percentage within the Maternal sired progeny (coefficient = 0.38 dressing percentage units/ PWWT unit). This appeared to underpin the reduced impact of PWWT on HCWT in the Maternal sired progeny compared to the Terminal sired progeny. In the current analysis of the much larger dataset this effect was no longer present. Although

PWWT was still associated with reduced dressing percentage, this coefficient was not significant and the magnitude was only 10% of that previously reported, and led to no difference relative to Terminal sires in terms of the magnitude of the PWWT effect on HCWT.

Given the importance of PWWT within the carcass plus index (growth has a 65% weighting) it is not surprising that the impact of sire carcass plus index value largely reflected the PWWT responses. Thus it led to an increase in pre-slaughter weight, HCWT, and dressing percentage, with a particularly strong impact in Merino lambs. This represents an important industry message given the reliance of producers on this index value for directing Terminal ram purchase decisions. Currently this index is not commercially available within the Merino industry, yet these results highlight the potential carcase gains that could be made if Merino producers made use of this index, which may be far greater than for producers of Terminal sired lambs.

4.2 Impact of sire Post Weaning Fat Depth breeding value

Relative to PWWT the effects of PFAT were much smaller in total magnitude. Within Merino sired lambs reducing PFAT reduced dressing percentage, aligning well with our initial hypothesis. Yet in contrast to this hypothesis there was no effect in Terminal sired lambs and a positive effect in the Maternal sired lambs. PFAT also increased pre-slaughter weight, however in this case the effect was small and consistent across lambs from all sire types. On this basis it seems unlikely that the impact of PFAT on dressing percentage was merely a correlate of its impact on pre-slaughter weight. This notion is further supported by the unchanged effect of PFAT on dressing percentage when the model was corrected for pre-slaughter weight. Ultimately, reducing PFAT produced a positive effect on HCWT, and similar to its effect on pre-slaughter weight, this was consistent across all sire types. This suggests that the differential effect of PFAT on dressing percentage between the different sire type groups was not sufficient to deliver a variable effect on HCWT. Thus the PFAT effect on HCWT aligns well with its effect on pre-slaughter weight. The association between reducing PFAT and increasing weight may be linked to an increase in mature size. Yet contrary to this assertion, Huisman & Brown (2008) demonstrated little phenotypic or genetic correlation with mature size – albeit in Merino lambs only. Explaining the variable impact of PFAT on dressing percentage is also difficult. It is likely that PFAT has reduced whole carcass adiposity (Gardner et al., 2010) which previous studies have demonstrated would lead to reduced dressing percentage (Atkins & Thompson, 1979). So while this would explain the PFAT effect in Merinos, it does not explain the lack of effect in terminal sired lambs or the positive effect in maternal sired lambs. In the absence of detailed data on the carcass and visceral tissues we cannot provide a definitive interpretation.

4.3 Impact of sire Post Weaning Eye Muscle Depth breeding value

This study demonstrated a positive effect of PEMD on dressing percentage. PEMD was also associated with a marked increase in HCWT, and given that it did not impact on pre-slaughter weight it appears that the increased carcass weight is entirely due to the increased dressing percentage. This result has been reported previously in an analysis using only the first year of the INF data (Gardner et al., 2010). However in this previous analysis the magnitude of the PEMD effect was only half that of the current analysis when compared on a per unit ASBV basis, possibly reflecting the smaller sample size and reduced ASBV range across which PEMD was tested. While the present study focuses on breeding values, there are other studies where high muscled genotypes have demonstrated increased dressing percentage. Abdulkhaliq et al. (2007) demonstrated higher dressing percentages in Dorset cross lambs that were heterozygous for the Callipyge gene compared to non-carrier Dorset, Suffolk and Texel sired lambs. Similarly, Kremer et al. (2004) compared Texel sired lambs with less muscular Corriedale sired lambs and found higher dressing percentage in the Texels. Therefore, the data presented here is consistent both with the earlier analysis of PEMD and with the earlier sire breed focused studies.

We can conclude that prime lamb enterprises maintain a significant production advantage using high PEMD sires, the progeny of which will be a similar weight on farm, yet produce a markedly larger carcass at slaughter. However to realise this advantage producers would need to sell on the basis of carcass weight, and not live weight.

4.4 Impact of sire and dam breed

Aligning with our initial hypothesis, the progeny of Merino sires had markedly lower dressing percentage than the progeny of Terminal or Maternal sires. The average pre-slaughter weight of these progeny was also lower than Terminal and Maternal sired lambs. Although pre-slaughter weight is correlated with dressing percentage, the dressing percentage differences were not explained by live weight differences, with the dressing percentage difference between sire types diminishing only slightly when the model was corrected for pre-slaughter weight. This difference in dressing percentage between sire types compares well with previous studies (Atkins & Thompson, 1979; Gardner et al., 1999; Ponnampalam et al., 2007), however in this case the distinction from these studies is that this result was not confounded by pre-slaughter weight, having been demonstrated in lambs of equivalent weight. Hence, the sire type differences in HCWT were a reflection of both the lighter pre-slaughter weight as well as the lower dressing percentage of Merino sired lambs compared to terminal and maternal sired lambs, with both factors contributing independently to the result.

The impact of dam breed was consistent with the sire type effect, with the progeny of Merino dams having lighter pre-slaughter weights, lower dressing percentage, and lighter HCWT than Cross-bred dams. Although the sire type differences were greater, particularly for the most relevant comparison of Merino versus Maternal sired lambs, this is likely due to the Cross-bred dams consisting of half Merino genetics, diluting the contrast in response. This result aligns well with a study by Kleemann et al., (1990), who demonstrated lower dressing percentages in the progeny of Merino dams compared to Poll Dorset x Merino and Border Leicester x Merino dams. These differences represent a clear production disadvantage of the Merino breed, and in part are likely the result of this breed having received relatively little selection pressure for carcass traits. Hence Merino's have relatively poor PWWT and PEMD breeding values, both of which have been associated with increased dressing percentage. Alternatively, these breeding values do not fully explain the difference in dressing percentage between the sire types, as the difference between them was relatively unchanged when they were compared in a model corrected for PWWT, PEMD, and PFAT. It is likely that this reflects the fact that these breeding values are derived from databases containing just Merino, Maternal, or Terminal sires, and therefore may not provide adequate between breed adjustment.

4.5 Impact of sex, birth and rearing type, and environmental factors

The differences in HCWT between males and females, and between multiple born and reared lambs compared to the rest were largely a reflection of differences in pre-slaughter weight. The dressing percentage differences were quantitatively too small to impact on HCWT, and the birth-rear type effects merely a reflection of the correlation with pre-slaughter weight, being accounted for by the pre-slaughter weight correction. None-the-less it was notable that the difference between single and multiple born and reared lambs was two-fold higher in the progeny of Terminal sired lambs, yet only 50% higher in the progeny of Cross-bred dams when both were compared to Merinos. This highlights maternal nutrition as a key factor to realise the full growth potential of high growth impetus lambs.

As expected, some of the largest effects on dressing percentage and pre and post slaughter weights were for differences between sites. In particular, the magnitude of the dressing percentage differences were sufficient to cause marked re-ranking when comparing site averages for weight between pre and post slaughter. Thus Cowra with the highest dressing percentage had among the lightest average pre-slaughter weights but one of the heaviest HCWT. Conversely, Katanning which had among the heaviest pre-slaughter weights also had the lowest dressing percentage resulting in HCWT that was similar to the average of all sites. These are likely to reflect differences in management practices that would ultimately lead to variation in time-off-feed at different sites, as well as differences in nutrition that would affect gut-fill. Differences in shearing time, and therefore wool-weight, would also have impacted as previously demonstrated by Kirton et al., (1995). However this effect was relatively small, as seen by correcting the model for wool length at slaughter which accounted for only a small part of the difference in pre-slaughter weight and dressing percentage. Part of this variation between sites may also reflect genetic divergence between the ewe flock at each site, however given that the differences between sire types was only as much as 1.2 dressing percentage units, genetic variation between ewe flocks is likely to account for only a small part of the between site variation. Lastly, variation in processing may also have contributed to the site effect. Although all abattoirs employ the same AUSMEAT protocols for trimming carcases, it is possible that there may have been some "operator variation" in how these protocols were applied.

The differences between kill groups are also likely to reflect the same environmental effects as described for site. However, these also strongly reflect the impact of age, with the average age of each kill group within a site varying by as much as 331 days. The impact of age was particularly strong for pre-slaughter weight and HCWT, simply reflecting growth. There was also a marked effect on dressing percentage which increased in older lambs. This response is consistent with previous analyses of dressing percentage (Atkins & Thompson, 1979; Hawkins et al., 1985; Kremer et al., 2004) which demonstrated a positive association with carcass weight – a proxy for age in this study. As already discussed in the context of pre-slaughter weight, this reflects the early maturing growth pattern the visceral tissues relative to live weight (Butterfield, 1988).

4.6 Comparison of effects impacting weight and dressing percentage

A key advantage of this study is the opportunity to quantitatively compare within a large dataset the magnitude of effects for a range of genotype and production traits that are relevant to the Australian lamb industry. Of the factors impacting HCWT, the largest differences were those observed between sire types, particularly for Merino compared to Terminal sired lambs, as well as the impact of the PWWT breeding value across its 23 point range, each differing by about 5.5kg. The environmental/age linked effects of kill group and site were the next most important, with magnitudes that were 75% and 50% of the sire type effect. Dam breed was also important, although it had only 40% the magnitude of the sire type effect. Lastly, the effects of birth-rear type, sex, sire PEMD and PFAT ASBV (across their ranges), and Year were all relatively similar, with magnitudes at about 15-25% of the sire type difference for HCWT. The relative magnitude of these effects was quite similar for pre-slaughter weight, except for PEMD which had no effect.

For dressing percentage the greatest impact was the site effect, with the largest difference between sites equal to 5.8 dressing percentage units reflecting environmental and management differences. This was closely followed by the Sire type effect, particularly comparing Merino's with Terminal sired lambs, their difference being 70% the magnitude of the largest site difference. Kill group and pre-slaughter weight, both age/maturity linked effects, impacted with 35-40% of the magnitude of the largest site difference, and then the genetic effects of PEMD and PWWT ASBV (across their ranges), dam breed, and year all impacted with about 20-30% the magnitude of the largest site difference. Lastly, birth-rear type, sex, and PFAT ASBV (no effect), had the smallest impacts on dressing %, being at most only 5% the magnitude of the largest site difference.

The comparative magnitude of these effects highlights the relative importance of genetics for the weight traits, compared to dressing percentage in which environmental and management factors play a much bigger role. Thus for lamb producers to reliably deliver predictable dressing percentages they must carefully monitor live weights and understand environmental factors. Alternatively the genetic responses do suggest some scope for improving dressing percentage using breeding values and selected sires. Dressing percentage has previously been shown to have a moderate heritability of between 0.25 (Greeff et al., 2008) and 0.4 (Fogarty, Safari, Taylor, & Murray, 2003) in Merinos. Along with the range in sire estimates, this demonstrates good potential for generating a sire breeding value for dressing percentage. Alternatively, given the mostly positive effect of the PWWT, PEMD, and PFAT breeding values, these are likely to be adequate for driving improvement in this trait. Furthermore, because feedback data from abattoirs on hot carcase weight is not currently provided on an individual animal basis, dressing percentage and hot carcase weights are parameters not available for most breeding programs.

5. Conclusion

In conclusion, we have identified and quantified a number of factors that impact on dressing percentage, pre-slaughter weight, and HCWT. The carcase breeding values for PWWT, PEMD, and PFAT all had a positive impact on HCWT, with the PWWT and PFAT effects delivered in part through their impact on live weight, and in part through their impact on dressing percentage. For PEMD the improved HCWT was entirely due to its impact on improving dressing percentage, given that it had no impact on live weight. There were marked differences between sire types and dam breeds, with these differences largely driven by Merino genetics. Generally Merino’s had lower pre-slaughter weights, reduced dressing percentages, and ultimately markedly lower HCWT. Variation in dressing percentage associated with genetic effects appears to indicate potential scope to improve this trait, which may provide additional production advantages for producers already selecting for improved growth rates.

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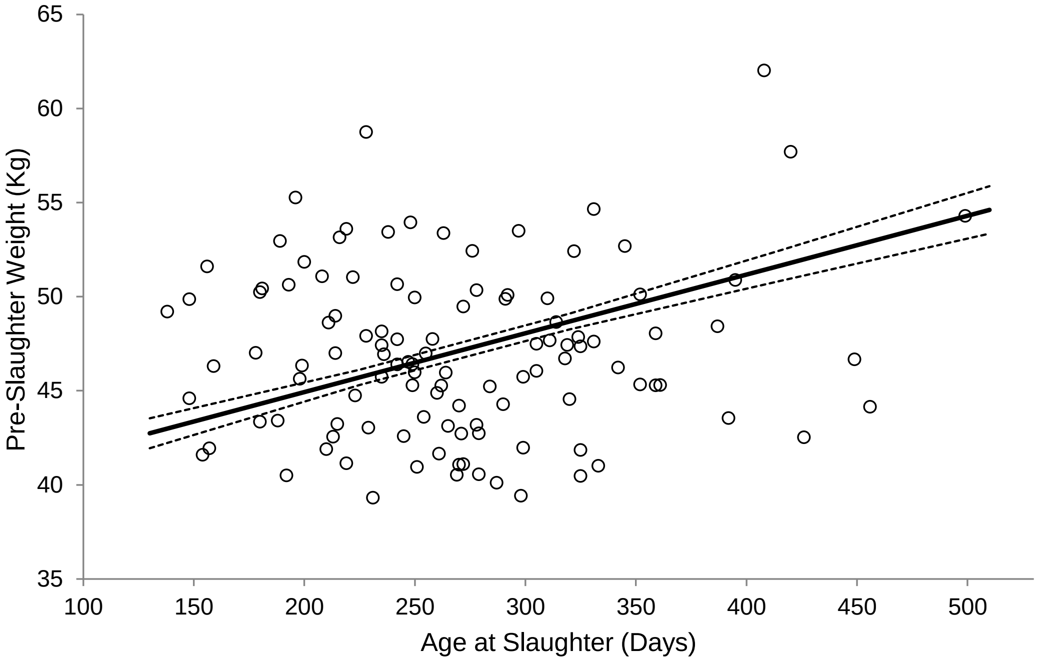

Figure 1. The relationship between pre-slaughter weight (kg) and age at slaughter (days). Symbols (○) represent kill group predicted means plotted against the average age for lambs in that kill group. Lines represent predicted means for age at slaughter (± SE) derived from the base model with kill group used as a random term. Coefficient of line = 0.031±0.005kg.

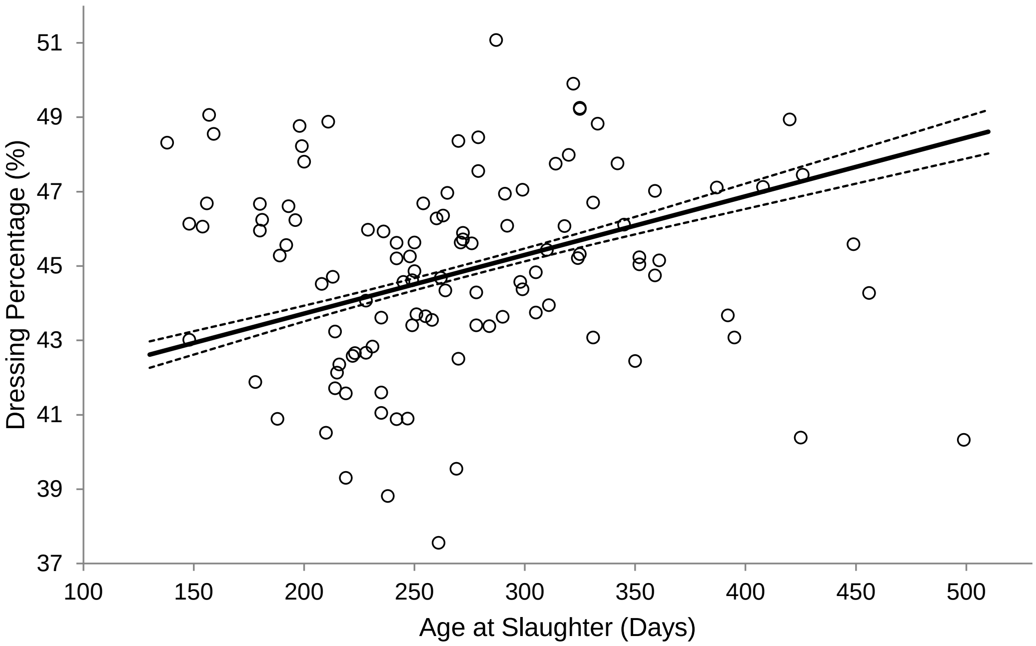

Figure 2. The relationship between dressing percentage (%) and age at slaughter (days). Symbols (○) represent kill group predicted means plotted against the average age for lambs in that kill group. Lines

represent predicted means for age at slaughter (± SE) derived from the base model with kill group used as a random term. Coefficient of line = 0.016±0.007.

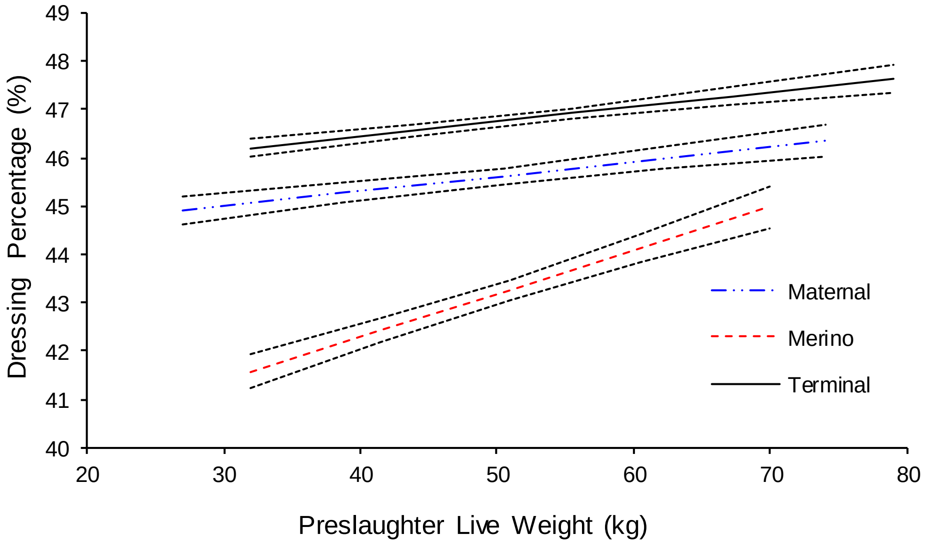

Figure 3 The relationship between live weight pre-slaughter (kg) and dressing percentage (%) within Terminal (coefficient = 0.030±0.007), Maternal (coefficient = 0.030±0.010), and Merino (coefficient = 0.090±0.012) sire types. Lines represent predicted means (± SE).

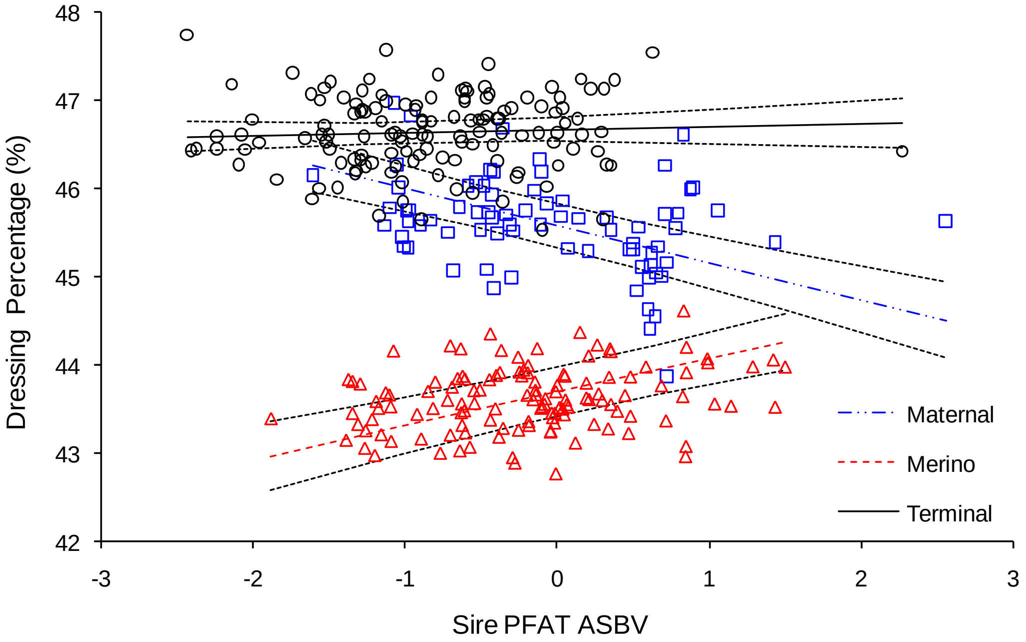

Figure 4. The association between dressing percentage (%) and the post-weaning Australian sheep breeding value for C-site fat depth (PFAT ASBV) within sire types. Lines represent predicted means (± SE), with coefficients of -0.422±0.121 (Maternal), 0.394±0.132 (Merino), 0.038±0.082 (Terminal). Icons represent sire estimates taken from the base model plus the sire type predicted mean for: ○, Terminal sires; □, Maternal sires; Δ, Merino sires.

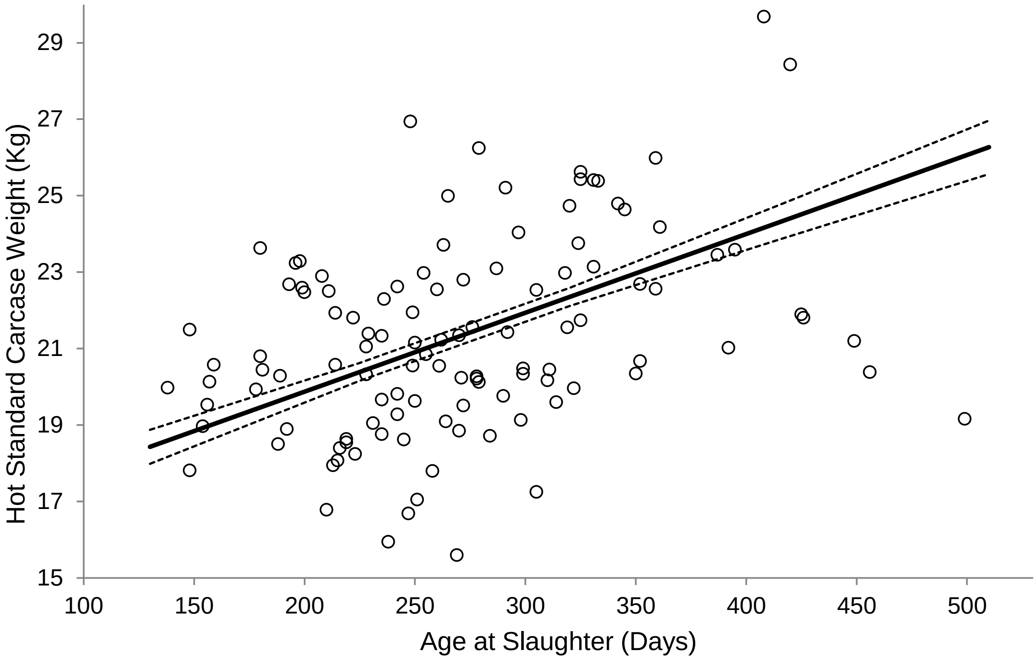

Figure 5. The relationship between hot standard carcase weight (kg) and age at slaughter (days). Symbols (○) represent kill group predicted means plotted against the average age for lambs in that kill group. Lines represent predicted means for age at slaughter (± SE) derived from the base model with kill group used as a random term. Coefficient of line = 0.021±0.003.

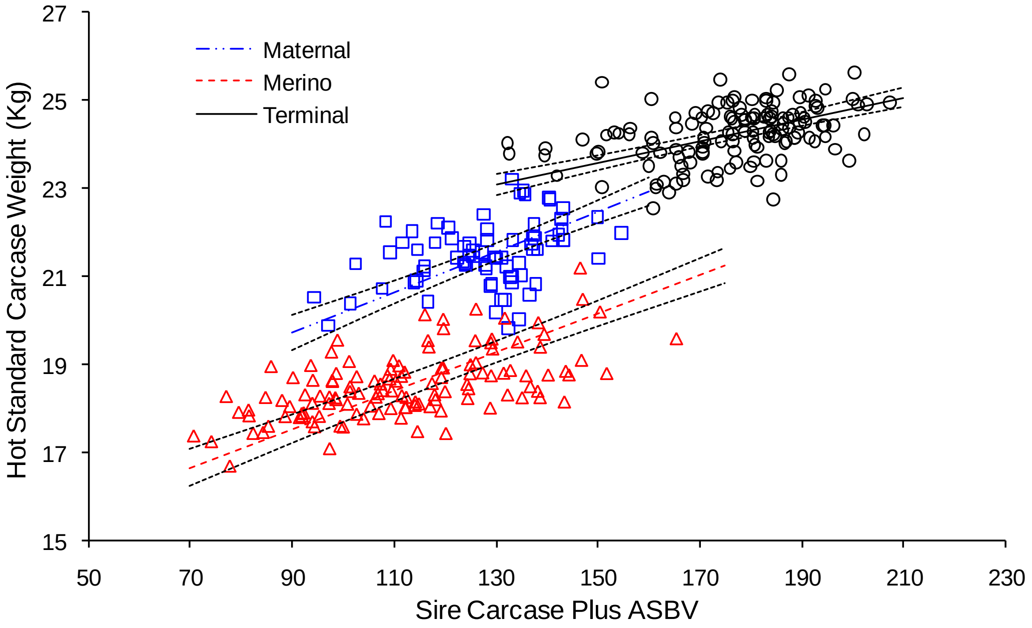

Figure 6. The association between hot standard carcase weight (kg) and the Carcase Plus Index. Lines represent predicted means (± SE), with coefficients of 0.042±0.008 (Maternal), 0.052±0.005 (Merino), 0.021±0.004 (Terminal). Icons represent sire estimates taken from the base model plus the sire type predicted means for: ○, Terminal sires; □, Maternal sires; Δ, Merino sires.

Table 1. Number of progeny analysed in the HCWT and Dressing Percentage analysis at each site according to year, sex, sire type, birth-rearing type and dam breed within sire type. Note: numbers shown reflect data available for the dressing percentage analysis where the data set was smallest.

Site	Year				Sex		Sire type			Birth-rearing type						Dam breed (sire type)				Total
	2007	2008	2009	2010	F	M	Maternal	Merino	Terminal	11	21	22	31	32	33	BLM	MM	TM	TBLM	
Kirby	233	391	279	360	404	859	272	224	767	629	169	441	12	11	1	272	224	324	443	1263
Trangie	0	217	193	199	198	411	117	120	372	124	30	330	8	42	75	117	120	147	225	609
Cowra	284	144	197	185	252	558	147	108	555	185	76	390	15	77	67	147	108	311	244	810
Rutherglen	292	213	208	204	301	616	137	126	654	241	49	526	11	30	60	137	126	115	539	917
Hamilton	192	191	167	180	249	481	130	107	493	355	81	266	4	14	10	130	107	309	184	730
Struan	257	123	172	163	245	470	135	74	506	231	56	362	5	33	28	135	74	105	401	715
Turretfield	261	215	213	235	297	627	183	154	587	282	50	492	5	29	66	183	154	390	197	924
Katanning	359	308	328	362	415	942	325	238	794	542	108	630	10	47	20	325	238	683	111	1357
Total	1878	1802	1757	1888	2361	4964	1446	1151	4728	2589	619	3437	70	283	327	1446	1151	2384	2344	7325

F, female; M, male (wethers); BLM, Border Leicester x Merino; MM, Merino x Merino; TM, Terminal x Merino; TBLM, Terminal x Border Leicester-Merino. Note: numbers shown reflect data available for the dressing percentage analysis where the data set was smallest.

Table 2. Raw mean ± STDEV (min, max) for pre-slaughter weight, HCWT, dressing percentage, and slaughter age.

	Pre-Slaughter Wt (Kg)	HCWT (Kg)	Dressing Percentage (%)	Slaughter age (days)
		Site		
Kirby	54.2±7.18	25.2±4.56	46.0±3.38	312±57.71
	(39.0, 78.2)	(15.4, 40.0)	(34.4, 59.4)	(221, 427)
Trangie	50.3±5.92	23.7±3.14	47.2±2.37	204±60.83
	(34.6, 69.8)	(16.2, 34.7)	(39.2, 53.7)	(145, 346)
Cowra	48.2±5.75	23.2±3.17	48.1±2.60	195±52.17
	(32.8, 68.8)	(14.0, 35.3)	(39.5, 58.8)	(134, 329)
Rutherglen	49.5±4.90	23.0±3.17	46.4±3.05	259±50.12
	(35.8, 65.5)	(14.2, 32.0)	(37.7, 55.8)	(183, 396)
Hamilton	46.7±5.21	21.8±3.19	46.5±3.11	282±60.21
	(27.8, 61.8)	(12.5, 32.2)	(34.9, 53.7)	(187, 460)
Struan	49.0±6.47	22.7±3.74	46.2±3.99	265±46.36
	(32.5, 66.0)	(12.8, 33.6)	(35.6, 59.6)	(205, 430)
Turretfield	50.4±5.88	22.6±3.42	44.6±2.82	261±46.93
	(35.6, 67.6)	(14.6, 34.2)	(37.6, 52.8)	(184, 364)
Katanning	52.0±6.23	22.0±3.44	42.0±3.35	290±87.37
	(33.5, 77.0)	(13.6, 36.0)	(31.1, 54.4)	(173, 504)
		Year		
2007	49.5±6.06	22.5±3.13	45.4±3.42	257±63.52
	(32.5, 77.0)	(12.8, 36.0)	(31.1, 58.8)	(152, 460)
2008	50.7±7.41	22.9±4.38	45.0±3.50	288±90.58
	(33.0, 78.2)	(13.6, 40.0)	(33.4, 55.0)	(134, 504)
2009	50.9±6.78	23.4±3.92	45.6±3.80	260±58.18
	(32.8, 76.2)	(13.4, 40.0)	(32.8, 59.4)	(148, 365)
2010	50.9±5.49	23.5±3.43	46.1±3.90	262±68.10
	(27.8, 67.6)	(12.5, 34.2)	(32.1, 59.6)	(144, 434)
		Sex		
Female	50.4±6.37	23.4±3.61	46.2±3.55	252±58.71
	(32.8, 77.0)	(12.8, 40.0)	(32.1, 58.0)	(134, 434)
Male (wether)	50.5±6.53	23.0±3.83	45.2±3.71	274±76.77
	(27.8, 78.2)	(12.5, 40.0)	(31.1, 59.6)	(134, 504)
		Birth - Rear Type		
11	51.4±6.71	23.3±3.94	45.0±3.80	270±72.12
	(31.4, 77.0)	(13.4, 40.0)	(31.1, 58.8)	(135, 503)
21	50.7±6.39	23.2±3.72	45.7±3.67	272±75.01
	(34.4, 72.2)	(13.8, 37.0)	(35.4, 59.4)	(134, 504)
22	50.1±6.33	23.0±3.71	45.7±3.61	267±71.16
	(27.8, 78.2)	(12.5, 40.0)	(32.1, 59.6)	(134, 503)
31	50.5±6.22	23.4±3.79	46.2±3.74	254±75.05
	(38.2, 66.8)	(15.0, 32.8)	(37.3, 55.4)	(146, 500)
32	48.5±6.01	22.5±3.50	46.2±3.66	258±82.13
	(33.5, 68.5)	(12.8, 33.4)	(35.6, 55.5)	(137, 501)
33	48.9±5.68	23.0±3.15	47.0±2.90	240±61.57

	(34.0, 67.0)	(15.2, 32.9)	(36.5, 54.0)	(139, 454)
Dam breed (Sire type)				
BLM	49.1±6.32	22.1±3.40	44.9±3.45	261±64.56
	(27.8, 73.6)	(12.5, 36.6)	(33.0, 59.4)	(136, 434)
MM	48.4±6.09	21.0±3.45	43.2±3.37	359±66.67
	(32.5, 69.2)	(12.8, 33.8)	(33.6, 56.2)	(187, 504)
TM	50.5±6.53	22.9±3.42	45.4±3.71	246±56.67
	(34.4, 77.0)	(14.8, 38.8)	(31.1, 56.4)	(134, 432)
TBLM	52.4±6.16	24.9±3.68	47.2±3.12	246±56.45
	(32.8, 78.2)	(15.4, 40.0)	(32.1, 59.6)	(138, 434)

BLM: Border Leicester x Merino; MM: Merino x Merino; TM: Terminal x Merino; TBLM: Terminal x Border Leicester-Merino.

Table 3. Minimum, maximum, and mean Australian Sheep Breeding Values (ASBV) and Carcase Plus Index values for the Maternal, Merino, and Terminal sires used in this study.

	PWWT ASBV	PEMD ASBV	PFAT ASBV	Carcase Plus Index
		Maternal Sires		
Minimum	-3.656	-1.44	-1.611	94.34
Maximum	10.486	1.819	2.556	154.56
Mean	5.219	0.141	-0.055	128.122
		Merino Sires		
Minimum	-4.995	-2.018	-1.89	70.62
Maximum	8.386	2.69	1.5	165.32
Mean	1.934	-0.023	-0.197	111.827
		Terminal Sires		
Minimum	1.128	-2.895	-2.439	132.19
Maximum	18.082	4.921	2.274	207.21
Mean	12.157	1.070	-0.834	176.290

Table 4 *F-values for the effects of site, year and kill group within site*year, sex, birth type-rear type, sire type, and maternal type within sire type on Pre-slaughter Weight, Dressing Percentage (%) with and without Pre-slaughter Weight included as a covariate, and Hot Standard Carcase Weight (HCWT; kg).*

Effect	Pre-slaughter Weight Model		Dressing Percentage Model		Dressing Percentage Model – pre-slaughter weight corrected		HCWT Model	
	NDF, DDF	F-Value	NDF, DDF	F-Value	NDF, DDF	F-Value	NDF, DDF	F-Value
Site	7, 1247	224**	7, 1235	480**	7, 1122	3.01**	7, 1310	168.39**
Year	3, 5681	3.44*	3, 5588	17.5**	3, 5586	7.81**	3, 5709	5.11**
Site*Year	20, 1247	51.3**	20, 1235	122**	20, 1122	6.43**	20, 1310	99.64**
Kill group (Site*Year)	81, 1247	52.0**	81, 1235	39.3**	81, 1122	3.96**	83, 1310	59.54**
Sex	1, 1247	309**	1, 1235	10.5*	1, 1122	4.24*	1, 1310	318.6**
Sire type	2, 1247	366**	2, 1235	158**	2, 1122	20.17**	2, 1310	255.88**
Birth type - Rear type	5, 1247	81**	5, 1235	3.2**	5, 1122	1.53	5, 1310	44.81**
Maternal type (Sire type)	1, 1247	532**	1, 1235	74.6**	1, 1122	21.44**	1, 1310	221.02**
Site*Sex	7, 1247	7.47**	7, 1235	3.61**	7, 1122	2.94**		
Year*Sex	3, 1247	3.90**						
Site*Year*Sex	20, 1247	3.06**						
Birth type - Rear type*Sire type					10, 1122	1.87*	10, 1310	3.81**
Birth type - Rear type*Maternal type (Sire type)			15, 1235	1.96*	5, 1122	2.4*	5, 1310	3.02*
Pre-slaughter weight (kg)					1, 1122	41.32**		
Pre-slaughter weight (kg)*Site					7, 1122	2.29*		
Pre-slaughter weight (kg)*Year					3, 1122	7.21**		
Pre-slaughter weight (kg)*Site*Year					20, 1122	4.59**		
Pre-slaughter weight (kg)*Sire type					2, 1122	4.59**		
Pre-slaughter weight (kg)* Maternal type (Sire type)					1, 1122	9.41**		
Pre-slaughter weight (kg)* Kill group (Site*Year)					81, 1122	3.12**		

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

Highlights

- In Merinos, increasing post-weaning weight breeding value increased dressing percentage.
- In Terminal lambs post-weaning weight breeding value had no effect on dressing percentage.
- Increasing post weaning eye muscle depth breeding value increased dressing percentage.
- Reducing post-weaning fat depth breeding value had no effect on dressing percentage.
- Post-weaning weight, eye muscle depth and fat depth breeding values all increased carcase weight.