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National Coordinator – Proof of concept of Lean Meat Yield and Eating Quality Producer Demonstration Sites

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Abstract

The value of the new research breeding values (RBVs) for lean meat yield (LMY), intramuscular fat (IMF), tenderness (SF5), dressing percentage and carcase eye muscle depth and c-fat was determined in 16 prime lamb and three Merino production systems. Lambs were finished according to normal on-farm practices for seven lamb supply chains and processed through 13 plants in NSW, Victoria, Tasmania, South Australia and Western Australia.

The new LMY and eating quality RBVs can be used with confidence in the terminal lamb industry. In terminal lamb production systems, all seven RBVs evaluated increased the correlated trait. In particular, a 1% increase in sire LMY RBV resulted in a 0.3% increase in terminal lamb LMY; a 1% increase in sire IMF RBV resulted in a 0.57% increase in terminal lamb IMF; and a 1N increase in sire SF5 RBV resulted in a 0.7N increase in terminal lamb SF5. There were no negative effects of the RBVs on liveweight or liveweight gain.

The new RBVs have significant value to lamb processors and supply chains. The RBVs can be used to add confidence to product eating quality claims. Nevertheless, although the RBVs are good predictors of comparative LMY and EQ within supply chains, they do not guarantee absolute values – these are affected by environment, sex and processing factors. It is essential that good processing controls are in place to ensure product integrity.

Executive summary

Lamb processors and consumers are demanding increased meat and decreased fat, whilst maintaining lamb eating quality. The lamb industry has made significant genetic change in growth rate, leanness and muscling, but has not been able to efficiently effect manage change in eating quality (EQ) and other hard to measure traits in lamb such as lean meat yield (LMY), dressing percentage or other carcase traits due to the difficulty in measuring and selecting for these traits.

The development of research breeding values (RBVs) for these hard to measure traits by the Sheep Genomics Project, the Sheep CRC and Sheep Genetics may enable the sheep industry to improve LMY and eating quality of lamb simultaneously. The overarching purpose of this project was to deliver “proof of concept” for lean meat and eating quality attributes within major lamb and sheep meat supply chains by facilitating, empowering and developing a common focus and normal trading mechanisms on these future key industry profit drivers right along the supply chain.

Twenty Producer Demonstration Sites (PDS) were established to demonstrate the impact RBVs for LMY and eating quality, particularly intramuscular fat (IMF) and shear force (SF5), will have on lamb production along the supply chain. Eleven site facilitators worked with the producers, four teams worked with the processing plants and collected carcase data, whilst five laboratories objectively measured eating quality (MLA projects B.SCC.0014, B.SCC.0059, B.SCC.0151, B.SCC.0152, B.SCC.0168, B.SCC.0169, B.SCC.0180, B.SCC.0181, B.SCC.0182, B.SCC.0183 and B.SCC.0184).

Ewes inseminated with semen from Poll Dorset, White Suffolk or Merino rams with divergent RBVs for LMY, IMF and SF5 were managed according to Lifetime Ewe Management recommendations. The lambs were weighed monthly until target slaughter specifications were achieved and were processed through 13 abattoirs for seven lamb supply chains.

In terminal lamb production systems, all RBVs evaluated increased the correlated trait. A 1% increase in sire LMY RBV resulted in a 0.31% increase in lamb LMY, as well as a $0.3cm^2$ increase in carcase eye muscle area and 0.2mm decrease in progeny carcase c-fat. LMY RBV did not have an impact on weaning weight, pre-slaughter weight or liveweight gain.

RBVs for eating quality traits can be used to manage eating quality of terminal sired lambs. A 1% increase in sire IMF RBV resulted in a 0.57% increase in lamb IMF and a 1N decrease in sire SF5 RBV resulted in an increase in loin tenderness in lambs equivalent to a 0.7N decrease in shear force. IMF and SF5 RBV did not affect weaning weight or pre-slaughter liveweight. There were no effects of SF5 RBV on terminal lamb average daily liveweight gain.

There were unfavourable effects of LMY RBV on tenderness and SF5 RBV on LMY, such that selection for improved tenderness using SF5 RBV is likely to decrease LMY in terminal lambs and selection for improved LMY using LMY RBV is likely to decrease loin

tenderness. Therefore, both LMY and SF5 RBVs need to be taken into consideration simultaneously in genetic improvement programs in terminal lamb productions systems.

The relationship between RBVs for lean meat and eating quality traits was less clear in Merino production systems. This is most likely due to only three Merino PDS successfully producing lambs for slaughter, with only 24 Merino rams evaluated (compared to 86 terminal rams). Merino LMY RBV increased Merino lamb LMY but there was no effect of IMF or SF5 RBV on Merino lamb IMF or tenderness. It is recommended that further Merino PDS are established to demonstrate that these RBVs can be confidently used in Merino lamb production systems.

The Lamb Value Calculator was used to quantify the value of LMY to processors. The value of LMY to the processor is dependent on hot carcase weight (HCWT) and the degree of value adding. In general, a 1% increase in LMY increased the value of a heavy carcase by approximately 12%, whereas the value increased by 10% in light carcases. In addition, fat score/GR thickness had a greater effect on returns from heavier carcases. The effect of fatness on carcase value increases as fatness increases such that fat score 5 carcases need to be at 2- 3 kg heavier than fat score 2 and 3 carcases to achieve the same return. Grids based on carcase weight and fat depth were developed which could form the basis for value based trading. The carcase weight/fat depth grid is more useful than a straight LMY based grid due to the confounding effects of HCWT and fatness on LMY. If LMY was to be used in value based trading, a grid would need to be developed that incorporates HCWT as this is still a key profit driver to the processor.

Understanding the value of LMY and EQ along the lamb supply chain has been boosted by the involvement of the producers hosting the sites in the processing and measurement of their lambs' carcases. In addition, over 500 people attended information sessions, workshops and field days associated with the PDS to increase their awareness of the value of LMY and EQ to the lamb supply chain.

This project has demonstrated that the newly created RBVs have a significant linear impact on actual values for their respective traits. Genetic selection for LMY, IMF and SF5 RBVs will improve productivity, profitability and efficiency of components of the prime lamb industry that use terminal sires, whilst providing consumers with lamb products a better and consistent eating experience.

Contents

1 Background

Lean meat yield (LMY), the amount of lean muscle tissue that can be boned out from a carcase [1], is an important productivity driver for producers, processors and retailers right along the lamb supply chain. For producers, leaner, higher yielding lambs are able to be finished to heavier weights without becoming over fat and accruing processing penalties [2]. Furthermore, fast growing, high yielding lambs can be finished to target weights in a shorter time frame, resulting in producer savings on feed [3]. Improvements in LMY and growth, in combination with greater muscling, increases efficiency of the boning room for processors, as higher yielding carcases have less carcase wastage and lower labour requirements to trim subcutaneous fat [1]. The production of leaner, more muscular lambs allows retailers to meet consumer's demands for value for money, by displaying cuts of meat with a high quantity of red meat with less bone and subcutaneous fat [4].

Genetic improvements for growth, leanness and muscling have substantially contributed to increased lamb productivity [5], with the average Australian lamb carcase increasing from 17.5kg to approximately 21kg between 1990 and 2006 [6]. LMY, carcase weight and dressing percentage can be improved by using PWT, FAT and EMD ASBVs [2, 7], however it is possible that direct selection for LMY will increase production at a faster rate.

Eating quality of lamb meat is largely driven by tenderness, juiciness and flavour, with consumers both domestically and internationally demanding premium quality and value for money when purchasing prime lamb meat [1]. Meat tenderness (objectively measured as shear force; SF5) and intramuscular fat (IMF) are the two key traits that determine eating quality and therefore consumer satisfaction for lamb [8]. There is a strong association of IMF with juiciness, flavour and tenderness of lamb meat [9], with levels of above 4.5% essential for consumer satisfaction [10, 11].

There is a growing concern that the use of sires that are superior for LMY might have a negative impact on the eating quality of lamb meat for consumers. Genetic selection for leanness and muscling has been linked to declining IMF levels [12], which can have detrimental effects on the eating quality of lamb. This highlights the importance of incorporating eating quality into selection criteria, when selecting sires with increased leanness, so as to not diminish eating quality of lamb for consumers.

Genetic selection for improvements in LMY, IMF and shear force (SF5) in lambs has recently been made possible due to the development of research breeding values (RBVs) by Sheep Genetics Australia for each of these hard to measure traits. However the impact that selection of sires for these newly generated RBVs will have for on-farm production traits, carcase traits and eating quality of their progeny in a commercial production system is not yet known.

The aim of this project is to deliver "proof of concept" for lean meat, eating quality and human health attributes within major lamb and sheep meat supply chains by facilitating, empowering and developing a common focus and normal trading mechanisms on these future key industry profit drivers right along the supply chain. From the Sheep Genomics Program and the Information Nucleus Flock of the Sheep CRC, Poll Dorset, White Suffolk and Merino sires were identified that have divergent RBVs for dressing percent, LMY and eating quality, particularly IMF and SF5.

Proof of concept Producer Demonstration Sites (PDS) were established to demonstrate the impact these new RBVs will have on lamb production along the supply chain. The project was an enormous collaborative effort involving 61 ram producers, 20 PDS hosts, 11 site facilitators, 3 lamb supply chain officers, 7 supply chains, 13 processing plants, 4 slaughter measurement/sampling teams, 5 laboratories, 4 state departments, 3 Universities, Sheep Genetics, Meat & Livestock Australia and private agribusinesses overseen by a project management team. Further information has been presented in MLA Final Reports B.SCC.0014, B.SCC.0059, B.SCC.0151, B.SCC.0152, B.SCC.0168, B.SCC.0169, B.SCC.0180, B.SCC.0181, B.SCC.0182, B.SCC.0183 and B.SCC.0184.

2 Project objectives

The project objective was to deliver "Proof of concept" for lean meat, eating quality and human health attributes within major supply chains by facilitating, empowering and developing a common focus and normal trading mechanisms on these future key industry profit drivers right along the supply chain. This was achieved by:

1. Determining the value of 6 or more new research breeding values for ram breeders, lamb producers & processors at 4 sites by March 2013, and 20-30 sites by March 2014 (amended to December 2014)

2. Developing suitable measurement technology and feedback mechanism for these breeding values at processing by March 2014 (amended to December 2014).

3. Initiating a common focus and fostering the development of normal trading mechanisms on these future key industry profit drivers right along the supply chain by March 2014 (amended to December 2014).

The National Coordinator managed the overall project and the outputs of Site Facilitators of 2 sites in Year 1 and a further 18 sites in years 2/3. Protocols were developed in association with the Project Management Team and the National Coordinator ensured that data was collected in an identical way across sites, preliminary data quality and auditing was undertaken and internal and external communications were managed.

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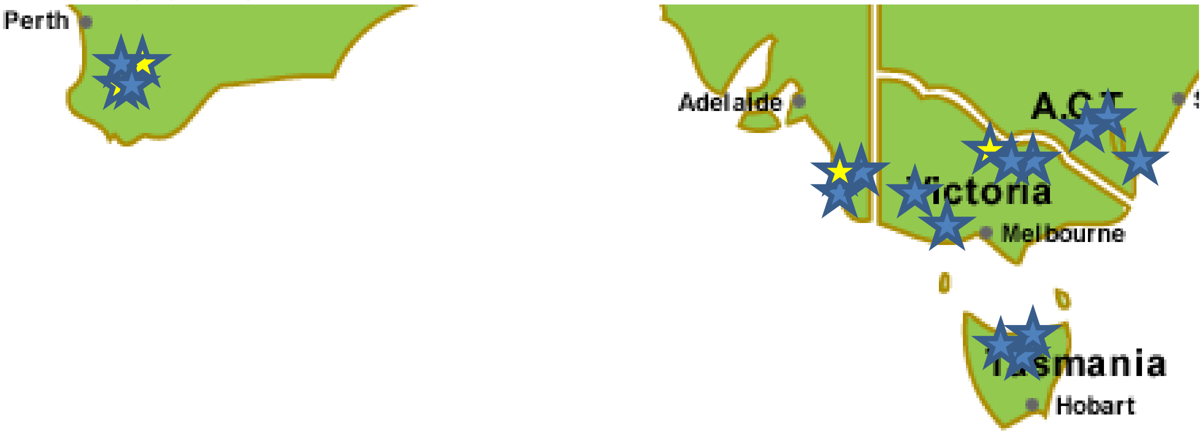
3 Methodology

Animal use in the project was approved by the respective organisational Animal Ethics Committees.

Twenty producers agreed to host producer demonstrations sites (Figure 1). Two sites in Victoria were conducted as pilot sites (March 2012 – April 2013) and the remaining 18 sites were established the following season (November 2012 - October 2014). Eleven site facilitators worked with the producers to implement protocols developed in association with the Project Management Team and the National Coordinator to ensure that data was collected in an identical way across all sites. Four slaughter teams undertook abattoir work and collected carcase data, three laboratories measured IMF and four laboratories measured shear force.

Figure 1. Location of producer demonstration sites (4 Merino sites- yellow stars; and 16 terminal sire sites - grey stars).



3.1 Lamb production

Each of the sites prepared ewes for an artificial insemination (AI) program and commercial AI operators were engaged to undertake the process. Composite, Merino, White Suffolk x Merino, Corriedale, Cormo and Coopworth ewes (N=5752) were mated with semen from terminal sires (Poll Dorset and White Suffolk) at 16 sites and Merino ewes (N=1807) were inseminated with semen from Merino rams at four sites (Table 1).

Rams were selected for divergent RBVs for LMY, IMF and SF5. Eight rams were used at each site with the exception of one site where semen from one sire was unviable so only seven rams were used at this site (PD03). A total of 86 terminal sires (39 Poll Dorset, 47 White Suffolk), one maternal sire (Corriedale) and 30 Merino sires were used. Twenty four terminal sires (9 PD; 15WS) were used at more than one site. In addition, one producer nominated ram (Corriedale) without RBVs was mated at a terminal site (PD13). Sheep Genetics sourced all of the semen and arranged delivery to the AI operators. Sires were given equal opportunity within site with ewes randomised for weight and CS.

Table 1. Location, ewe type, artificial insemination (AI) dates and sire type used at the 20 PDS.

PDS	Location	Ewe type	AI date	Sire type
PD01	Heywood, Vic	Composite	29/30 March 2012	Terminal
PD02	Byaduk, Vic	Composite	22/23 March 2012	Terminal
PD03	Kojonup, WA	Merino	13/14 Dec 2012	Terminal
PD04	Yealering, WA	Merino	5/6 Jan 2013	Terminal
PD05	Woolumbool, SA	White Suffolk x Merino	20/21 Nov 2012	Terminal
PD06	Conmurra, SA	Composite	21/22 Jan 2013	Terminal
PD07	Kotupna, Vic	Composite	6 Feb 2013	Terminal
PD08	Benalla, Vic	Composite	27 Feb 2013	Terminal
PD09	Hexam, Vic	Coopworth	25 Feb 2013	Terminal
PD10	Hamilton, Vic	Composite	4 Mar 2013	Terminal
PD11	Bombala, NSW	Composite	20/21 Mar 2013	Terminal
PD12	Harden, NSW	Merino	4 Apr 2013	Terminal
PD13	Kingsvale, NSW	Corriedale	13 Mar 2013	Terminal
PD14	Wesley Dale, Tas	Kelso	9 Apr 2013	Terminal
PD15	Dungrove, Tas	Cormo	16 Apr 2013	Terminal
PD16	Cressy, Tas	Coopworth	15 Apr 2013	Terminal
PD17	Tincurrin, WA	Merino	29 Nov 2012	Merino
PD18	WA	Merino	15 Feb 2013	Merino
PD19	Keilira, SA	Merino	11/12 Feb 2013	Merino
PD20	Dookie, Vic	Merino	13 Mar 2013	Merino

Sire RBVs were provided by Sheep Genetics from a run completed in September 2014 and did not contain the progeny used in this experiment. RBVs for LMY, IMF, SF5, dressing percentage (DRESS), hot carcase weight (HCWT), carcase eye muscle depth (CEMD) and carcase c-fat (CCFAT) were evaluated. The range in RBVs across the terminal and Merino sites are presented in Table 2a and within each of the sites is shown in Table 2b.

Table 2a. Range across sites of sire RBVs for lean meat yield (LMY), intramuscular fat (IMF), shear force (SF5), dressing percentage (DRESS), hot carcase weight (HCWT), carcase eye muscle depth (CEMD) and carcase c-fat (CCFAT).

	Terminal	
	Range	Difference
LMY (%)	-2.0 to 2.2	4.2
IMF (%)	-0.9 to 1.2	2.1
SF5 (N)	-5.3 to 6.4	11.8
Dress %	-1.3 to 1.2	2.4
HCWT (kg)	-1.7 to 1.5	3.2
CEMD (mm)	-2.4 to 2.2	4.6
CCFAT (mm)	-1.5 to 1.2	2.7
	Merino	
LMY (%)	0.0 to 1.8	1.8
IMF (%)	-0.6 to 0.6	1.2
SF5 (N)	-2.1 to 4.0	6.0
Dress %	-1.5 to 0.8	2.3
HCWT (kg)	-2.4 to 1.9	4.4
CEMD (mm)	-1.3 to 0.7	1.9
CCFAT (mm)	-1.0 to 0.5	1.5

Table 2b. Range within sites of sire RBVs for lean meat yield (LMY), intramuscular fat (IMF), shear force (SF5), hot carcase weight (HCWT), dressing percentage (DRESS), carcase c-fat (CCFAT) and carcase eye muscle depth (CEMD).

	LMY	IMF	SF5	HCWT	DRESS	CCFAT	CEMD
PD01	3.69	1.98	11.75	2.84	1.28	2.03	2.30
PD02	3.69	1.98	11.75	2.84	1.28	2.03	2.30
PD03	3.29	2.10	8.03	1.40	1.05	1.21	2.66
PD04	2.02	1.14	7.01	1.33	1.17	1.25	2.29
PD05	2.34	1.08	7.21	2.92	0.81	1.22	2.05
PD06	3.10	1.19	8.28	2.46	1.69	1.88	2.21
PD07	2.36	1.62	9.08	0.58	1.79	1.26	2.87
PD08	2.78	1.36	9.11	1.70	1.97	1.23	2.31
PD09	2.71	1.62	8.64	1.82	0.95	1.86	3.77
PD10	4.34	1.53	8.64	1.51	1.01	2.31	2.01
PD11	2.32	1.19	6.57	1.44	1.17	1.09	1.24
PD12	1.90	1.11	9.19	1.66	1.25	1.55	2.60
PD13	2.02	0.44	7.69	1.73	1.61	0.68	1.11
PD14	2.60	1.35	7.16	1.23	1.80	1.52	1.51
PD15	1.16	1.28	6.86	1.57	1.64	1.56	2.00
PD16	2.38	1.22	5.28	1.42	0.67	0.64	1.26
PD18	1.69	0.87	4.85	2.63	1.61	1.50	0.93
PD19	1.05	0.82	3.79	2.73	1.43	0.39	1.47
PD20	0.97	0.99	3.70	4.38	1.19	0.79	1.13

Ewes were condition scored prior to AI and light ewes were removed from the flock. All producers managed the ewes to Lifetime Ewe Management (LTEM) targets at mating and through pregnancy (http://www.makingmorefromsheep.com.au/wean-more-lambs/). Subsamples of ewes (30-50) were condition scored during pregnancy to monitor ewe condition (Table 3).

Pregnancy scanning was undertaken by commercial scanning operators approximately 60-70 days after the AI program at each site, to identify ewes carrying single, twins or triplets to AI rams. Ewes were split into single bearing and multiple bearing mobs at all sites at scanning. The ewes remained in these mobs through lambing in order to ascertain the birth type of the lambs. Lambs were tagged with electronic tags and visual identification tags prior to combining lambing mobs two weeks after the completion of lambing or at marking. A small blood sample was collected from the ear of each lamb at marking and sent to a commercial provider for parentage testing (sire only). Lambs were weighed at monthly intervals from marking until slaughter. Pre-slaughter weights (PSWT; kg) were collected on-farm after 1h to 23h curfew prior to transport to the abattoir.

Table 3. Average condition scores of ewes at AI, mid-pregnancy and prior to lambing.

Site	AI	Mid preg	Pre lamb
PD01	3.2	3.6	NR
PD02	3.2	3.0	NR
PD03	>2.5	>2.5	NR
PD04	2.6	>2.5	NR
PD05	4.3	3.9	NR
PD06	3.4	2.9	NR
PD07	3.1	3.5	3.3
PD08	2.6	2.8	NR
PD09	3.5	2.8	2.7
PD10	3.6	3.0	2.7S, 2.8T
PD11	3.1	NR	NR
PD12	2.8	2.7	2.7
PD13	3.1	3.3	3.4
PD14	3.0	3.3	NR
PD15	2.7	2.7	NR
PD16	2.9	2.9	NR
PD17	2.9	>2.5	NR
PD18	>2.5	3.4	NR
PD19	3.5	3.4	NR
PD20	2.9	2.8	2.9S, 2.8T, 2.5Tr

NR – not recorded; S=Single-bearing ewes; T=Twin-bearing ewes; Tr=Triplet bearing ewes

Full details of lamb management at individual sites can be found in MLA Final Reports B.SCC.0014, B.SCC.0152, B.SCC.0059, B.SCC.0169, B.SCC.0168 and B.SCC.0151.

3.2 Carcase measurement

Seven supply chains and 13 processing plants were involved in the processing of the PDS lambs (Table 4).

Table 4. Supply chains and processing plants through which the PDS lambs were slaughtered.

Supply Chain	Processor Location
Woolworths	TFI Murray Bridge GM Scott Cootamundra JBS Devonport V&V Walsh Bunbury
JBS Australia	Bordertown Cobram Brooklyn Longford
Coles	JBS Brooklyn Gundagai Meat Processor
Thomas Foods International (TFI)	Tamworth
WAMMCO	Katanning
Australian Lamb Company	Colac
Frewstal Pty Ltd	Stawell

Carcase and eating quality measurements were undertaken in accordance with those developed by the Sheep CRC [13].

Hot carcase weight (HCWT), and works fat score and/or works GR fat was provided by the processing plant. GR fat (mm) was measured with a GR knife 4-6h post-mortem at the 12th rib, 110mm from the spinal column on the right-hand side of the carcase. Carcases were cut between the 12th and 13th ribs approximately 20 hours after slaughter to expose a cross-section of the *m. longissimus thoracic et lumborum* (LL; Figure 2). Eye muscle width (EMW; mm), eye muscle depth (EMD; mm) and c-site fat (CFAT; mm) were measured with digital calipers (Kincrome, K11100) on the exposed surface of the LL. Eye muscle area (EMA) was calculated from EMW and EMD according to the equation:

$$\text{EMA (cm}^2\text{)} = \text{EMW (mm)} * \text{EMD (mm)} * 0.008.$$

LMY of the carcases were calculated from the algorithm to predict carcase CTLean (%). HCWT, GR depth, cfat thickness, and EMA at the 12th rib were used to calculate LMY according to the equation:

$$\text{LMY} = 61.4844 - 0.0925\,\text{HCWT} - 0.3751\text{GR} - 0.2231\text{CFat} + 0.2923\text{EMA}$$ (G. Gardner *pers.comm*).

At approximately 20h post-mortem, pH levels were recorded in the left *m. longissimus thoracic et lumborum* (LL) at the 13th rib and in the *m. semitendinosus* (ST) as an estimate of ultimate pH.

Figure 2. A PD06 carcase split between the 12th and 13th ribs to allow colour and eye muscle area measurements on the exposed surface of the LL. A 13cm section of LL has been removed from the left side for EQ samples.

Fresh eye muscle colour was measured approximately 21 hours post-mortem on the exposed section of LL that was allowed to ‘bloom’ for 30-60 minutes. A Minolta Chromameter was used to measure lightness (L^*), redness (a^*) and yellowness (b^*).

Pre-slaughter weights (PSWT) were compared to HCWT (kg) at slaughter to calculate dressing percent (DP).

3.3 Shear force and IMF measurements

At approximately 21h post-mortem, 13cm of the left section of the LL was removed from above the 12th rib (Figure 2). From this section of LL, the fat and epimysim were removed and SF5 (65g) and IMF (40g) samples were collected. IMF samples were frozen immediately after collection, and stored at -20^{o}C. The weight of the frozen IMF samples was recorded.

The SF5 samples were vacuum packed and aged at 4-5ºC for five days prior to freezing at -20ºC. PD06 carcases were not electrically stimulated, therefore the SF5 samples were aged at 4-5^{o}C for 12 days before storing at -20^{o}C.

Frozen SF5 samples were placed into a water bath at 71°C for 35min to cook, and then immersed in chilled water prior to processing. The samples were processed according to the methods of Hopkins and Thompson (2001) and a Lloyd LRX machine was used to measure 5-6 1cm^3 sub-samples from each 65g LL sample. Shear force results are presented using the SI unit of force - Newtons (N) - rather than the non SI unit - kgF. Shear force was measured at four laboratories (Lab W, M, S, C; Table 5).

IMF samples were freeze dried and the IMF content was determined using a near infrared procedure [14]. IMF was measured at three laboratories (Lab W, M, A; Table 5).

Table 5. Laboratories where measurement of shear force and IMF were undertaken from each PDS.

Site	Shear force	IMF
PD01	Lab W	Lab W
PD02	Lab W	Lab W
PD03	Lab M	Lab M
PD04	Lab M	Lab M
PD05	Lab S	Lab A
PD06	Lab S	Lab A
PD07	Lab S	Lab A
PD08	Lab W	Lab M
PD09	Lab W	Lab M
PD10	Lab W	Lab M
PD11	Lab C	Lab A
PD12	Lab C	Lab A
PD13	Lab C	Lab A
PD14	Lab S	Lab A
PD15	Lab S	Lab A
PD16	Lab S	Lab A
PD17[1]	-	-
PD18	Lab M	Lab M
PD19	Lab S	Lab A
PD20	Lab W	Lab M

[1] No samples were collected from PD17 due to poor conception rate

3.4 Analysis

For all analyses, data from the terminal PDS were analysed separately to the Merino PDS as there was no linkage between terminal and Merino sites and the RBVs were generated from different datasets in Sheep Genetics.

Live data were recorded on 3,457 lambs across the 16 terminal PDS for weaning weight (WWT) and PSWT with daily weight gain measured from WWT to PSWT. These terms were analysed as dependent variables in a linear mixed effects model in SAS (SAS v9.3, SAS Institute, Cary, NS, USA). The fixed effects included in the model were PDS, sex and their interaction and birth type within site. As birth type was not recorded at PD03 or PD04, birth type within PDS was included as a fixed effect. RBVs for LMY, IMF and SF5 were included as covariates in the model. The curve linear term for each RBV along with interactions with sex and PDS were also included in the models. For the analysis of daily weight gain from weaning to slaughter, the number of days from weaning to slaughter was also included in the analysis as a covariate.

Carcase data were analysed with a linear mixed effects model (SAS v9.3, SAS Institute, Cary, NS, USA). The model included site, kill group within site, birth type within site (single, multiple, unknown) and sex as fixed effects. As birth type was not recorded at PD03, PD04 or PD18 and only male lambs were measured at PD19 and PD20, birth type within PDS was included as a fixed effect in both the terminal and Merino analysis and sex within PDS was included as a fixed effect in the Merino analysis. The curve linear term for each RBV along with interactions with sex and PDS were also included in the models. Breed (PD, WS) was included as a fixed effect in the terminal analysis and sex within site was included in the Merino analysis. Sire was included as a random effect. HCWT and its interaction were included as a covariate in the analysis of CEMA, CEMD, CCFAT, HGRFAT, IMF and SF5. The sire solutions from the analysis of each trait were estimated from the model with the RBV removed.

3.5 Lamb Value Calculator as a tool to develop potential value based trading mechanisms for LMY

HCWT and GR sire solutions from PD01 and PD02 were used in the Lamb Value Calculator (v4.32; developed by Chris Smith) to compare the output with estimated CTLean sire solutions from Phase I. To model a greater range in yield (beyond the range of the sire solutions), data from 24 carcases with GR ranging from 2-20mm were used in the Lamb Value Calculator.

3.6 Value of lean meat yield to processors

The Lamb Value Calculator (v4.32) was used to quantify the impact carcase weight and fatness of lambs on saleable yield processed at an export plant and on saleable yield with two levels of fabrication. From this output, grids based on carcase weight and fat depth were developed which could form the basis for value based trading.

4 Results and discussion

4.1 Determining the value of 6 or more new research breeding values for ram breeders, lamb producers & processors at 4 sites by December 2014

4.1.1 Ewe performance

Condition scores of the ewes generally met Lifetime Ewe targets (Table 3) which is a compliment to the site hosts given the extremely dry conditions experienced through pregnancy nationally. CS ranged from 2.6 to 4.3 at AI and from 2.7 to 3.9 at mid pregnancy. PDS hosts were expected to record CS at AI and at mid-pregnancy in order to manage CS through pregnancy into lambing. Liveweights and pre-lambing CS were optional – only two sites recorded liveweights and six sites measured pre-lambing CS.

Overall, pregnancy rate (65%; proportion of ewes pregnant to AI; Table 6) was lower than that reported for the Information Nucleus (IN) Flock (72%; [15]). Pregnancy rate was highly variable across sites and ranged from 18% to 80%. Four sites which mated early had pregnancy rates less than 50% (PD03; PD04, PD05, PD17). The number of ewes scanned at PD05 is misleading in Table 6, as approximately half of the ewes scanned pregnant to AI failed to lamb during the expected lambing period and were actually pregnant to the backup ram as there was a distinct break of approximately a week between the end of AI lambing and the start of back-up lambing. At these four sites, the AI operators reported that the ewes were cycling and responded well to the pre-insemination programming and were in reasonable condition. PD05 and PD17 both underwent AI in November, prior to the summer solstice which is recognised as the trigger for cycling (decreasing day length), particularly in British breed ewes. The ewes at PD05 were White Suffolk/Merino crossbred ewes, so could have been more susceptible to this. Conversely, the ewes at PD17 were Merino ewes which are less susceptible to day length. Nevertheless it is recommended for future trials involving AI that AI occurs after the summer solstice. In addition to timing, weather events are likely to have had an impact on the AI result, but this is much more difficult to prepare for, due to programming of the ewes commencing 14 days before AI. At the four low success sites, AI occurred on hot days followed by significant weather change through thunderstorms and rainfall within two weeks of AI coinciding with implantation (PD03 41mm rainfall; PD04 37^{o}C; PD05 34^{o}C and dry lightning that caused significant fires; PD17 unseasonably hot and humid weather and over 100mm of rain).

Table 6. Number (N) of ewes inseminated with Terminal or Merino sires, the proportion of ewes pregnant to AI (pregnancy rate; PR), number of foetuses at scanning, the reproductive rate (RR; N foetuses/ewe AI) and the number of lambs weaned (NLW).

	N ewes	PR	N foetus	RR	NLW
Terminal					
PD01	600	70%	636	106%	279#
PD02	591	80%	839	142%	203#
PD03	576	46%	400	69%	270
PD04	321	23%	144	34%	126
PD05	300	*51%	254	85%	72
PD06	300	66%	305	102%	264
PD07	297	66%	304	102%	242
PD08	311	70%	273	88%	254
PD09	297	67%	333	112%	248+
PD10	294	79%	386	131%	284
PD11	317	60%	307	97%	275
PD12	251	60%	216	86%	136
PD13	300	66%	328	109%	265
PD14	300	80%	407	136%	289
PD15	300	71%	295	98%	205
PD16	300	80%	420	140%	347
Merino					
PD17	302	18%	67	22%	45
PD18	317	66%	313	99%	237
PD19	599	80%	689	115%	299#
PD20	589	70%	615	104%	206#
Total	7559	65%	6056	97%	4546

* This is likely an overestimate as a significant proportion of ewes scanned were actually pregnant to the back up ram, rather than to AI rams, determined by time of lambing.
+ Lambs not weaned
# Males only

Average reproductive rate (N foetuses scanned/N ewes AI) across all sites (97%; Table 6) was lower than that reported in the IN (107%) but is at the upper level reviewed in earlier reports [16]. Conception rate (N foetuses scanned/N ewes pregnant) was 149% which is similar to the IN lamb litter size (1.48 lambs born/N ewes pregnant). Overall, the PDS hosts have managed the AI process to a high standard, generally equivalent to that reported elsewhere.

4.1.2 Parentage testing

DNA parentage was used to assign the sires of the progeny across the sites. Doing so allowed the host sites to keep ewes in the one lambing mob and eliminated the need for mothering up.

There were challenges that arose in that not all progeny within the sites were able to be allocated to a sire. There were three major reasons for this:

1. The individual animal's sample did not contain high enough quality DNA to be able to get a reliable sample;
2. The progeny came from sires not used in the trial, ie. backup sires joined on farm; and
3. Issues with the sire genotype.

Of the above three issues the biggest problem that occurred during the project was issues with sire genotypes. Sires that had issues with genotypes required additional work to be able to assign parentage. Some of the issues that occurred were:

1. The genotype on file for the sire was not the sire in question; and
2. The sire has RBVs for eating quality based on progeny test results while not being genotyped itself.

4.1.3 Lamb performance

Liveweights of the lambs were collected at weaning (WWT) and 4 to 8 weekly thereafter (Appendix 1). The majority of sites collected pre-slaughter weights (PSWT) with a range in pre-weight curfew periods (TOFW; Table 7).

Terminal lambs had an average weaning weight of 33.9kg (SD=7.6kg) across the 3690 weaning weight records, with a range from 9.5kg to 59.8kg at weaning (Table 7). Lambs were generally weaned at approximately 100 days with two sites not weaning the lambs and finishing the lambs as suckers (PD05 and PD09). Lambs were weighed at PD09 at 105 days of age and this was used as their weaning weight. There was an average growth rate of 171g/d from weaning to slaughter across the 2761 terminal lambs that had weaning weights and pre-slaughter liveweights. Growth rate from weaning to slaughter ranged from 50g/d (PD08) to 270g/d (PD07, PD09) across 13 terminal PDS. Terminal lambs were killed between 116 to 302 days of age.

Merino lambs had an average weaning weight of 26.4kg (SD=4.9kg) across the 729 weaning weight records, with a range from 12.7kg to 41.0kg at weaning (Table 7). Lambs from PD18 and PD19 were weaned at approximately 100 days and lambs from PD20 were weaned at approximately 140 days of age. Across the three Merino sites, average growth rate from weaning to slaughter ranged from 70g/d to 110g/d. Merino lambs were killed between 234 and 416 days of age.

Table 7. Number of lambs weaned at each site with raw means ± s.d. (min, max) for weaning weight, pre-slaughter weight and daily weight gain from weaning to pre-slaughter and age at slaughter and time off feed and water prior to pre-slaughter weight (TOFW) at each of the producer demonstration sites (PDS).

PDS	N lambs	Weaning weight (kg)	Pre-slaughter weight (kg)	Age (d)	TOFW (h)	Daily weight gain (kg)
PD01	557	36.9 ± 5.5 (16.8, 58.5)	-	165-234	-	-
PD02	233	32.7 ± 5.6 (17.5, 47.5)	-	165-234	-	-
PD03	264	22.0 ± 3.9 (9.5, 31.5)	46.3 ± 6.4 (29.5, 62.5)	162	13	0.22 ± 0.1 (0.11, 0.31)
PD04	126	29.4 ± 3.8 (20.5, 38)	47.6 ± 6.1 (31, 62)	164	13	0.21 ± 0.1 (-0.06, 0.31)
PD05	70	-	44.6 ± 3.9 (35, 56.2)	134-159	16-19	-
PD06	258	40.6 ± 6.1 (22.6, 59.8)	48.8 ± 4.8 (36.1, 64.4)	159-215	17-23	0.11 ± 0.1 (-0.05, 0.30)
PD07	181	40.3 ± 5.3 (23.5, 54)	50.5 ± 4.0 (38.5, 61)	116-145	5	0.27 ± 0.1 (0.11, 0.45)
PD08	191	38.0 ± 4.9 (23, 50.5)	44.6 ± 4.8 (35, 59.5)	126-259	6	0.05 ± 0.2 (-0.13, 0.27)
PD09	253	33.2 ± 5.3 (20.4, 46.3)	44.2 ± 6.2 (28.7, 61)	146	6	0.27 ± 0.4 (0.05, 0.42)
PD10	224	38.9 ± 5.3 (20.5, 51.5)	43.4 ± 4.3 (31, 55)	136	6	0.10 ± 0.4 (-0.16, 0.40)
PD11	217	33.9 ± 5.0 (16.6, 46.2)	46.3 ± 3.4 (38.2, 56.5)	121-167	0	0.19 ± 0.1 (0.04, 0.44)
PD12	131	23.3 ± 3.6 (14, 35.2)	48.8 ± 4.6 (36.5, 59.5)	302	2	0.11 ± 0.1 (0.07, 0.14)
PD13	200	36.2 ± 5.4 (21.3, 55)	51.5 ± 5.4 (37.3, 68)	153-233	9-14	0.20 ± 0.1 (-0.03, 0.47)
PD14	220	32.6 ± 4.4 (12.5, 47.5)	49.0 ± 4.7 (39.5, 65)	152-157	0-15	0.26 ± 0.1 (0.11, 0.49)
PD15	144	35.5 ± 4.6 (20.6, 47.2)	50.5 ± 3.7 (39.2, 64)	238	2	0.12 ± 0.1 (0.04, 0.25)
PD16	188	31.4 ± 4.6 (17.6, 56.5)	47.9 ± 3.1 (36.2, 57)	148-153	1-6	0.23 ± 0.1 (-0.10, 0.32)
PD18	236	30.1 ± 4.5 (17, 41)	49.4 ± 4.3 (37, 62.5)	234-309	13	0.11 ± 0.02 (0.05, 0.18)
PD19	299	23.6 ± 3.8 (12.7, 35.1)	43.7 ± 5.0 (28.3, 61.2)	299-346	19-21	0.09 ± 0.02 (0.03, 0.13)
PD20	193	26.5 ± 4.0 (15.9, 40.9)	45.4 ± 3.9 (36.5, 59)	374-416	6	0.07 ± 0.02 (0.07, 0.12)

The following section was analysed and interpreted by Joshua Barton as part of Bachelor of Science (Honours) The University of Western Australia.

4.1.4 Impact of LMY, IMF and SF5 RBV on the on-farm production traits of terminal sired lambs.

There were no negative effects of the new RBVs on on-farm production traits in the terminal sired lambs. Importantly, there was no decrease in growth rate associated with sires that have increased LMY or IMF RBVs.

The LMY RBV did not significantly impact WWT, PSWT or average daily weight gain ($P > 0.05$), however sex and PDS had an effect on WWT, PSWT and average daily weight gain ($P < 0.001$). The time between weaning and slaughter also had a significant impact on the average daily weight gain ($P < 0.01$).

There was no significant impact of IMF RBV on WWT or PSWT ($P > 0.05$), however sex and PDS did affect WWT, PSWT and average daily weight gain ($P < 0.001$).

IMF RBV was a significant covariate for average daily weight gain from weaning to slaughter (P=0.04). A 1 unit increase in IMF RBV was associated with an additional 16 ± 7.9g/d growth in terminal sired lambs. Growth rate is a strong driver of IMF [8], thus the relationship seen in the current study may simply be a function of better feed rather than an association with genetic growth. Further analysis of this is required.

There was no significant impact of SF5 RBV on WWT, PSWT or average daily weight gain ($P > 0.05$), however sex and PDS did affect WWT, PSWT and average daily weight gain ($P < 0.001$).

4.1.5 Impact of LMY, IMF and SF5 RBV on the on-farm production traits of Merino sired lambs.

There were no negative effects of the new RBVs on on-farm production traits in the Merino lambs, however there was a tendency for LMY RBV to decrease WWT as LMY RBV increased (P=0.08). Furthermore, there was a tendency for PSWT to increase as SF5 decreased (P=0.09). However, when HCWT was included in the analysis as a covariate, HCWT was a significant covariate and the effect of the LMY and SF5 RBV was removed, suggesting that the larger carcases resulting from heavier pre-slaughter weights were increasing tenderness, rather than the SF5 RBV. Similarly, leaner carcases are associated with lighter carcases which most likely come from lambs with lower weaning weights. Therefore it is unlikely that the LMY RBV is directly affecting the weaning weight of the Merino lambs.

Importantly, there was no decrease in growth rate associated with sires that have increased LMY or IMF RBVs.

Slaughter date and birth type within farm had a significant effect on WWT (1>2; P<0.0001) and sex within farm had a significant effect on PSWT (M>F; P=0.005). Within farm, males had a higher growth rate than females (P<0.0001) and there was a significant effect of slaughter date on growth rate (P<0.0001).

4.1.6 Lamb slaughter.

Lambs from 19 sites were slaughtered and measured; two sites in Phase I and 17 sites in Phase II of the project. Overall, 3486 lambs were killed from the 19 sites (2839 terminal sired progeny & 647 Merino sired progeny; Table 8). Individual measurements were not collected on 117 Merino sired progeny from PD19 due to lambs being slaughtered and chilled prior to the slaughter team arriving at the processing plant.

Table 8. Summary of kill date, location, number of lambs slaughtered and the average pre-slaughter weight (PSWT; kg), carcase weight (CWT; kg), dressing percentage (DP) and GR depth (mm).

PDS	Kill date	Location	N	PSWT	CWT	DP	GR
PD01	30/01/2013	PP01	132		20.3		5.1
	9/04/2013	PP01	56		22.1		11.7
PD02	30/01/2013	PP01	62		21.9		9.6
	14/02/2013	PP01	83		21.9		10.5
	5/03/2013	PP01	40		21.7		10.1
	9/04/2013	PP01	14		22.8		14.1
PD03	24/10/2013	PP02	175	49.6	23.1	47%	13.3
PD04	20/11/2013	PP03	120	48.4	23.3	49%	12.6
PD05	30/08/2013	PP04	53	45.3	22.4	50%	13.4
	23/09/2013	PP04	18	42.5	20.2	48%	9.1
PD06	27/11/2013	PP05	126	51.4	23.5	46%	12.4
	22/01/2014	PP05	79	47.6	21.2	45%	9.2
PD07	30/10/2013	PP06	121	50.3	25.9	50%	15.9
	28/11/2013	PP06	71	50.3	25.0	49%	15.3
PD08	28/11/2013	PP06	101	44.0	20.7	47%	9.3
	10/04/2014	PP06	98	46.4	22.8	49%	9.6
PD09	19/12/2013	PP07	200	46.0	21.3	46%	12.6
PD10	17/12/2013	PP08	193	44.4	19.7	45%	7.5
PD11	17/12/2013	PP09	52	49.5	21.4	43%	10.9
	31/01/2014	PP09	143	45.2	20.5	45%	9.8
PD12	10/07/2014	PP06	135	49.8	23.3	48%	12.0
PD13	20/01/2014	PP10	118	49.3	22.7	46%	11.5
	11/04/2014	PP11	122	53.9	24.9	46%	15.1
PD14	06/02/2014	PP12	100	53.4	25.5	48%	14.5
	10/02/2014	PP13	100	44.5	22.7	51%	13.0
PD15	14/05/2014	PP12	132	50.6	22.6	44%	11.3
PD16	05/02/2014	PP12	99	48.9	23.0	47%	11.4
	11/02/2014	PP13	96	46.9	21.2	45%	11.4
Total number of terminal lambs slaughtered			**2839**				
PD18	07/03/2014	PP02	107	49.9	20.5	41%	9.2
	12/05/2014	PP02	92	48.1	20.4	42%	11.6
PD19	07/05/2014	PP04	117	46.6	19.5	42%	
	23/06/2014	PP08	163	42.3	18.9	44%	8.1
PD20	27/08/2014	PP01	111	46.1	18.5	40%	4.4
	08/10/2014	PP06	57	44.5	18.6	45%	5.4
PD17	Not slaughtered - insufficient numbers						
Total number of Merino lambs slaughtered			**647**				

There was a good range in HCWT across sites (Table 9), reflecting the different environments, finishing systems and targets for different supply chains. Terminal lambs had an average HCWT of 22.5kg (SD=2.7kg) across the 2700 carcase weight records, with a range from 14.9kg to 32.4kg and Merino lambs had an average HCWT of 19.3kg (SD=2.4kg) across the 520 carcase weight records, with a range from 12.9kg to 27.0kg.

Terminal carcases dressed at an average of 46.9% (SD=3.15%, min=35.2%; max=60.3%) and Merino carcase dressed at an average of 42.3% (SD=2.90%, min=33.7%; max=51.2%) across the 2341 terminal lambs and the 513 Merino lambs that had both pre-slaughter liveweights and HCWT records (Table 9). Variation across sites is partly due to difference in time off feed and water prior to pre-slaughter weight measurements, as well as total curfew period prior to slaughter and wool length.

GR fat thickness covered the full scale in terminal lambs from 1 to 25mm (equivalent to a fat scores 1-5) with an average of 11.5mm (SD=4.25) across the 2708 carcases measured (Table 9). Merino lambs were leaner and had a smaller range in fatness than the terminal lambs. The Merinos had a maximum fat score of 4, with the range in GR fat thickness between 1 and 20mm and an average of 7.9mm (SD=3.85) across the 524 carcases measured. Terminal lambs had an average carcase c-fat thickness of 3.8mm (SD=1.92; min=0.5mm; max=12mm) across the 2651 lambs with c-fat records. Merino lambs had an average carcase c-fat thickness of 2.6mm (SD=1.71; min=0.1mm; max=11mm) across the 471 lambs with c-fat records.

Carcase eye muscle depth ranged from 18mm to 43mm (mean=31mm; SD=3.7mm) and eye muscle area ranged from 6.6 cm^2 to 26.9 cm^2 (mean=15.6 cm^2; SD=2.46 cm^2) in terminal lambs. Carcase eye muscle depth ranged from 18mm to 37mm (mean=26mm; SD=3.2mm) and eye muscle area ranged from 7.1cm^2 to 20.4 cm^2 (mean=12.6 cm^2; SD=2.14 cm^2). These ranges are very similar to the values in the IN flock [8].

Table 9. Number of HCWT measurements from each producer demonstration site (PDS) along with their raw mean± s.d. (min, max) for hot carcase weight (HCWT), dressing (DP), eye muscle depth (EMD), eye muscle width (EMW), eye muscle area (EMA), GR tissue depth (HGRFAT) and C-site fat (CCFAT).

Terminal	N HCWT	HCWT (kg)	DP (%)	EMD (mm)	EMW (mm)	EMA (cm^2)	HGRFAT (mm)	CCFAT (mm)
PD01	162	21.1 ± 1.87 (16.6, 25.8)	-	27.1 ± 2.84 (20, 35)	63.3 ± 3.50 (55, 73)	13.77 ± 1.88 (9.6, 19.3)	7 ± 4.0 (1, 21)	2.6 ± 1.20 (1, 7)
PD02	172	22.1 ± 1.63 (16.3, 26)	-	30.97 ± 3.18 (21, 43)	63.03 ± 3.60 (53, 74)	15.64 ± 2.07 (10.8, 25.5)	10 ± 3.4 (4, 21)	3.8 ± 1.53 (1, 11)
PD03	160	23.1 ± 2.63 (17.6, 30.9)	46.2 ± 2.20 (39.6, 50.7)	30.5 ± 2.79 (23, 39)	65.4 ± 3.47 (57, 74)	16.0 ± 1.93 (12.0, 21.8)	13 ± 4.2 (5, 23)	4.9 ± 2.1 (1, 11)
PD04	100	23.6 ± 2.86 (17.5, 30.9)	47.9 ± 2.59 (35.2, 53.7)	29.3 ± 2.61 (23, 35)	55.0 ± 5.16 (41, 65)	12.9 ± 2.05 (8.2, 17.2)	12 ± 4.0 (5, 22)	3.2 ± 1.36 (1, 7)
PD05	69	21.9 ± 2.65 (16.8, 30.2)	49.2 ± 2.30 (45.1, 55.1)	32.1 ± 3.43 (25.0, 40.9)	64.3 ± 3.64 (54.5, 72.1)	16.5 ± 2.24 (12.4, 22.6)	12 ± 4.5 (3.5, 24)	3.2 ± 1.6 (1.1, 8.8)
PD06	201	22.7 ± 2.25 (18.6, 29.3)	45.2 ± 2.56 (37.6, 54.5)	29.6 ± 2.82 (21.7, 39.2)	63.1 ± 3.6 (52.8, 71.8)	14.9 ± 2.00 (6.6, 22.0)	11 ± 4.0 (3, 25)	2.8 ± 1.54 (0.5, 8.5)
PD07	192	25.5 ± 2.08 (19.0, 32.4)	50.7 ± 3.11 (40.0, 59.3)	33.1 ± 3.04 (23.0, 40.3)	67.2 ± 3.72 (56.3, 78.7)	17.8 ± 1.95 (13.1, 22.8)	16 ± 3.92 (1, 25)	4.4 ± 1.94 (1, 11)
PD08	198	21.8 ± 2.77 (15.6, 31.6)	48.8 ± 2,46 (40.9, 54.2)	31.0 ± 3.94 (20, 43)	63.8 ± 3.87 (54.0, 74.5)	15.9 ± 2.56 (10.2, 24.7)	9 ± 3.6 (3, 23)	3.7 ± 2.80 (0.5, 11.0)
PDS9	200	21.2 ± 2.80 (14.9, 28.8)	46.1 ± 2.07 (39.1, 53.9)	28.6 ± 2.98 (19, 38)	62.7 ± 3.44 (52, 73)	14.4 ± 1.81 (8.5, 18.5)	13 ± 3.8 (5, 25)	4.1 ± 1.89 (1, 11)
PD10	193	19.7 ± 1.85 (15.1, 24.7)	44.5 ± 2.44 (37.6, 53.1)	27.6 ± 2.89 (20, 35)	64.7 ± 3.61 (55, 76)	14.3 ± 1.89 (9.6, 19.0)	7 ± 2.9 (3, 17)	2.4 ± 1.03 (1, 5)
PD11	195	20.8 ± 1.49 (16.9, 24.5)	44.8 ± 2.11 (39.0, 50.9)	30.3 ± 3.14 (22, 40)	57.2 ± 4.68 (48, 71)	13.9 ± 2.18 (9.2, 22.2)	10 ± 3.1 (4, 19)	3.6 ± 1.41 (1, 9)
PD12	133	23.3 ± 2.54 (16.2, 30.6)	47.9 ± 3.53 (37.3, 60.3)	33.6 ± 3.50 (23, 43)	60.4 ± 3.63 (49, 69)	16.3 ± 2.16 (11.4, 21.3)	12 ± 4.1 (3, 22)	3.5 ± 1.83 (1, 8)
PD13	210	24.1 ± 2.90 (17.5, 31.8)	46.6 ± 2.39 (40.5, 54.7)	33.9 ± 4.21 (18, 43)	63.6 ± 5.10 (50, 75)	17.3 ± 2.7 (9.8, 26.9)	13.5 ± 3.89 (5, 23)	5.8 ± 2.37 (1, 12)
PD14	198	24.1 ± 2.09 (18.8, 30.0)	49.4 ± 2.67 (42.2, 56.2)	33.3 ± 2.79 (27.1, 42.0)	64.0 ± 3.04 (55.7, 74.2)	17.1 ± 1.81 (12.8, 24.89)	13.7 ± 2.98 (5.5, 23.5)	4.6 ± 1.81 (0.9, 11.4)
PD15	132	22.6± 1.81 (18.6, 27.9)	44.7 ± 1.63 (40.4, 50.0)	31.8 ± 2.70 (26.7, 39.7)	66.1 ± 3.54 (58.1, 76.5)	16.8 ± 1.90 (13.2, 24.1)	11.3 ± 3.08 (5.5, 21.5)	3.6 ± 1.48 (1.0, 8.2)
PD16	191	22.1 ± 1.69 (18.6, 28.6)	46.2 ± 2.35 (41.7, 59.1)	30.7 ± 2.80 (24.0, 38.9)	63.8 ± 3.33 (53.7, 72.3)	15.6 ± 1.76 (10.3, 21.3)	11.4 ± 2.88 (5.5, 21.0)	3.5 ± 1.51 (0.9, 11.3)

Table 9 cont. Number of HCWT measurements from each producer demonstration site (PDS) along with their raw mean± s.d. (min, max) for hot carcase weight (HCWT), dressing (DP), eye muscle depth (EMD), eye muscle width (EMW), eye muscle area (EMA), GR tissue depth (HGRFAT) and C-site fat (CCFAT).

Merino	N HCWT	HCWT (kg)	DP (%)	EMD (mm)	EMW (mm)	EMA (cm^2)	HGRFAT (mm)	CCFAT (mm)
PD18	200	20.5 ± 2.12 (14.1, 27)	41.6 ± 2.11 (36.1, 46.1)	26.5 ± 3.42 (19, 37)	63.3 ± 5.78 (50, 77)	13.3 ± 2.31 (7.1, 20.4)	10.3 ± 3.43 (3, 20)	3.5 ± 1.89 (1, 11)
PD19	164	19.0 ± 2.62 (12.9, 26.1)	44.7 ± 2.27 (37.8, 51.2)	26.5 ± 2.49 (20.5, 33.1)	61.8 ± 3.53 (52.3, 77)	13.2 ± 1.68 (8.6, 18.7)	8 ± 3.32 (2.5, 18.5)	2.4 ± 1.24 (0.6, 6.9)
PD20	160	18.5 ± 2.01 (13.9, 24.7)	40.6 ± 2.66 (33.8, 47.1)	24.6 ± 2.97 (18, 33)	57.7 ± 4.04 (44, 68)	11.4 ± 1.62 (7.7, 14.9)	4.7 ± 2.21 (1, 12)	1.5 ± 0.96 (0, 6)

Yield estimates from the PDS lambs are estimates of CTLean, based on an algorithm derived from carcases scanned using X-ray computed tomography (CT) scanning [2], not estimates of boned out yield, hence the PDS LMY estimates are different to cuts-based or boned-out yields. Nevertheless, the estimated LMY are in a similar range to that reported for CTLean in the IN Flock. Terminal lambs had an average LMY of 58.8% (SD=1.87%) across the 2648 lambs that had HCWT, HGRFAT, CEMA and CCFAT measurements, with a range from 54.0% to 63.2% (Table 10). Merino lambs had a higher average LMY of 59.7% (SD=1.71%) across the 466 lambs that had HCWT, HGRFAT, CEMA and CCFAT measurements, with a range from 54.0% to 63.2%

IMF levels were similar to that reported for the terminal lambs IN Flock [8]. Terminal carcases had an average IMF of 4.05% (SD=0.852%, min=1.42%; max=7.98%) across the 1303 lambs measured (Table 10). However, Merino carcases had an average IMF of 4.16% (SD=0.942%, min=2.48%; max=8.58%) across the 312 Merino lambs measured. This is lower than the average of 4.5% previously reported for Merinos [8]. On average, lambs in the PDS were younger at slaughter than in the IN and this may account for some of the difference in IMF levels.

Loins from the LMY & EQ PDS lambs were tougher than loins in the IN flock; the terminal PDS lambs were 10N greater and the Merino lambs were 20N greater than the average shear force of the IN lambs which had a range from 11-95N [5]. Average shear force was 36.9N (SD=13.63N; min=14.2N; max=100.1N) across 1292 terminal lambs and 48.0N (SD=25.61N; min=19.5N; max=132N) across 278 Merino lambs (Table 10). It was noted that there may have been some cold shortening in four of the plants – one of these plants did not have an electrical stimulation unit installed, so the loins were aged for 12 days. Despite this, average shear force at this site (PD06) was still 53.4N. Carcases from PD10, PD12, PD13, PD15 and PD18 all had average shear forces greater than 40N, the level deemed acceptable for consumer satisfaction. As all plants and lambs were MSA accredited, this failure to achieve target levels of tenderness needs to be investigated further.

The pH of the loin, 20-24 hours after slaughter, ranged from 5.08 to 6.62 (mean=5.69; SD=0.154) in terminal lambs and ranged from 5.40 to 6.76 (mean=5.80; SD=0.160) in Merino lambs (Table 10). Fresh colour was measured on 2425 terminal lambs and loin lightness (L^*) ranged from 24.41 to 45.94 (mean=34.93; SD=2.628), loin redness (a^*) ranged from 10.70 to 25.41 (mean=18.30; SD=1.925), and loin yellowness (b^*) ranged from -3.31 to 11.89 (mean=5.55; SD=3.496). Similarly L^* ranged from 21.17 to 41.36 (mean=34.01; SD=2.842), redness ranged from 11.19 to 25.36 (mean=17.65; SD=1.862), and yellowness ranged from -3.81 to 10.29 (mean=3.22; SD=4.202) in the 405 Merino lambs. These raw data are similar to that reported for the IN flock [5].

Table 10. Number of lean meat yield (LMY) and intra muscular fat (IMF) measurements from each producer demonstration site (PDS) along with their raw mean ± s.d. (min, max) for tenderness (SF5), pH of the loin (pHLL) and fresh colour lightness (L*), redness (a*) and yellowness (b*).

	N LMY	LMY	N IMF	IMF	SF5	pHLL	L*	a*	b*
PD01	159	60.3 ± 1.74	82	3.46 ± 0.854	28.7 ± 8.11	5.82 ± 0.282	33.77 ± 2.569	17.05 ± 1.236	8.17 ± 1.228
		(54.6, 63.4)		(1.75, 5.65)	(15.6, 50.4)	(5.43, 6.61)	(28.65, 38.93)	(14.02, 20.28)	(5.15, 11.62)
PD02	171	59.2 ± 1.42	81	3.33 ± 0.893	32.3 ± 8.82	5.6 ± 0.074	35.74 ± 1.903	17.0 ± 1.326	8.65 ± 1.042
		(54.9, 62.4)		(1.42, 6.43)	(19.1, 56.9)	(5.48, 5.78)	(31.83, 41.2)	(13.3, 19.95)	(5.90, 10.94)
PD03	157	58 ± 2.01	66	4.33 ± 0.779	35.9 ± 7.51	5.69 ± 0.084	34.65 ± 1.768	20.16 ± 1.958	0.24 ± 1.101
		(52.7, 62.3)		(3.02, 7.00)	(21.6, 53.0)	(5.56, 6.26)	(30.18, 42.41)	(12.32, 23.7)	(-3.31, 3.38)
PD04	100	57.7 ± 1.73	75	3.85 ± 0.803	34 ± 6.93	5.82 ± 0.075	36.47 ± 1.564	19.43 ± 0.994	0.4 ± 0.922
		(53.1, 61.3)		(2.43, 7.11)	(21.8, 58.9)	(5.67, 6.02)	(32.5, 40.23)	(17.22, 21.47)	(-1.72, 2.31)
PD05	69	58.9 ± 1.86	70	4.09 ± 0.661	34.1 ± 8.32	5.59 ± 0.132	35.35 ± 2.350	18.70 ± 1.250	1.49 ± 1.245
		(53.7, 62.5)		(2.9, 6.43)	(18.9, 57.8)	(5.43, 6.25)	(28.5, 40.70)	(15.2, 21.4)	(-1.40, 5.00)
PD06	188	58.8 ± 1.84	83	4.56 ± 0.693	53.4 ± 13.66	5.83 ± 0.104	33.42 ± 3.122	19.08 ± 2.011	1.04 ± 0.956
		(53.7, 62.1)		(3.28, 6.71)	(28.4, 92.9)	(5.60, 6.16)	(26.54, 40.96)	(14.29, 24.68)	(-1.32, 5.78)
PD07	192	57.5 ± 1.85	80	3.43 ± 0.509	25.0 ± 5.90	5.63 ± 0.108	34.57 ± 1.406	18.83 ± 1.112	9.61 ± 0.876
		(53.3, 63.0)		(2.34, 4.99)	(14.2, 43.0)	(5.43, 6.32)	(30.30, 41.00)	(14.60, 22.000)	(6.30, 11.5)
PD08	196	59.7 ± 1.67	77	3.87 ± 0.946	23.9 ± 7.89	5.81 ± 0.193	35.17 ± 1.5	17.70 ± 1.365	8.76 ± 0.97
		(52.8, 63.0)		(2.2, 6.3)	(14.2, 62.0)	(5.49, 6.62)	(30.40, 40.34)	(13.09, 20.92)	(6.00, 11.74)
PD09	200	58.1 ± 1.74	78	4.81 ± 0.865	26.7 ± 7.76	5.71 ± 0.034	35.58 ± 1.474	18.08 ± 1.111	9.53 ± 0.895
		(52.0, 61.8)		(2.65, 7.61)	(14.9, 58.5)	(5.62, 5.83)	(31.79, 38.47)	(15.79, 21.00)	(6.86, 11.89)
PD10	190	60.5 ± 1.27	81	4.04 ± 0.849	46.5 ± 8.76	5.75 ± 0.093	33.35 ± 1.668	16.58 ± 1.116	8.53 ± 1.06
		(56.1, 63.0)		(2.77, 6.29)	(30.4, 68)	(5.08, 6.12)	(29.00, 37.23)	(13.15, 20.22)	(6.15, 11.01)
PD11	193	59.1 ± 1.46	85	3.97 ± 0.587	30.7 ± 7.44	5.64 ± 0.176	38.78 ± 2.35	17.94 ± 1.600	5.99 ± 1.018
		(54.7, 62.8)		(2.98, 5.74)	(17.6, 51.1)	(5.38, 6.39)	(32.16, 44.08)	(12.79, 22.13)	(2.50, 8.14)
PD12	131	58.8 ± 1.74	110	4.59 ± 0.777	42.1 ± 11.88	5.73 ± 0.167	35.01 ± 1.73	18.37 ± 1.331	6.66 ± 0.771
		(54.5, 62.9)		(3.27, 7.98)	(21.6, 83.4)	(5.46, 6.29)	(30.69, 40.39)	(14.36, 21.83)	(4.32, 8.59)
PD13	182	58.1 ± 2.01	96	4.14 ± 0.677	46.2 ± 18.94	5.65 ± 0.102	35.81 ± 2.782	17.60 ± 2.083	6.23 ± 1.239
		(52.6, 62.7)		(2.73, 6.26)	(19.8, 100.1)	(5.50, 5.99)	(27.67, 45.94)	(10.7, 24.54)	(3.44, 9.16)

Table 10 cont. Number of lean meat yield (LMY) and intra muscular fat (IMF) measurements from each producer demonstration site (PDS) along with their raw mean ± s.d. (min, max) for tenderness (SF5), fresh colour lightness (L*), redness (a*), yellowness (b*) and pH of the loin (pHLL).

	N LMY	LMY	N IMF	IMF	SF5	pHLL	L*	a*	b*
PD14	197	58.1 ± 1.41	81	4.31 ± 0.694	39.3 ± 9.59	5.62 ± 0.137	34.31 ± 2.375	19.19 ± 2.434	3.64 ± 1.346
		(53.5, 61.2)		(2.81, 6.26)	(24.8, 83.2)	(5.39, 6.26)	(28.97, 41.31)	(12.11, 25.41)	(0.48, 7.58)
PD15	132	59.3 ± 1.5	80	3.88 ± 0.767	49.5 ± 14.72	5.65 ± 0.083	32.02 ± 2.637	19.37 ± 1.68	2.28 ± 1.32
		(54.3, 61.8)		(2.57, 6.54)	(22.4, 85.2)	(5.45, 5.9)	(27.09, 38.62)	(15.7, 24.12)	(-0.71, 5.76)
PD16	191	58.9 ± 1.4	78	3.99 ± 0.502	35.6 ± 9.15	5.60 ± 0.143	34.6 ± 2.566	18.06 ± 2.366	2.31 ± 1.81
		(54.5, 62.5)		(3.14, 5.25)	(24.4, 84.3)	(5.34, 6.17)	(24.41, 41.42)	(11.61, 22.63)	(-2.44, 5.67)
PD18	196	58.8 ± 1.65	134	4.2 ± 1.052	38.7 ± 8.25	5.87 ± 0.147	35.66 ± 2.136	17.96 ± 2.043	-1.44 ± 0.958
		(54, 63)		(2.55, 8.58)	(22.6, 63.7)	(5.54, 6.76)	(31.06, 41.22)	(12.69, 25.36)	(-3.81, 0.91)
PD19	112	59.4 ± 1.42	80	3.84 ± 0.719	83.1 ± 19.3	5.80 ± 0.102	31.43 ± 3.038	18.62 ± 1.588	2.00 ± 1.163
		(55, 62.5)		(2.48, 6.33)	(37.0, 132)	(5.65, 6.13)	(21.17, 40.79)	(12.52, 22.77)	(-1.23, 4.4)
PD20	158	61.0 ± 1.04	98	4.36 ± 0.883	28.9 ± 5.25	5.70 ± 0.173	34.45 ± 1.758	16.73 ± 1.404	8.00 ± 0.97
		(57.2, 63.2)		(2.70, 7.61)	(19.5, 43.6)	(5.40, 6.22)	(30.17, 41.36)	(11.19, 19.97)	(4.95, 10.3)

4.1.7 The effect of sire RBV on progeny performance.

In terminal lamb production systems, all RBVs evaluated significantly increased the correlated trait in the progeny. Relationships were less clear in the Merino systems.

Sections 4.1.8 – 4.1.14 describe the effect of 7 new RBVs (LMY, IMF, SF5, HCWT, DRESS, CEMD and CCFAT) on the same trait in the progeny (eg the effect of *LMY* RBV on the *LMY* of the lambs) as well as the fixed effects for terminal and Merino lambs. The fixed effects tables for the LMY, IMF and SF5 RBVs are in Appendix 2 and the tables for HCWT, DRESS, CEMD and CCFAT RBVs are in Appendix 3.

Section 4.1.15 – 4.1.16 describes the effect of the key RBVs (LMY, IMF and SF5) on the alternate LMY and eating quality traits (eg the effect of *LMY* RBV on *tenderness* and *IMF*) and on other carcase and eating quality traits of interest in terminal lambs (HCWT, EMD, EMA, CCFAT, HGRFAT, pH and fresh colour). The fixed effects tables for the LMY, IMF and SF5 RBVs the carcase traits and eating quality traits are in Appendix 4-6. Similar results are not reported for the Merino lambs, as the value of the new RBVs in Merino production systems was less clear due to;

- only three sites producing sufficient lambs for measurement;
- only 24 sires being represented across the three sites; and
- no linkage between sires across the sites.

4.1.8 LMY RBV and progeny performance.

4.1.8.1 Terminal sires.

Terminal sires had a significant effect on LMY of their progeny (P<0.0001). When LMY RBV was included as a covariate, the RBV had a significant effect on progeny LMY (P=0.0007). Across a 3% LMY RBV range, progeny LMY increased by 0.93 units of LMY, resulting in a 0.31 ± 0.090% increase in LMY associated with 1% increase in LMY RBV (Figure 3). There was no effect of breed on LMY, and there was no interaction between LMY RBV and breed. This means that terminal lamb producers that select rams based on their LMY RBVs can expect an effect on the LMY of the lambs that are produced.

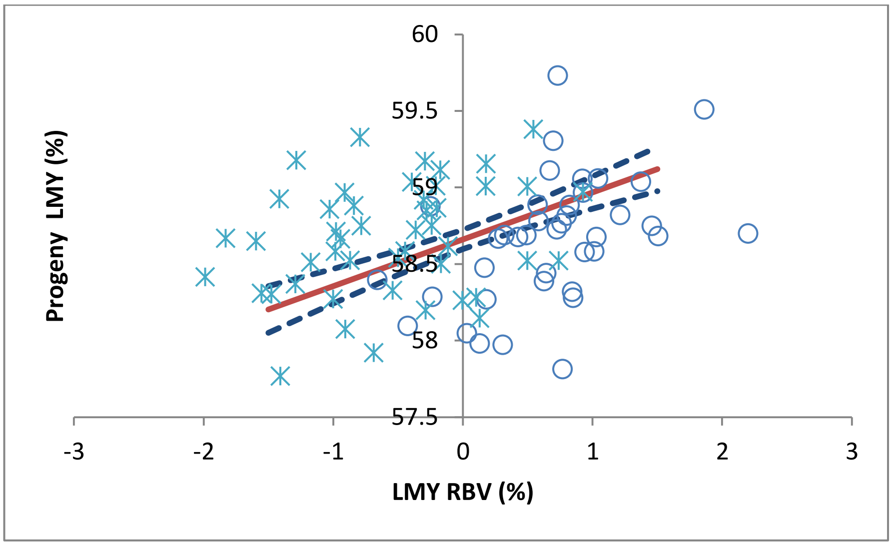


Figure 3. Relationship between LMY RBV and sire estimate for LMY. Solid lines represent least square means of the sires for LMY RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing LMY RBV. Circle = PD, Cross = WS.

Slaughter date within PDS had a significant impact on LMY (Figure 4a; P<0.0001). Of the ten farms that had multiple slaughter dates, lambs from the first kill had significantly higher LMY than lambs from the second kill from five farms, however from three farms, lambs from the first kill had significantly lower LMY than lambs from the second kill. Lambs from two farms had the same LMY at both of the kills. There was also an interaction between PDS and sex (P=0.001) and birth type within PDS (P<0.0001). Twins had higher LMY at PD07 (PD<0.0001), whereas singles had a higher LMY at PD15 (P=0.016)

HCWT had a significant impact on LMY (P<0.0001; Figure 4b). As the HCWT of the lamb increased from 18kg to 30kg, LMY decreased from 60 ± 0.1% to 56 ± 0.1%. Therefore, for every 1kg increase in HCWT, there was a 0.3 unit decrease in LMY. There tended to be a significant interaction between HCWT and PDS (P=0.06) and HCWT and sex (P=0.002) on LMY. There was more of an impact of HCWT on LMY in females than in males. As female HCWT increased from 18 to 30kg, LMY decreased from 60 ± 0.1% to 55 ± 0.2%, whereas, as male HCWT increased from 18 to 30kg, LMY decreased from 60 ± 0.1% to 57 ± 0.1%.

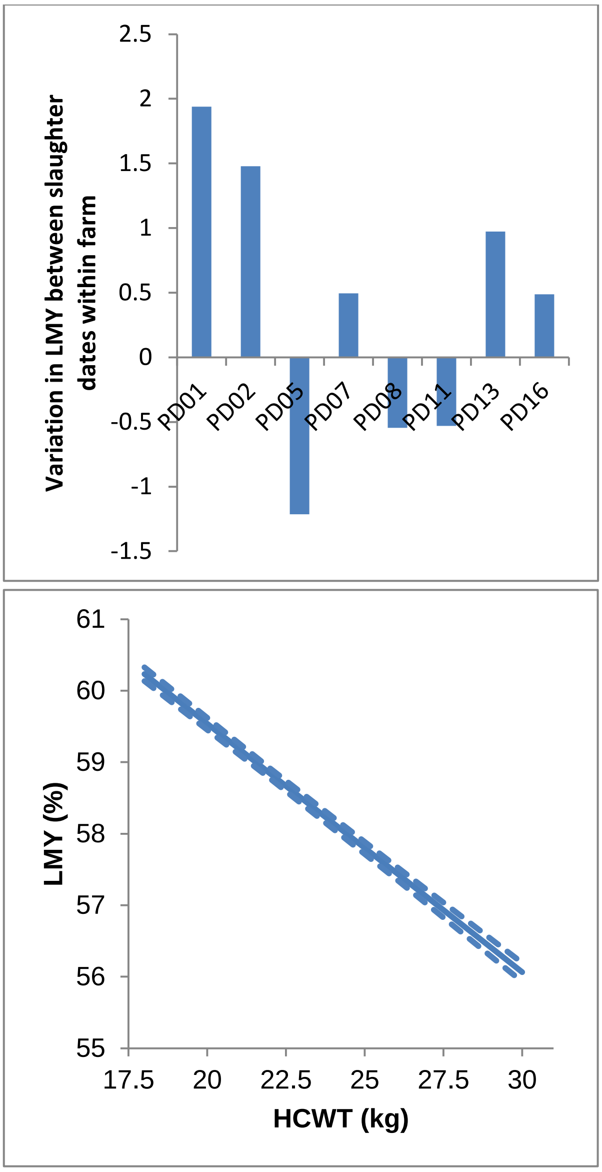


Figure 4 (a). Difference in LMY between first kill and final kill at eight farms and (b) the relationship between LMY and HCWT in terminal sired lambs.

4.1.8.2 Merino sires.

Sires had a significant effect on LMY of their progeny (P=0.035). When LMY RBV was included as a covariate, the RBV had a significant effect on progeny LMY (P=0.036). Across a 1% LMY RBV range, progeny LMY increased by 0.42 ± 0.200 units of LMY (Figure 5a).

There was no effect of PDS on LMY of Merino lambs. Slaughter date within PDS had a significant impact on LMY (P<0.0001). At PD18, the LMY was 1.3 ± 0.18% higher at the first kill compared to the second kill. PD19 only had a single kill at which measurements were undertaken and there was no difference in LMY between kills at PD20. PD19 & PD20 only measured male lambs and at PD18, female lambs tended to have a lower LMY than male lambs (0.3 ± 0.18%; P=0.09).

HCWT had a significant impact on LMY (P<0.0001; Figure 5b). As the HCWT of the lamb increased from 16kg to 26kg, LMY decreased from 61.0 ± 0.14% to 57.7 ± 0.20%. Therefore, for every 1kg increase in HCWT, there was a 0.3 unit decrease in LMY. There also tended to be a significant interaction between HCWT and PDS (P=0.06) on LMY.

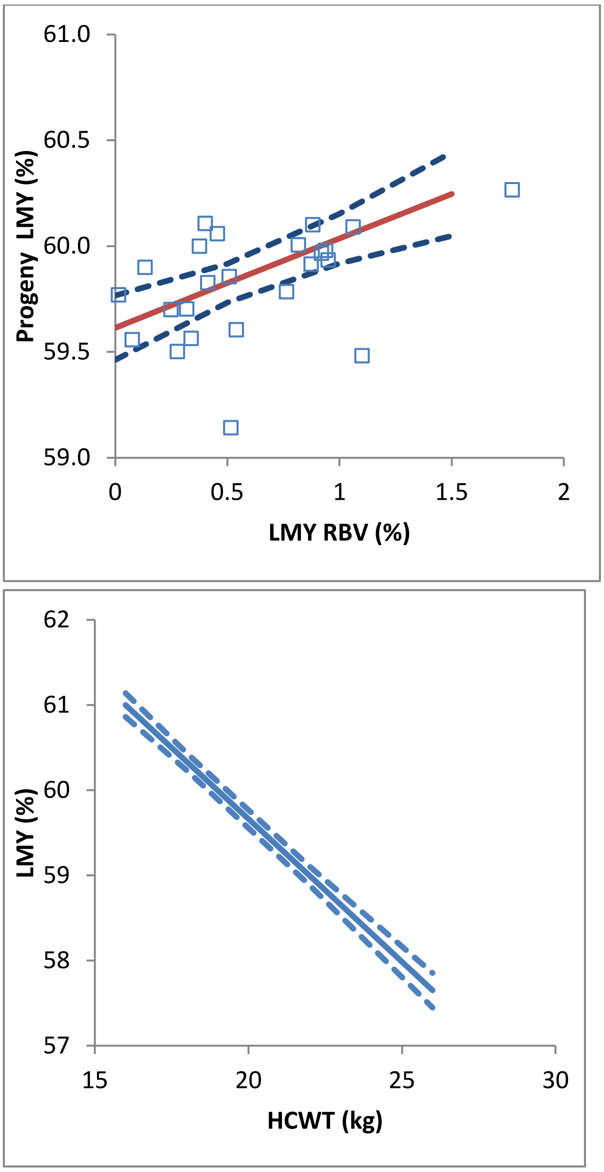


Figure 5 (a) Relationship between LMY RBV and sire estimate for LMY in Merino lambs. Solid lines represent least square means of the sires for LMY RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing LMY RBV and (b) relationship between LMY and HCWT in Merino lambs.

4.1.9 Relationship between IMF RBV and progeny performance.

4.1.9.1 Terminal sires.

Sire was a significant covariate for IMF (P=0.0002). When IMF RBV was included as a covariate, the RBV had a significant effect on progeny IMF (P<0.0001). Across a 1.5% IMF RBV range, progeny IMF increased by 0.86 units of IMF, resulting in a 0.57 ± 0.097% increase in IMF associated with 1% increase in IMF RBV (Figure 6). The use of the IMF RBV is likely to illicit a more rapid change in IMF levels than using PFAT ASBV which achieves between 0.1% IMF to 0.17%IMF per mm PFAT [8, 17]. Additionally, use of the IMF RBV may enable IMF and subcutaneous fat to be managed independently.

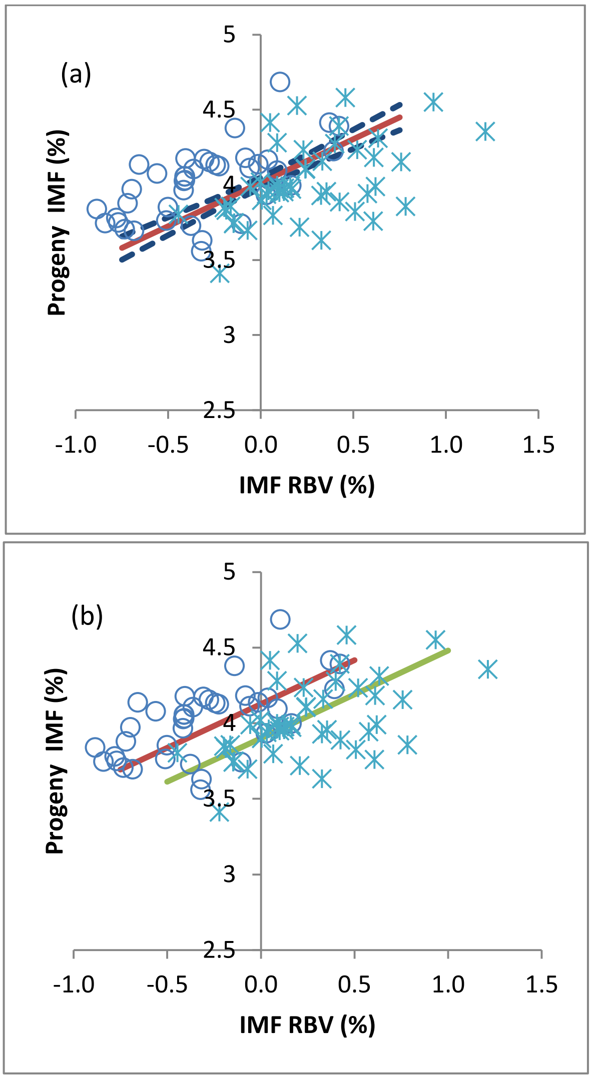


Figure 6. Relationship between intramuscular fat (IMF) RBV and sire estimate of progeny IMF. Solid lines represent (a) least square means of the sires for IMF RBV and dashed lines are the SEM and (b) red lines represent PD sires, green line represents WS sires. Sire estimates are obtained from the model not containing IMF RBV. Circle = PD, Cross = WS.

Progeny from Poll Dorset rams had 0.22±0.092 units more IMF than lambs from WS sires (P=0.0145) at the same IMF RBV (Figure 6b). There was no interaction between IMF RBV and breed, indicating that the effect of IMF RBV on IMF of the progeny is the same across the two terminal breeds. It is important to note, that despite the difference in IMF between breeds, there is an overlap in IMF of the progeny across the breeds.

Sex, PDS and HCWT had a significant effect on IMF (P<0.0001). Female lambs had 0.17 ± 0.041 units more IMF than males. PD01, PD02, PD07 and PD08 had significantly lower IMF than all other sites and PD06, PD09, PD10 and PD12 had significantly higher IMF than all sites (Figure 7a). As the HCWT of the lamb increased from 18kg to 30kg, IMF increased from 3.8 ± 0.08% to 4.5 ± 0.10% (Figure 7b). Therefore, for every 1kg increase in HCWT, there was a 0.06 unit increase in IMF. These effects are similar to those reported for the IN Flock [8].

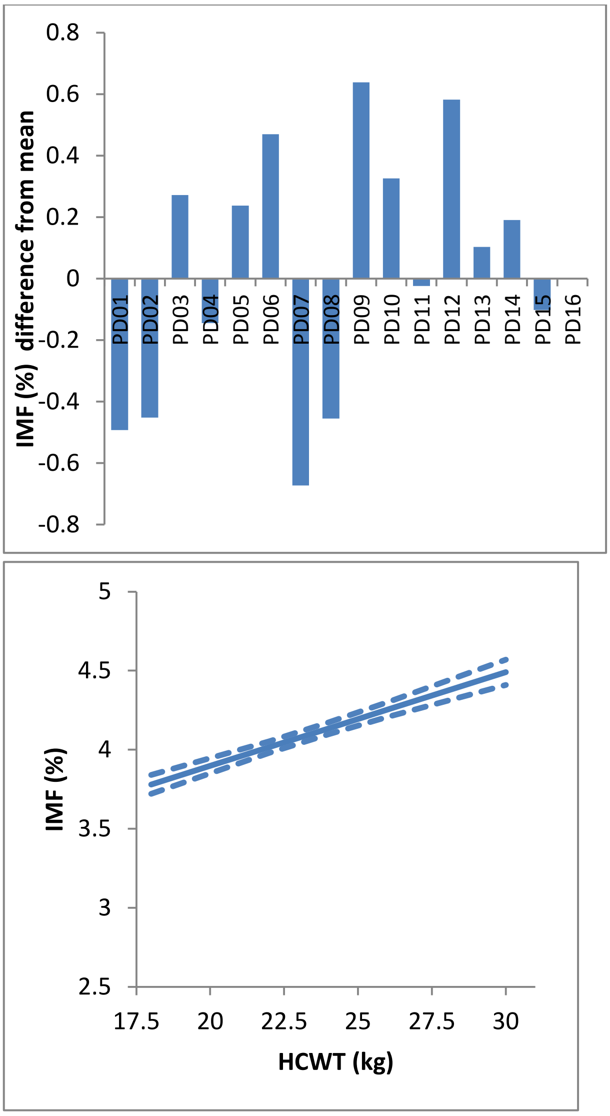


Figure 7. (a). Difference in IMF of lambs between PDS and (b) relationship between IMF and HCWT in terminal sired lambs.

4.1.9.2 Merino sires.

Merino sire had a significant effect on IMF (P=0.011), however when IMF RBV was included as a covariate, the RBV did not have a significant effect on progeny LMY (P=0.15; Figure 8a). IMF of the Merino lambs at PD20 was 0.8 ± 0.24 units greater than IMF at PD19. At PD18, IMF increases by 0.5 ± 0.18 units in the second kill compared to the first kill. HCWT was a significant covariate, with 0.12 ± 0.02 unit increase in IMF for a 1kg increase in HCWT (P<0.0001; Figure 8b)

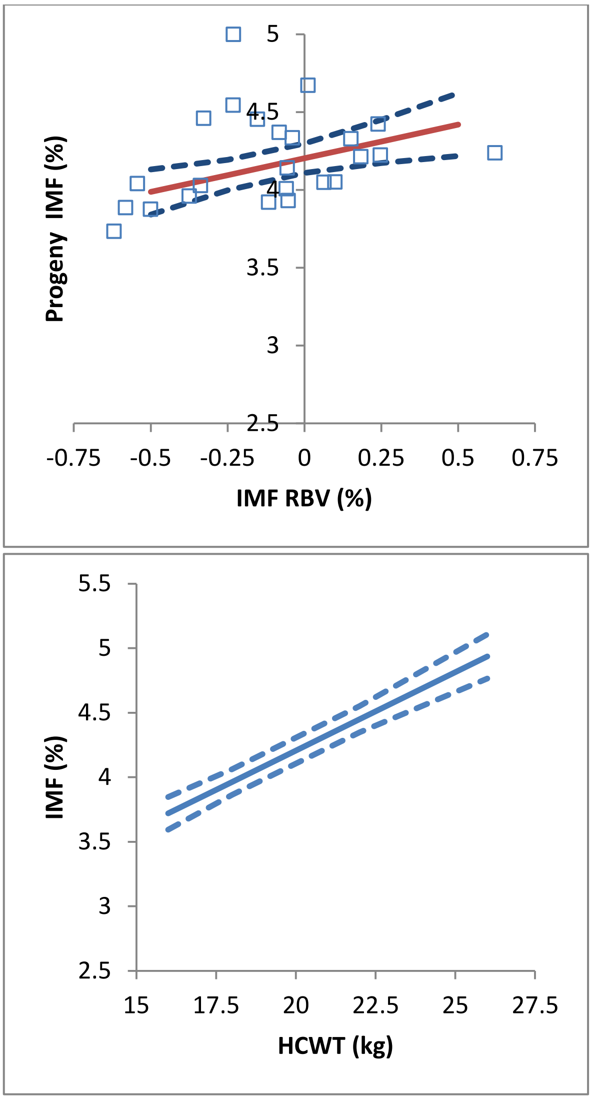


Figure 8 (a) Solid lines represent least square means of the sires for IMF RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing IMF RBV. (b) The relationship between IMF and HCWT in Merino lambs.

4.1.10 Relationship between SF5 RBV and progeny performance.

4.1.10.1 Terminal sires.

Sire tended to be a significant covariate for shear force (P=0.052). When SF5 RBV was included as a covariate, the RBV had a significant effect on progeny shear force (P<0.0001). Across a 10N SF5 RBV range, progeny shear force increased by 7.2 N of shear force, resulting in a 0.7 ± 0.16N increase in shear force associated with 1N increase in SF5 RBV (Figure 9). There was no effect of breed, nor any interaction between breed and SF5 RBV.

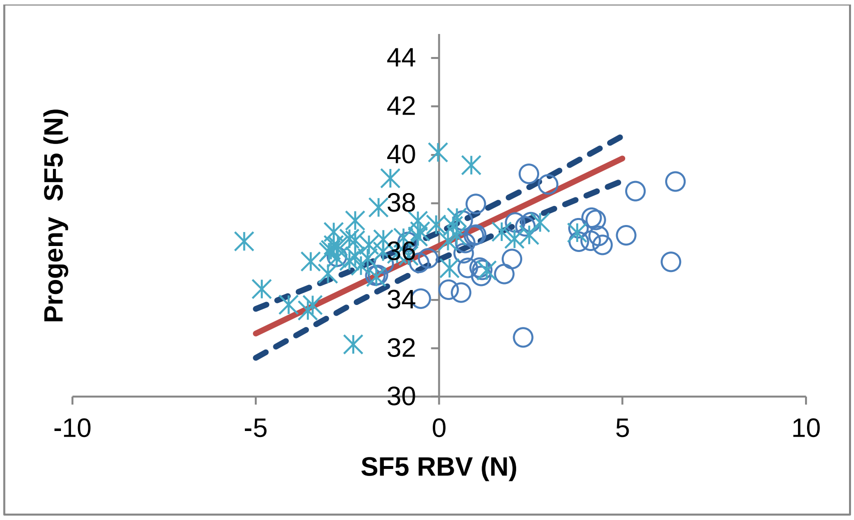


Figure 9. Relationship between shear force (SF5) RBV and sire estimate of progeny shear force. Solid lines represent least square means of the sires for SF5 RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing SF5 RBV. Circle = PD, Cross = WS.

PDS, sex and slaughter date within PDS had a significant impact on shear force (Figure 10a; P<0.0001). Female lambs (35.9 ± 0.71N) were more tender than male lambs (37.4 ± 0.65N; P=0.023). There was a significant difference in shear force between kill dates at PD05 (11.9 ± 2.93N) and PD13 (22.0 ± 2.67N). PD13 was processed at different plants on the two different dates and it was noted in MLA report B.SCC.0183 that the high shear force at PD13 on 21 January 2013 may have been due to cold shortening conditions in the carcases. The reason for the difference between shear force at PD05 where both measurements were undertaken at the same processing plant is unclear.

HCWT and HCWT*HCWT were significant covariates for shear force (P<0.001; Figure 10b). As the HCWT of the lamb increased from 18kg to 30kg, shear force changed from 41.8 ± 1.38N to 37.1 ± 2.4N.

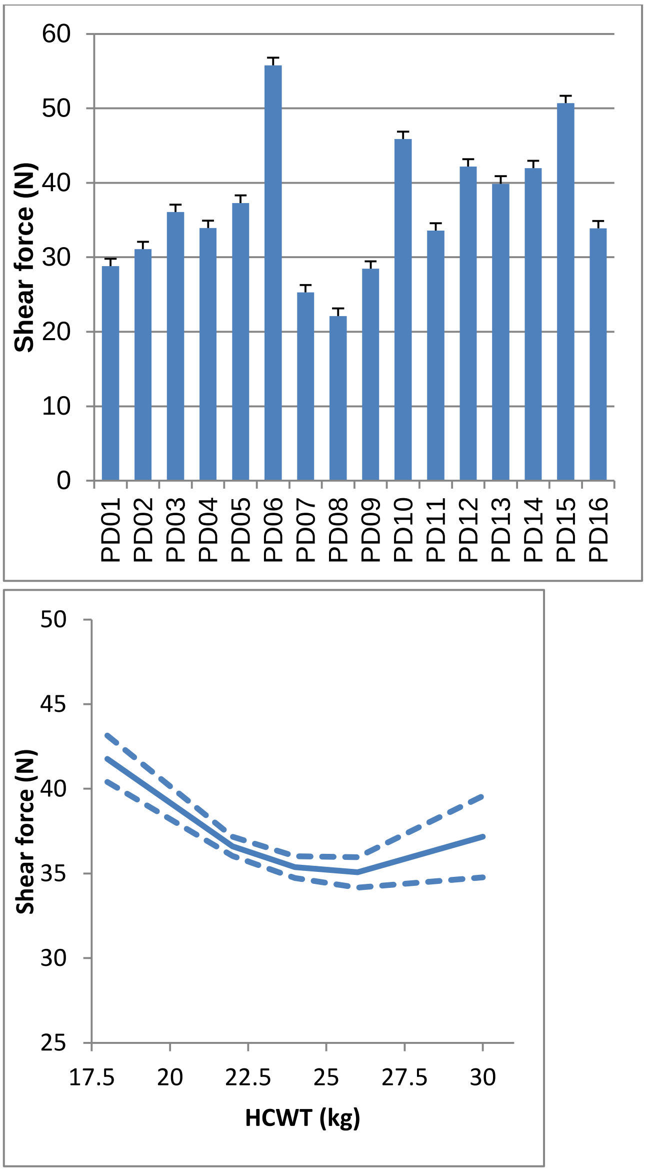


Figure 10 (a). Least square mean shear force of lambs from each PDS and (b) relationship between shear force and HCWT in terminal lambs.

4.1.10.2 Merino sires.

Merino sire was not a significant covariate for shear force (P=0.36). When SF5 RBV was included as a covariate, the RBV tended to have a significant effect on progeny shear force (P=0.058; Figure 11a). HCWT was a significant covariate for Merino lamb shear force; as HCWT increased from 16 to 26 kg, there was a 10N decrease in shear force. This is equivalent to a 1.1N increase in shear force for every 1kg decrease in HCWT (P=0.002; Figure 11b).

There was no effect of slaughter date, sex or birth type (within PDS for all traits) on shear force of Merino lambs. PDS had a significant effect on Merino lamb shear force, with PD20 having the lowest shear force and PD19 having the highest shear force. Indeed, it was noted in MLA Final Report B.SCC.0180 that the shear force of the lambs from PD19 was extremely high, with only two of the 80 samples falling below 40N. The Research Officer who undertook the measurements commented that the samples were “tougher” to prepare for measurement, supporting the significantly high results. These lambs were graded into light export and domestic based on a carcase weight placed into different chillers. The domestic chiller contained only the PD19 lambs for 4-5 hours, before other carcases were added, therefore the temperature of the chiller was very cold. A subsample of lambs were measured for pH temp decline and 4 hours after entering the chiller, carcases had an average temperature of 11°C and average of 6.40pH. This may have contributed to the very high SF5 measurement. The values seem to indicate that the electrical stimulation was ineffective.

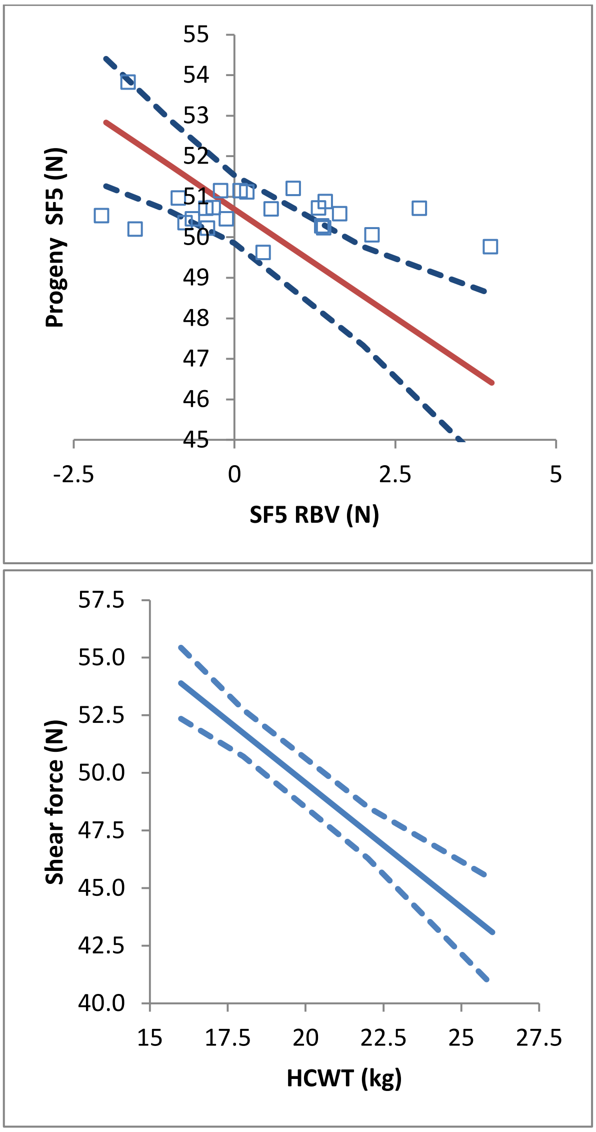


Figure 11 (a) Relationship between SF5 RBV and sire estimate for shear force. Solid lines represent least square means of the sires for SF5 RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing SF5 RBV. (b) The relationship between shear force and HCWT in Merino lambs.

4.1.11 Relationship between HCWT RBV and progeny performance.

4.1.11.1 Terminal sires.

Terminal sire was a significant covariate for HCWT (P=0.017). When HCWT RBV was included as a covariate, the RBV had a significant effect on progeny HCWT (P=0.017).

Across the 2.5kg range in HCWT RBV, progeny HCWT increased by 653g, resulting in a 261 ± 109g increase HCWT associated with 1kg increase in HCWT RBV (Figure 12a). This is a greater response to the predicted effect of PWT ASBV on HCWT (0.18kg/PWT) in terminal lambs [7] although there is a greater range in PWT ASBVs than HCWT RBVs.

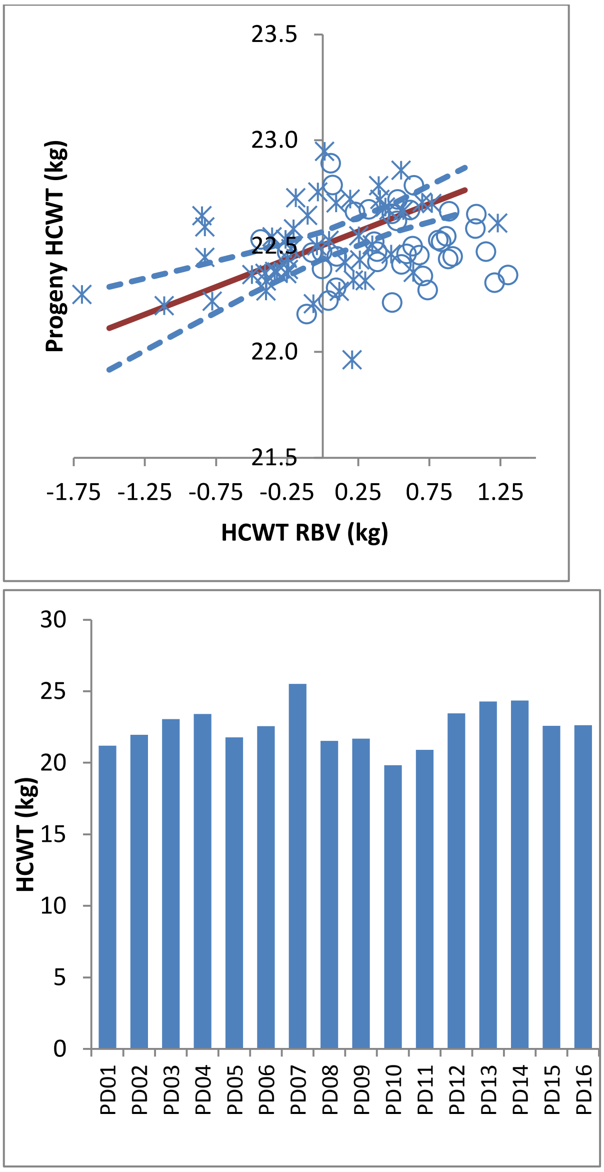


Figure 12 (a) Relationship between HCWT RBV and sire estimate for hot carcase weight (HCWT). Solid lines represent least square means of the sires for HCWT RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing HCWT RBV. Circle = PD, Cross = WS (b) Least square means of HCWT of terminal lambs across PDs.

There was a significant effect of PDS on HCWT with a 5.6kg range in HCWT across sites (Figure 12b). Poll Dorsets had 299 ± 130g heavier carcases than White Suffolks (P=0.021) and males were 610 ± 83g heavier than females (P<0.0001). Single born lambs were heavier than twin born lambs (P<0.0001).

4.1.11.2 Merino sires.

Merino sire was a significant covariate for HCWT (P=0.006). When HCWT RBV was included as a covariate, the RBV had had a significant effect on progeny HCWT

(P=0.038; Figure 13). Over the 4kg range in HCWT RBV, progeny HCWT increased by 1.56kg, equivalent to 390 ± 187g increase in HCWT for each unit increase in HCWT RBV. This is a similar response to the predicted effect of PWT ASBV on HCWT (0.35kg/PWT) in Merino lambs [7].

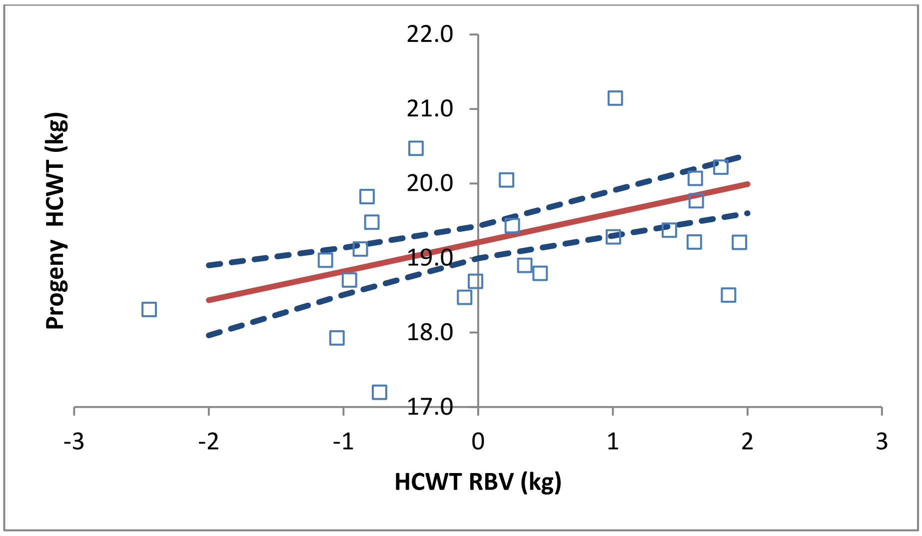


Figure 13. Relationship between HCWT RBV and sire estimate for HCWT in Merino lambs. Solid lines represent least square means of the sires for HCWT RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing HCWT RBV.

PDS had a significant effect on progeny HCWT (P=0.002); Merino lambs from PD18 were 2.6kg heavier than lambs from PD20 (P<0.0001) and male lambs were 1.1kg heavier than female lambs at PD20 (P=0.0003).

4.1.12 Relationship between Dressing RBV and progeny performance.

4.1.12.1 Terminal sires.

Terminal sire was a significant covariate for dressing percent (P=0.0002). When Dressing RBV was included as a covariate, the RBV had a significant effect on progeny dressing percentage (P=0.003). Across the 2% range in Dressing RBV, progeny dressing percent increased by 1%, resulting in a 0.5 ± 0.17% increase in dressing percent associated with 1 unit increase in Dressing RBV (Figure 14a).

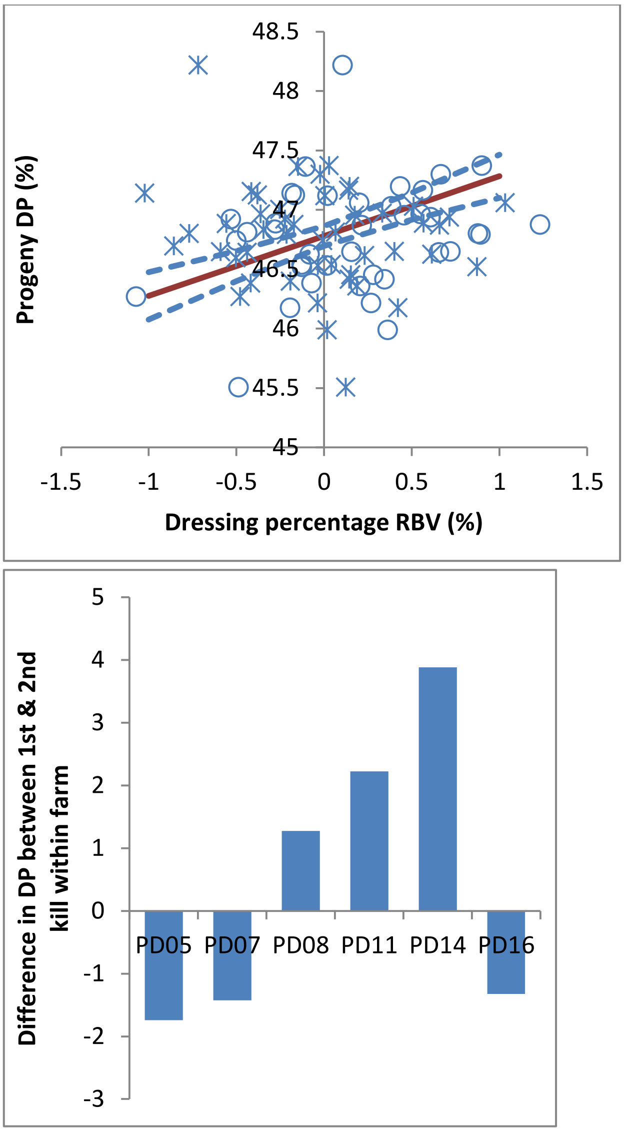


Figure 14 (a) Relationship between DRESS RBV and sire estimate for dressing percentage (DP). Solid lines represent least square means of the sires for DRESS RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing Dressing RBV. Circle = PD, Cross = WS. (b) Difference in DP between first kill and final kill at six PDS in terminal sired lambs.

Poll Dorset sired lambs had a 0.5 ± 0.17% higher dressing percentage than White Suffolk lambs (P=0.002). At PD05, PD06, PD08, PD10, PD11 and PD13, single born lambs had a higher dressing percentage than multiple born lambs (P<0.0001). There was a significant effect of slaughter date within PDS (P<0.0001), but no clear trends (Figure 14b). PD14 and PD16 were killed at different plants across the two kill dates (Table 8), however there were no trends across plants either. It is possible curfew time had an impact on dressing percent, however, time off feed and water could not be included in the base model as a covariate as there were too few degrees of freedom.

4.1.12.2 Merino sires.

Merino sire was a significant covariate for dressing percent (P=0.004). When Dressing RBV was included as a covariate, the RBV had a significant effect on progeny dressing percentage (P=0.017). Across the 2% range in Dressing RBV, progeny dressing percentage increased by 3.1%, resulting in a 1.2 ± 0.51% increase dressing percent associated with 1 unit increase in Dressing RBV (Figure 15). PD19 had a significantly higher dressing percentage than the other two sites (P<0.0001) and there was a significant effect of date (P<0.0001) and sex (P=0.02) on dressing percentage within PDS (PD18).

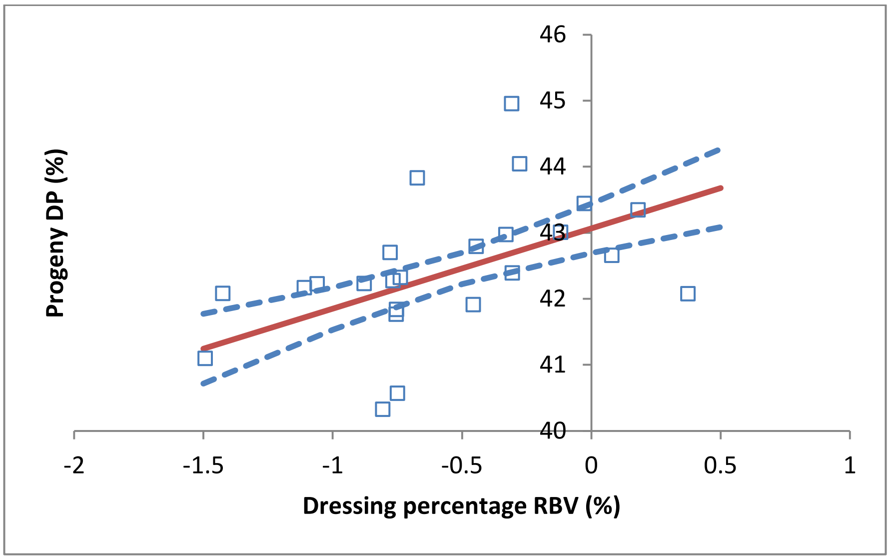


Figure 15. The relationship between DRESS RBV and sire estimate for dressing percentage (DP) in Merino lambs. Solid lines represent least square means of the sires for DRESS RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing DRESS RBV.

4.1.13 Relationship between CEMD RBV and progeny performance.

4.1.13.1 Terminal sires.

Terminal sire was a significant covariate for carcase EMD (P<0.0001). When CEMD RBV was included as a covariate, the RBV had a significant effect on progeny carcase EMD (P=0.003). Across the 4mm range in CEMD RBV, progeny carcase EMD increased by 2mm, resulting in a 0.5 ± 0.17mm increase in carcase EMD associated with 1 mm increase in CEMD RBV (Figure 16).

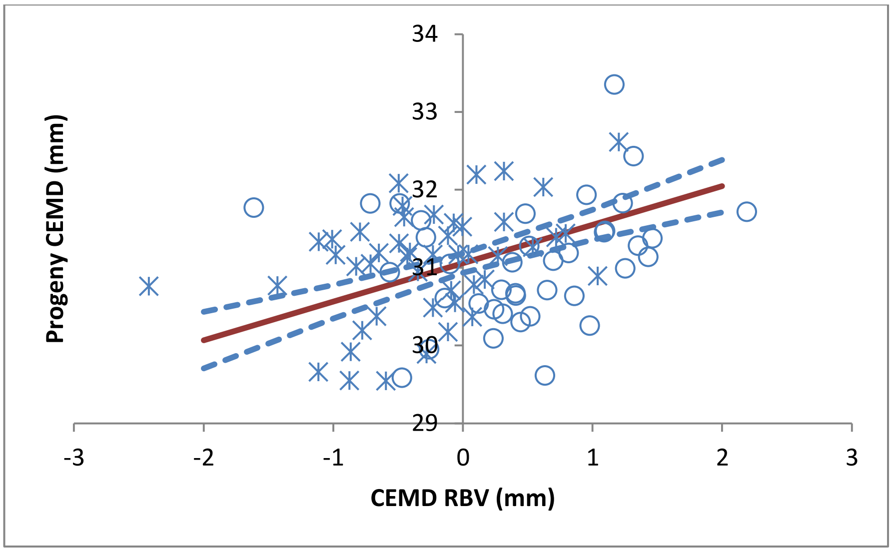
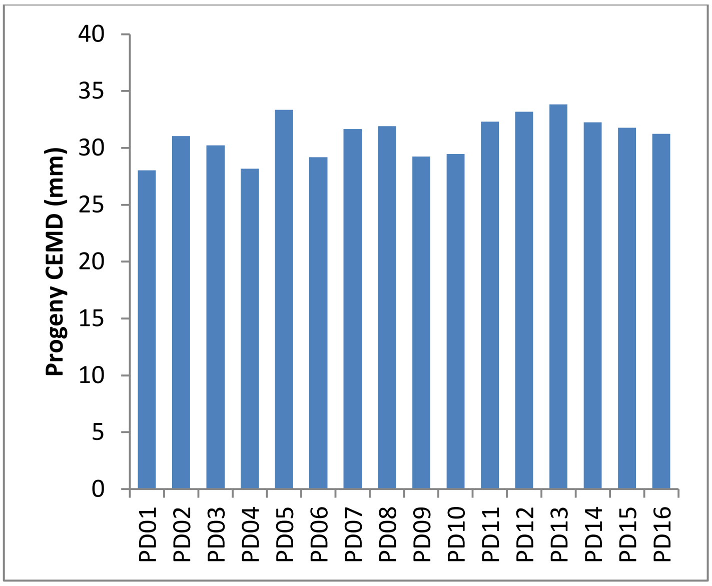


Figure 16 Relationship between CEMD RBV and sire estimate for carcase EMD (CEMD). Solid lines represent least square means of the sires for CEMD RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing CEMD RBV. Circle = PD, Cross = WS.

PDS had a significant effect on progeny carcase EMD (P=0.0002; Figure 17a) with a 5.8mmm range in EMD. There was also an effect of slaughter date within PDS on CEMD (P<0.0001). Females had 0.5 ± 0.11mm more EMD than males (P<0.0001) but there was no effect of birth type or breed. HCWT was a significant covariate (P<0.0001), with a 0.6 ± 0.15mm increase in carcase EMD with a 1kg increase in HCWT (Figure 17b).



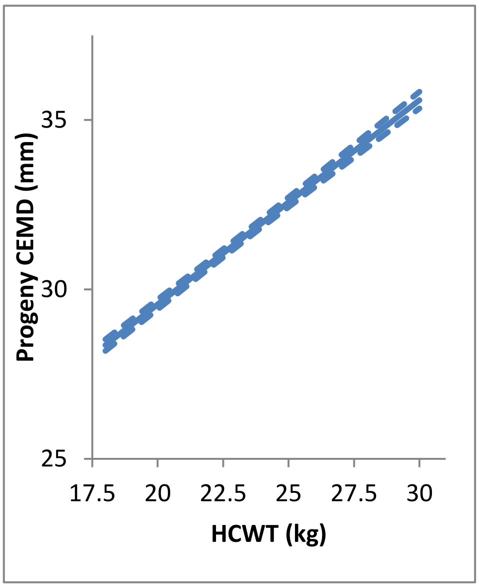


Figure 17. (a). Least square mean carcase EMD (CEMD) of lambs from each PDS and (b) the relationship between CEMD and HCWT in terminal lambs

4.1.13.2 Merino sires.

Merino sire was not a significant covariate for carcase EMD (P=0.12) and when CEMD RBV was included as a covariate, the RBV did not have a significant effect on progeny carcase EMD (P=0.12; Figure 18a). Slaughter date within PDS was the only main effect that had an influence on Merino progeny carcase EMD (P<0.0001). HCWT was a significant covariate (P<0.0001; Figure 18b); there was 0.5 ± 0.06mm increase in carcase EMD associated with a 1kg increase in HCWT.

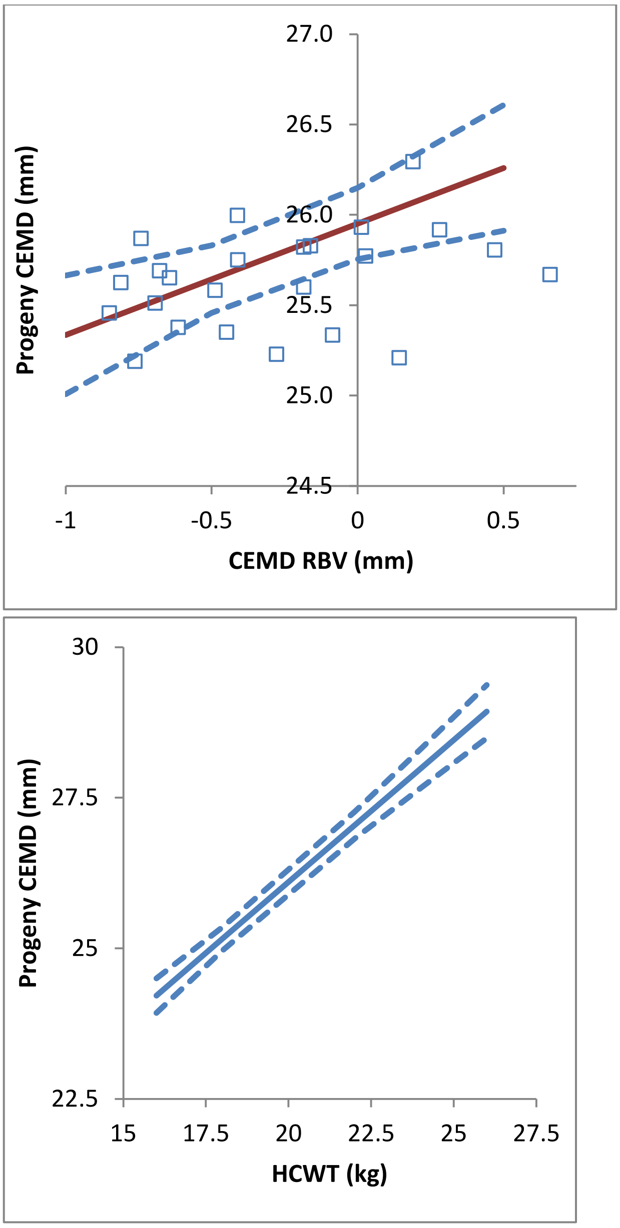


Figure 18 (a) Relationship between CEMD RBV and sire estimate for carcase EMD (CEMD). Solid lines represent least square means of the sires for CEMD RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing EMD RBV. (b) The relationship between HCWT and CEMD in Merino lambs.

4.1.14 Relationship between CCFAT RBV and progeny performance.

4.1.14.1 Terminal sires.

Terminal sire was a significant covariate for carcase c-fat ($P<0.0001$). When CCFAT RBV was included as a covariate, the RBV had a significant effect on progeny carcase c-fat ($P<0.0001$). Across the 2.5mm range in CCFAT RBV, progeny carcase c-fat increased by 1.7mm, resulting in a 0.7 ± 0.14mm increase in carcase c-fat associated with 1 mm increase in CCFAT RBV (Figure 19). There was no effect of breed on c-fat.

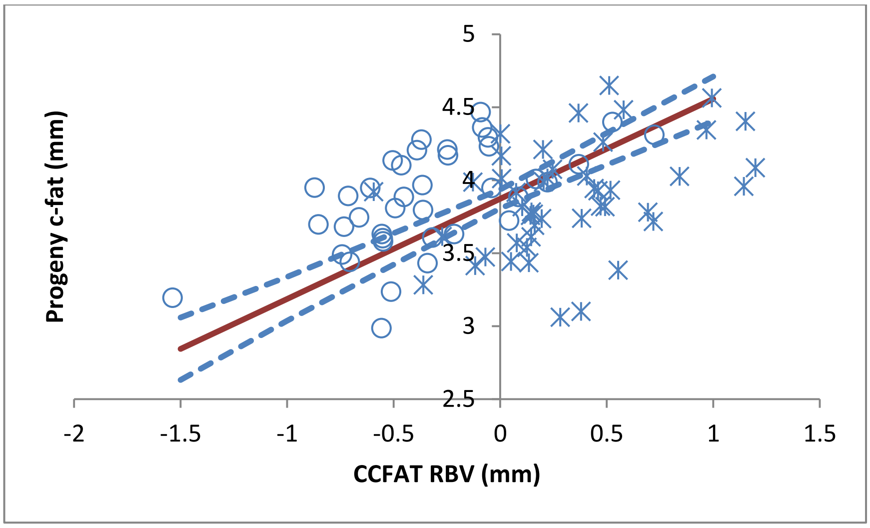


Figure 19. Relationship between CCFAT RBV and sire estimate for carcase c-fat. Solid lines represent least square means of the sires for CCFAT RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing CCFAT RBV. Circle = PD, Cross = WS.

There was a significant effect of PDS on c-fat (P=0.02; Figure 20a) with a 2.7mm range in c-fat across the farms. Within PDS, there was an effect of slaughter date (P<0.0001) and birth type (P=0.007), with single born lambs having a higher c-fat than multiple born lambs. There was an interaction between PDS and sex (P=0.01) with females being fatter than males in most cases. HCWT and HCWT*HCWT were significant covariates for progeny c-fat (Figure 20b). The linear covariate was 0.35 ± 0.219mm and the curvilinear covariate was -0.008 ± 0.004mm.

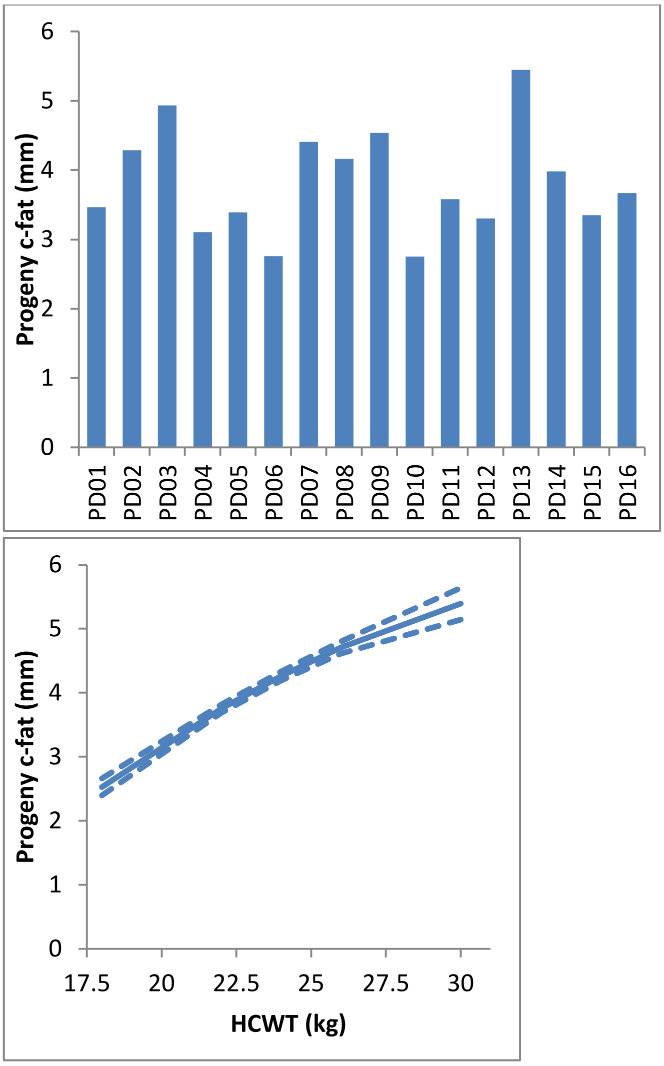


Figure 20 (a). Least square mean carcase c-fat of lambs from each PDS and (b) the relationship between CCFAT and HCWT in terminal lambs

4.1.14.2 Merino sires.

Merino sire was a not significant covariate for carcase c-fat (P=0.11), however when CCFAT RBV was included as a covariate, the RBV had a significant effect on progeny carcase c-fat (P=0.02). Across the 1.5mm range in CCFAT RBV, progeny carcase c-fat increased by 0.9mm, resulting in a 0.6 ± 0.25mm increase in carcase c-fat associated with 1 mm increase in CCFAT RBV (Figure 21a).

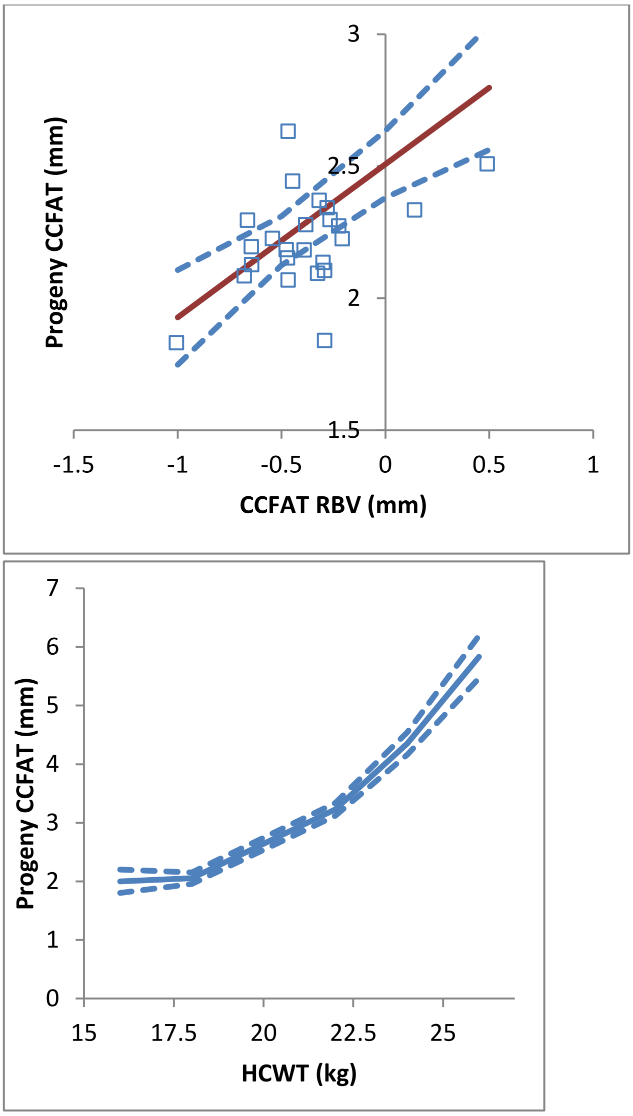


Figure 21 (a) Relationship between CCFAT RBV and sire estimate for carcase c-fat (CFAT). Solid lines represent least square means of the sires for CCFAT RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing CCFAT RBV. (b) The relationship between HCWT and c-fat in Merino lambs.

There was a significant effect of PDS on c-fat (P=0.01) with a 1.3mm range in c-fat across the farms. Within PDS, there was an effect of slaughter date (P<0.0001). HCWT and HCWT*HCWT were significant covariates for progeny c-fat (Figure 21b). The linear covariate was -1.4 ± 0.36mm and the curvilinear covariate was 0.04 ± 0.009mm. There was a significant interaction between PDS and HCWT (P=0.004).

4.1.15 The cross over effect of terminal sire RBVs on progeny LMY, tenderness and IMF

This section describes the effect of the key RBVs (LMY, IMF and SF5) on the alternate LMY and eating quality traits (eg the effect of *LMY* RBV on *tenderness* and *IMF*). As the value of the new RBVs in Merino production systems was less clear due to insufficient sires assessed, similar results are not reported for the Merino lambs.

SF5 RBV had a significant effect on LMY (P<0.0001); a 1 N decrease in SF5 RBV resulted in 0.1 ± 0.03% decrease in progeny LMY. This means that producers of terminal lambs selecting rams based solely on tenderness are likely to decrease LMY in their lambs. Similarly, LMY RBV was a significant covariate for tenderness (P=0.01), with a 1% increase in LMY RBV resulting in a 1.6 ± 0.60N decrease in tenderness and producers focussing solely on increasing LMY are likely to produce lambs with tougher meat.

IMF RBV had a significant effect on tenderness (P=0.003); a 1% increase in IMF RBV resulted in a 3.3 ± 1.10N decline in shear force. Similarly, a 1N decrease in SF5 RBV resulted in a 0.08 ± 0.016% increase in IMF (P<0.0001). This means selecting for either tenderness or IMF will have a positive effect on both eating quality traits in terminal lambs.

4.1.16 The effect of terminal sire RBV on carcase traits, fresh colour and loin pH.

This section describes the effect of the key RBVs (LMY, IMF and SF5) on other carcase and eating quality traits of interest in terminal lambs (HCWT, EMD, EMA, CCFAT, HGRFAT, pH and fresh colour). As the value of the new RBVs in Merino production systems was less clear, similar results are not reported for the Merino lambs.

LMY RBV, IMF RBV and SF5 RBV did not have an effect on hot carcase weight, carcase EMD (Appendix 4), or the three fresh colour measurements (Appendix 6).

LMY RBV had a significant effect on EMA (P=0.035; Figure 22a) and progeny c-fat (P=0.034; Figure 22b). A 1 unit increase in LMY RBV was associated with 0.3 ± 0.15cm^2 increase in carcase EMA and 0.2 ± 0.04mm decrease in progeny carcase c-fat. LMY RBV was not a significant covariate for HGRFAT (P=0.06) or the pHLL of terminal sired lambs.

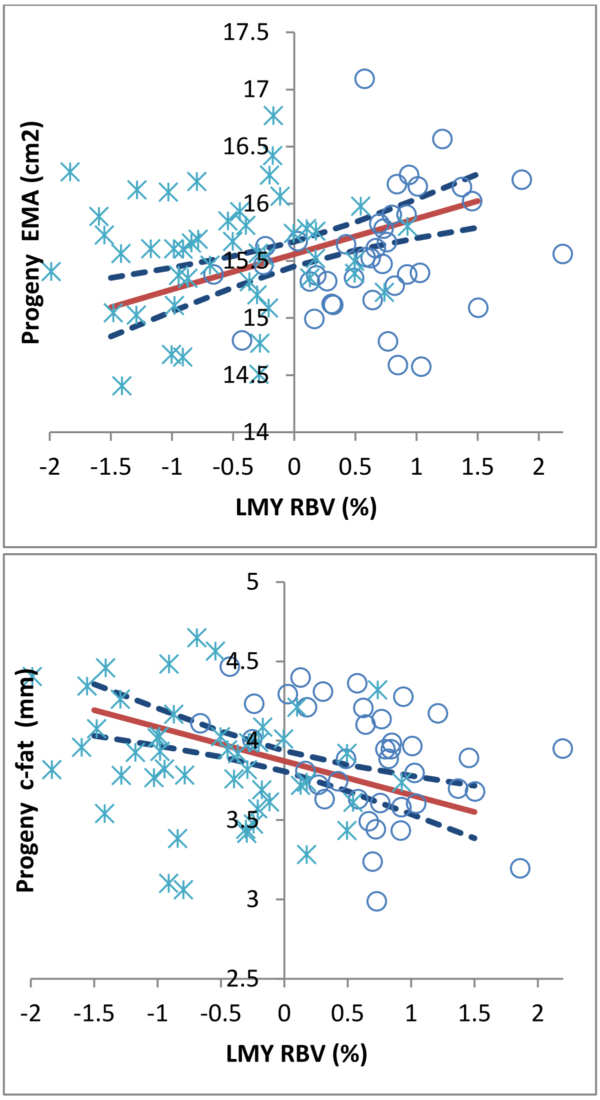


Figure 22. Relationship between LMY RBV and sire estimate for carcase (a) EMA and (b) c-fat. Solid lines represent least square means of the sires for LMY RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing LMY RBV. Circle = PD, Cross = WS.

IMF RBV did not have a significant effect on EMA or pHLL (Appendices 4 & 5), although there was a significant curvilinear relationship with pHLL (P=0.02). Progeny carcase c-fat (P=0.07; Figure 23a) and HGRFAT (P=0.09) tended to decrease with increasing IMF RBV although the effect was small. This maybe an important effect and would mean that producers would be able to select for increased IMF, without significantly increasing subcutaneous fatness in the lambs.

SF5 RBV was a significant negative covariate for progeny carcase c-fat (P<0.0001; Figure 23b), with a 1N decrease in SF5 RBV resulting in a 0.13 ± 0.035 mm increase in carcase c-fat. There was a similar relationship for HGRFAT, with a 1N decrease in SF5 RBV resulting in a 0.2 ± 0.07 mm increase in GR thickness (P=0.002). SF5 RBV was not a significant covariate for pHLL or EMA.

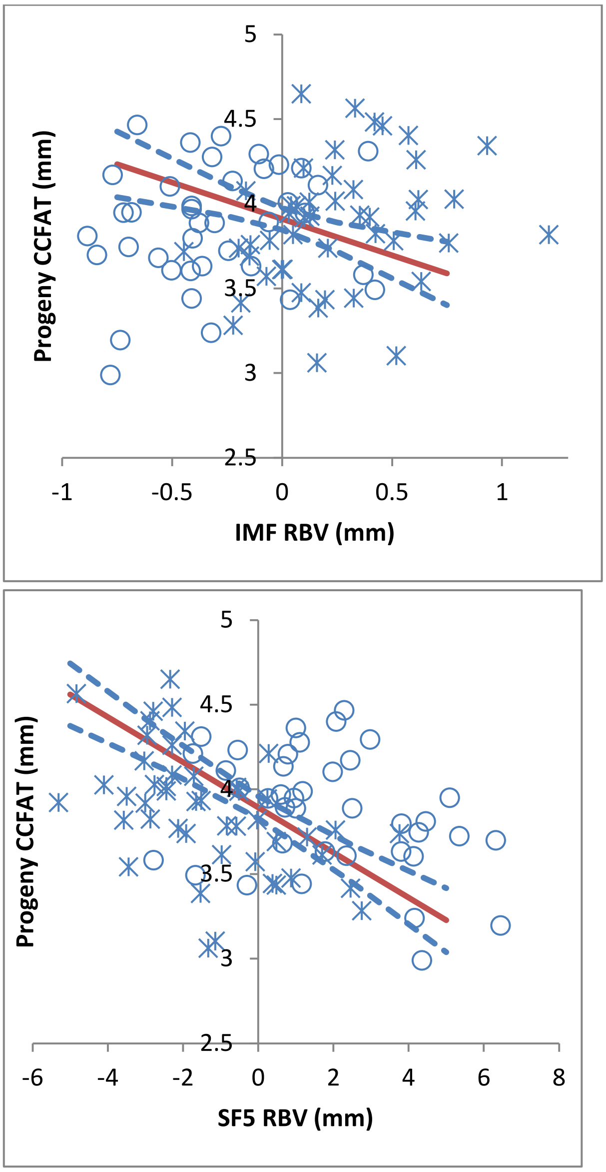


Figure 23 Relationship between (a) IMF RBV and (b) SF5 RBV and the sire estimate c-fat (CCFAT). Solid lines represent least square means of the sires for RBV and dashed lines are the SEM. Sire estimates are obtained from the model not containing the RBV. Circle = PD, Cross = WS.

4.1.17 Lamb Value Calculator as a tool to develop potential value based trading mechanisms for LMY.

HCWT and GR sire solutions from Phase I of the trial were used in the Lamb Value Calculator to compare the LMY outputs from the Lamb Value Calculator with estimated LMY sire solutions from PD01 and PD02. Good relationships exist between estimated LMY (based on HCWT, GR, EMA, cfat) and Lamb Value Calculator estimated export saleable yield (R^2=0.87; Figure 24a) and between estimated LMY and Lamb Value Calculator predicted yield on fully boned out cuts (R^2=0.82; Figure 24b). Therefore, the Lamb Value Calculator can be confidently used to model the value of yield to supply chains for groups of lambs such as PDS lots (in this case sire groups).

To model a greater range in yield (beyond the range of the sire solutions), data from 24 carcases with GR ranging from 2-20mm were used in the Lamb Value Calculator (Figure 24c). This relationship between estimated LMY and the calculator yield was also significant (R^2=0.89), therefore the calculator is a valid tool to predict the **comparative** value of individual carcases. These results indicate that the two prediction methods provide equivalent predictions of yield, however, they do not necessarily predict **absolute** yield. To convert the predictions to absolute yield it is necessary to apply a plant specific conversion to each of the methods.

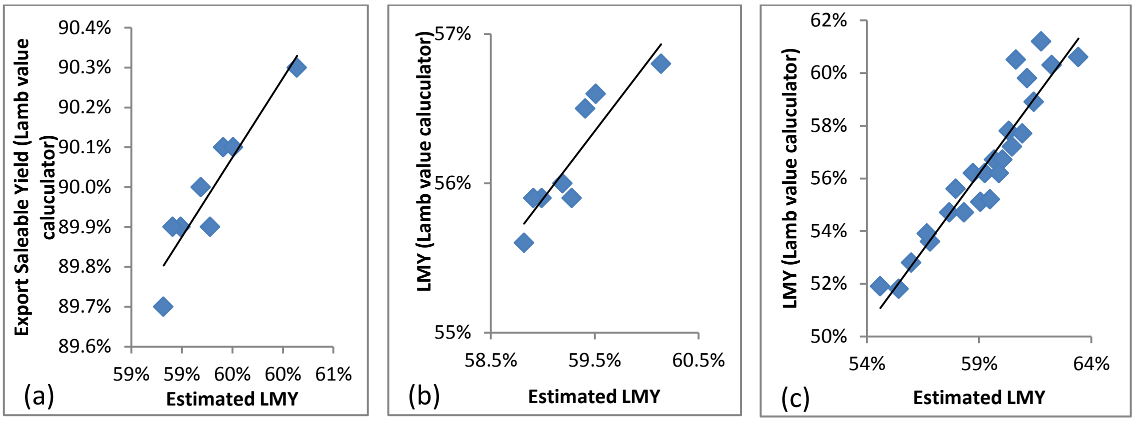


Figure 24. Relationship between LMY sire solutions and Lamb Value Calculator estimates for (a) export saleable yield, (b) full boned out yield and (c) the relationship between individual lamb LMY estimates and Lamb Value Calculator estimate of fully boned out yields.

4.1.18 Value of LMY to processors and development of potential value based trading.

Full results were submitted to the processor and MLA as separate reports due to the confidentiality of the data.

In summary, the value of LMY to the processor was dependant on HCWT such that a 1% increase in LMY increased the value of a heavy carcase by approximately 12%, and approximately 10% in light carcases. In addition, fat score/GR has a greater effect on net return from heavier carcases. On heavier carcases, an increase of 5mm GR (1 fat score) decreased the value by approximately 11%, whereas in lighter carcases, an increase of 5mm GR decreased carcase value by approximately 7%. The effect of fatness on carcase value increased as fatness increases such that fat score 5 carcases need to be at 2- 3 kg heavier than fat score 2 and 3 carcases to achieve a similar return.

Value added cuts were more sensitive to carcase weight, GR thickness and LMY than traditionally processed carcases. For a 1% increase in LMY, there was a 4-6% increase in value across carcase weights with traditional processing; however when value added cuts are included, there was a 9-11% increase in value across carcase weights for a 1% increase in LMY.

4.1.19 Field Days

In consultation with the project management group, interested producers, Site Facilitators and Site Hosts, and feedback from the Phase I Field day Field Days were held after results from the PDS were available. In addition, opportunities for awareness of the project and the new RBVs were utilised by linking into established workshops and Field Days that are not solely focussed on LMY & EQ. Therefore results and background of the project were presented at stud Field days, scanning workshops, Your Lamb Your Profit workshops, PDS management group annual Sticky Beak days, animal health and production workshops and lot-feeding field days.

Field Days were held on 15 occasions across all states (see individual Final reports for full details). In addition, the project was promoted widely by individual Site Facilitators through client and group newsletters and media releases. Attendees were producers, service providers and agribusinesses and secondary school students.

4.2 Suitable measurement technology and feedback mechanism for new breeding values at processing developed.

PDS lambs were used to validate measurement technology for LMY and IMF as the opportunities arose. However, within the time frame of this project, no new measurement technologies were successfully developed which could be used to measure the new breeding traits at processing. As such, until measurement technologies are available it is not possible to develop feedback mechanisms, although this is a key area of concern for producers and processors alike. Questions and comments from field days and workshops indicate that producers are seeking improved feedback from processors. There is opportunity for this to be realised through Livestock Data Link and MSA.

4.3 A common focus initiated and normal trading mechanisms developed for the new breeding values.

The interest in the new breeding values across the lamb supply chain is high and there appears to be a common focus, or at least awareness that LMY and EQ need to managed and improved. Therefore, a common focus of the potential to use the new breeding values has been initiated.

Potential normal trading mechanisms for LMY have been developed with one supply chain and there is opportunity to develop more with other key supply chains that have been engaged in this project.

From the information generated using the Lamb Value Calculator to demonstrate the value of LMY to processors, grids based on carcase weight and fat depth were developed which could form the basis for value based trading. The carcase weight/fat depth grid was more useful than a straight LMY based grid due to the confounding effects of HCWT and fatness on LMY. Table 11 shows the LMY grid based on HCWT and GR. This grid shows that lean animals, regardless of carcase weight, have a higher proportion of saleable product. If LMY was to be used in value based trading, a grid would need to be developed that incorporates HCWT as this is still a key profit driver to the processor. Development of LMY based trading must be balanced with EQ to ensure that market signals for LMY do not lead to reduced eating quality.

Table 11. LMY grid based on HCWT and GR depth

	7mm	12mm	17mm	22mm	25mm
21kg	90.6%	89.6%	88.8%	87.9%	87.5%
24kg	90.7%	89.7%	88.7%	87.7%	87.2%
27kg	90.8%	89.7%	88.6%	87.5%	86.9%

The use of multiple producer demonstration sites nationally and simultaneously, with linkages through the whole supply chain was a novel method to develop a common focus for new technologies (in this instance the new RBVs). Feedback from Phase I producers about their involvement in the Phase I PDS has been positive. It is recommended that formal evaluation of all PDS hosts and facilitators is undertaken to assess learning outcomes of the trial and inform future PDS development (Milestone 4, B.SCC.0144).

5 Conclusions

"Proof of concept" for lean meat and eating quality attributes within major supply chains were delivered by facilitating, empowering and developing a common focus and normal trading mechanisms on these future key industry profit drivers right along the supply chain. This was achieved by:

1. Determining the value of 7 new research breeding values for ram breeders, lamb producers & processors at 20 sites by December 2014.

2. Developing suitable measurement technology and feedback mechanism for these breeding values at processing by December 2014.

3. Initiating a common focus and fostering the development of normal trading mechanisms on these future key industry profit drivers right along the supply chain by December 2014.

The National Coordinator managed the overall project and the outputs of Site Facilitators of 2 sites in year 1 and a further 18 sites in year 2/3. Protocols were developed in association with the Project Management Team and the National Coordinator ensured that data was collected in an identical way across sites, and preliminary data quality and auditing was undertaken and internal and external communications were managed.

In terminal lamb production systems, all seven RBVs evaluated increased the correlated trait in the lambs (Table 12).

Table 12. Summary of the impact of a 1 unit change in sire RBV on the correlated change in lamb production for the seven key traits.

Trait	Sire RBV	Terminal lamb	Merino lamb
LMY	1 %	0.31 ± 0.090% ***	0.42 ± 0.200% *
IMF	1 %	0.57 ± 0.097% ****	n.s.
SF5	1 N	0.7 ± 0.16N ****	n.s.
DRESS	1 %	0.5 ± 0.17%**	1.2 ± 0.51% *
HCWT	1 kg	260 ± 109g *	390 ± 187g *
CEMD	1 mm	0.5 ± 0.17mm **	n.s.
CCFAT	1 mm	0.7 ± 0.14mm ****	0.6 ± 0.25mm *

n.s. P>0.05; *P<0.05; **P<0.01; ***P<0.001; ****P<0.0001

LMY RBV can be used confidently by ram breeders and prime lamb producers in terminal lamb production systems. A 1% increase in sire LMY RBV resulted in a 0.31% increase in terminal lamb LMY. This was associated with an increase in carcase EMA and decrease in progeny carcase c-fat. Importantly, LMY RBV did not have an impact on weaning weight, pre-slaughter weight or liveweight gain. However, LMY RBV had a negative effect on lamb tenderness, therefore care must be taken by ram breeders and lamb producers that using the LMY RBV does not decrease lamb eating quality.

Fortunately, the RBVs for the key eating quality traits, IMF and tenderness, had a positive effect on their directly correlated trait and on the alternate eating quality trait, therefore RBVs for eating quality traits can be confidently used to manage eating quality of terminal sired lambs. A 1% increase in sire IMF RBV resulted in a 0.57% increase in terminal lamb IMF. Lamb carcase c-fat and GR thickness tended to decrease with increasing IMF RBV at a constant carcase weight. IMF RBV did not affect weaning weight or pre-slaughter liveweight.

A 1N decrease in sire SF5 RBV resulted in an increase in loin tenderness in terminal lambs equivalent to a 0.7N decrease in shear force. There were no effects of SF5 RBV on terminal lamb weaning weight, pre-slaughter liveweight or average daily liveweight gain, however SF5 RBV did have a negative impact on LMY. Selection for improved tenderness using SF5 RBV is likely to decrease LMY in terminal lambs. Therefore, both LMY and SF5 RBVs need to be taken into consideration simultaneously.

A positive correlation between RBVs for dressing percentage, HCWT, CEMD and CCFAT and their directly correlated trait was also observed in terminal lambs, indicating that these RBVs are able to be used to directly select for carcase traits, rather than using the indirect live animal traits. Further analysis is required to determine whether selection for carcase traits using the RBVS based on genomics is more efficient than using the correlated live animal trait (PWWT, EMD and PFAT).

In Merino production systems, the relationships between RBVs for lean meat and eating quality traits were less convincing. This is most likely due to only three Merino PDS successfully producing lamb for slaughter with only 24 Merino rams evaluated (compared to 86 terminal rams). Merino LMY RBV increased Merino lamb LMY but there was no effect of IMF or SF5 RBV on Merino lamb IMF or tenderness. It is recommended that further Merino PDS are established to demonstrate that these RBVs can be confidently used in Merino lamb production systems.

The new RBVs have significant value to lamb processors and supply chains. Modelling with the Lamb Value Calculator using processor specific inputs demonstrated that the value of LMY to the processor is dependent on HCWT and the degree of value adding. It is important to note that the value of LMY is likely to vary across different plants, due to different inputs, outputs and cut specifications. Grids based on carcase weight and fat depth were developed which could form the basis for value based trading. It is recommended that plant specific modelling is undertaken to demonstrate the full value of LMY to plants and supply chains that are interested in exploring these outcomes.

The RBVs for IMF and SF5 are predicting eating quality of lamb well. These RBVs therefore have the potential to be used by the supply chain to add confidence to product eating quality claims. It is important to acknowledge that, although the RBVs are good predictors of comparative EQ between progeny groups, they do not guarantee absolute values – these are affected by environment, sex and processing factors. It is essential that good processing controls are in place to ensure product integrity – even the best RBVs cannot overcome some environmental conditions.

6 Contributors

LMY & EQ PDS project management team

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Bruce Hancock (PIRSA, Sheep CRC)
Janelle Hocking Edwards (SARDI)

Producer demonstration site hosts

Georgina Gubbins (Maneroo Partnership, Heywood), Tony Fleetwood (Wexford Pastrol Co, Hamilton), Graham and Polly Sudholz (Sudholz Farm, Kotupna), Tom Marriott (Yarallah Lamb, Benalla), Lachie Ranken (Boonerah, Hexam), Andrew and Diana Sutherland (Berachah, Hamilton), Frank O'Connor (Melbourne University – Dookie Campus, Dookie) Graham and Karen Clothier, (Greenvale, Woolumbool). Peter and Elke Hocking (II & PE Hocking; Scottglade), Lachie and Amanda Stewart (Cherrita Pastoral, Keilira), Scott and Andrew Colvin (Nosswick, Blackwood Creek), Greg Sheather and Jonathon Barnes (Wesley Dale, Chudleigh) and Emma Boon and Jamie Downie (Dungrove, Bothwell), Brad and Lauren Yelds (Cobana Pastoral, Bombala), Alan Manton (Yealering), Craig and Liz Heggaton (Kojonup), Andrew Thompson and Vicki Scanlan (DAFWA/Murdoch) and Don Thomson and Wade (dec) and Gerri Hinkley (Tincurrin), Tony Manchester (Kingsvale), Peter Holding (Harden).

Ram breeders

Anna Villa, Ashmore, Belka Valley, Bundara Downs, Cashmore, Charinga, Cobana, Collinsville Poll, Coromandel Poll, Denroy, Derella Downs, Derrynock, Detpa Grove, Ejanding, Ella Matta, Farrer, Gloroy, Hannaton, Hermes, Hillcroft Farms, Ilfracombe, Illoura, Ingle, Ivadene, Jewsharp, Kelvale, Kennedy Creek, Kilfeera Park, Kurralea, Lambpro, Langley, Langley Heights, Leahcim, Leahcim Poll, Leawarra, Leith, Linden, Majardah, Malleetech, Meat Elite, Merinotech WA, Millswyn, Moojepin, Newbold, One Oak, Pendarra, Penrise, Pepperton, Pollambi, Pooginook, Ridgway Advance, Shirlee Downs, Spring Valley, Toland Poll, Trigger Vale, Valma, Wallaloo Park, Waratah, Woodyarrup, Woolumbool, Wunnamurra.

Processing plants and supply chains

Australian Lamb Company (Colac), Coles, Frewstal Pty Ltd (Stawell), GM Scott Pty Ltd (Cootamundra), Gundagai Meat Processors (Gundagai), JBS Australia Pty Ltd (Bordertown, Brooklyn, Cobram, Devonport and Longford), Thomas Food International (Murray Bridge, Tamworth), V&V Walsh (Bunbury), WAMMCO Ltd (Katanning), Woolworths.

Supply Chain Officers

Mark Inglis (JBS Australia), Melissa Neal (Department of Environment & Primary Industries), David Rutley (Thomas Food International).

MLA Account Managers

Gary McAlister, Stephen Pocock.

Site Facilitators and teams

Peter Bailey, Gervaise Gaunt, Garry Hallam, Ruth Corrigan (Department of Environment & Primary Industries)
Janelle Hocking Edwards and Emma Babiszewski (South Australian Research and Development Institute)
Kelly Pearce (Murdoch University)
Leanne Sherriff, Jason Lynch (Macquarie Franklin), Mandy Allen
Anthony Shepherd (Sheepmatters)
Nancy Spoljaric (Monaro Farming Systems)
Rob Davidson (WAMMCO Ltd)

Slaughter measurement and sampling teams and EQ testing laboratories

Peter Bailey, Wayne Brown, Matthew Kerr, Nick Linden, Greg Seymour (Department of Environment & Primary Industries)

Janelle Hocking Edwards and Emma Babiszewski (South Australian Research and Development Institute)

Geert Geesink, Xuemei Han, Colin Starkey, Aaron van den Heuvel (University of New England)

Kelly Pearce, Andrew Williams, Malcolm Boyce, Graham Gardner (Murdoch University)

David Hopkins (NSW Department of Primary Industries)

Sheep Genetics

Sam Gill, Luke Stephen, Tom Hooke

Parentage testing and DNA analysis

Klint Gore, Marg Shedden (Sheep CRC)

Lamb Value Calculator

Chris Smith (Agbiz Solutions)

Agribusiness sponsorship

TP Jones, Gallagher, Allflex, Gallagher, Sapien Technology, Shearwell Australia. Delta Livestock, Cootamundra.

Honours student

Joshua Barton (The University of Western Australia) supervised by Peter McGilchrist (Murdoch Univeristy), Kelly Pearce, Dominique Blache (UWA) & Janelle Hocking Edwards

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8 Appendices

Appendix 1. Summary of key dates, age of measurement and raw liveweight data from all producer demonstration sites.

	Site	Date	Age (d)	Count	Min (kg)	Max (kg)	Ave (kg)
PD01	AI	29-30/3/12		591			
	Scanning	07-Jul-12					
	DOB	28-Aug-12	0	520			
	WWT	06-Dec-12	100	467	20.6	51.0	37.6
	EPWT1	14-Jan-13	140	520	26.2	56.0	43.4
	EPWT2	08-Apr-13	223	21	44.4	56.0	49.0
	PSWT	Pre-slaughter full or curfew weights were not obtained					
PD02	AI	22-23/3/12		600			
	Scanning	04-Jul-12					
	DOB	18-Aug-12	0	365			
	WWT	03-Dec-12	93	233	17.5	47.5	32.7
	EPWT1	18-Dec-12	122	244	23.0	50.5	36.3
	EPWT2	11-Jan-13	146	354	21.5	56.0	37.0
	EPWT3	06-Feb-13	172	141	26.0	55.0	41.6
	EPWT4	13-Feb-13	179	158	25.5	58.5	44.4
	PWWT1	28-Feb-13	194	159	24.0	55.0	42.8
	PSWT	Pre-slaughter full or curfew weights were not obtained					
PD03	AI	13-Dec-12		576			
	Scanning	04-Feb-13		576			
	DOB	09-May-13	0	286			
	MWT	07-Jun-13	28				
	WT	05-Jul-13	56	276	9.5	31.5	21.9
	WWT	15-Aug-13	96	270	15.5	48.5	34.6
	EPWT2	05-Sep-13	116	273	21.0	53.0	37.0
	EPWT1	04-Oct-13	145	266	25.0	59.0	41.8
	PSWT2	21-Oct-13	162	270	29.5	62.5	46.3
PD04	AI	05-Jan-13		321			
	Scanning	01-Mar-13		321			
	DOB	01-Jun-13	0	133			
	MWT	15-Jul-13	44				
	WWT	19-Aug-13	78	128	12.0	38.0	28.6
	EPWT1	08-Oct-13	127	128	28.0	65.0	42.4
	EPWT2	28-Oct-13	147	128	33.5	62.0	47.3
	PWWT1	15-Nov-13	164	120	25.5	62.0	47.2
PD05	AI	19/20 Nov 2012		300			
	Scanning	14-Feb-13		300			
	DOB	17-Apr-13		73			
	MWT	14-Jun-13	58	72	16.5	36.0	26.2
	WWT	18-Jul-13	92	72	18.1	50.8	35.2
	EPWT1	15-Aug-13	120	72	19.7	60.0	44.0
	EPWT2	12-Sep-13	148	18	24.4	47.0	41.1

	PSWT1	29-Aug-13	134	52	39.5	56.2	45.3
	PSWT2	23-Sep-13	159	18	35.0	47.2	42.5

Appendix 1 cont. Summary of key dates, age of measurement and raw liveweight data from all producer demonstration sites.

	Site	Date	Age (d)	Count	Min (kg)	Max (kg)	Ave (kg)
PD06	AI	21/22 Jan 2013		300			
	Scanning	21-Apr-13					
	DOB	20-Jun-13	0	268			
	MWT	17-Jul-13	27	267	7.2	22.2	15.2
	WWT	10-Oct-13	112	264	22.6	59.8	40.6
	EPWT1	04-Nov-13	137	263	27.0	61.0	44.8
	EPWT2	26-Nov-13	159	139	32.3	49.6	43.0
	PWWT1	23-Dec-13	186	137	38.8	57.8	49.8
	PSWT1	26-Nov-13	159	124	43.0	64.4	51.8
	PSWT2	21-Jan-14	215	79	41.7	55.0	47.6
PD07	AI	06-Feb-13		299			
	Scanning	29-Apr-13	82	297			
	DOB	05-Jul-13	0	241			
	MWT	27-Aug-13	53	241	13.0	35.0	24.4
	WWT	07-Oct-13	94	235	23.5	54.0	40.3
	EPWT1	28-Oct-13	115	241	29.0	62.5	46.9
	EPWT2	27-Nov-13	145	117	37.0	61.5	49.8
	PSWT1	29-Oct-13	116	121	42.5	61.0	50.6
	PSWT2	27-Nov-14	145	71	59.5	50.6	50.3
PD08	AI	27-Feb-13		317			
	Scanning	20-May-13		311			
	DOB	24-Jul-13	0	224			
	WWT	01-Nov-13	100	221	23.0	30.5	38.0
	EPWT1	21-Nov-13	120	208	24.0	55.0	40.4
	EPWT2	27-Nov-13	126	213	24.5	53.0	40.1
	EPWT3	20-Dec-13	149	118	25.0	43.5	36.0
	EPWT4	28-Jan-14	188	118	23.5	48.0	34.9
	EPWT5	24-Feb-14	215	121	26.5	56.0	38.9
	EPWT6	24-Mar-14	243	123	30.5	59.5	43.6
	EPWT7	09-Apr-14	259	118	31.5	59.5	45.1
	PSWT1	27-Nov-13	126	101	36.0	52.0	42.9
	PSWT2	09-Apr-14	259	98	35.0	59.5	46.4
PD09	AI	25-Feb-13		297			
	Scanning	27-May-13		297			
	DOB	25-Jul-13	0	259			
	PreWWT1	08-Jan-13	75	256	14.4	36.5	24.8
	PreWWT2	07-Nov-13	105	254	20.4	46.3	33.2
	PreWWT3	05-Dec-13	133	257	20.6	60.4	44.2
	PSWT1	18-Dec-14	146	208	35.7	61.0	46.0

Appendix 1 cont. Summary of key dates, age of measurement and raw liveweight data from all producer demonstration sites.

	Site	Date	Age (d)	Count	Min (kg)	Max (kg)	Ave (kg)
PD10	AI	25-Feb-13		294			
	Scanning	22-May-13		288			
	DOB	01-Aug-13	0	311			
	WWT	18-Nov-13	109	292	20.5	51.5	38.8
	EPWT1	11-Dec-13	132	268	25.5	54.0	41.6
	PSWT1	15-Dec-14	136	193	38.0	55.0	44.4
PD11	AI	20-21 Mar-13		317			
	Scanning	18-19 Jun-13		317			
	DOB	16-Aug-13	0	311			
	WWT	14-Nov-13	90	272	16.6	46.2	33.9
	EPWT1	09-Dec-13	115	274	23.6	50.0	38.5
	EPWT2	12-Jan-14	149	221	29.2	52.0	42.2
	EPWT3	24-Jan-14	161	165	40.8	57.0	47.7
	PSWT1	15-Dec-13	121	52	45.2	56.5	49.5
	PSWT2	30-Jan-14	167	143	38.2	53.5	45.2
PD12	AI	01-Apr-13		251			
	Scanning	30-May-13		255			
	DOB	08-Sep-13	0	148			
	WWT	20-Nov-13	73	143	14.0	35.2	23.3
	PWT1	22-Feb-14	167	134	26.4	51.0	37.4
	PWT2	14-May-14	248	136	35.0	57.5	46.4
	PSWT1	07-Jul-14	302	132	36.5	59.5	48.8
PD13	AI	13-Mar-13		300			
	Scanning	07-May-13		300			
	DOB	19-Aug-13	0	286			
	MWT	30-Oct-13	72	284	16.0	47.9	32.1
	WWT	09-Dec-13	112	242	21.3	55.0	36.3
	EPWT1	12-Mar-14	208	96	35.8	61.0	48.4
	EPWT2	31-Mar-14	227	121	41.2	60.5	50.3
	PSWT1	19-Jan-14	156	118	37.3	68.0	49.3
	PSWT2	09-Apr-14	236	122	43.9	65.5	53.9
PD14	AI	09-Apr-13		300			
	Scanning	18-Jun-13		241			
	DOB	05-Sep-13	0				
	Marking	19-Sep-13	14	306			
	WWT	09-Dec-13	95	288	16.5	47.5	32.7
	EPWT1	03-Jan-14	120	271	24.5	52	39.5
	EPWT2	22-Jan-14	139	285	32	56	45.1
	PSWT1	04-Feb-14	152	127	46.5	65	52.5
	PSWT2	09-Feb-14	157	99	39.5	47.5	44.4

Appendix 1 cont. Summary of key dates, age of measurement and raw liveweight data from all producer demonstration sites.

	Site	Date	Age (d)	Count	Min (kg)	Max (kg)	Ave (kg)
PD15	AI	16-Apr-13		300			
	Scanning	04-Jul-13		212			
	DOB	16-Sep-13	0				
	Marking	07-Nov-13	52	223			
	WWT	19-Jan-14	125	199	20.6	47.2	35.5
	EPWT1	24-Feb-14	161	211	26.6	55.5	39.9
	EPWT2	26-Mar-14	191	205	28.2	50.5	39.2
	PWWT1	29-Apr-14	225	208	33	62	46.6
	PSWT1	12-May-14	238	149*	39.2	64	50.5
PD16	AI	15-Apr-13		300			
	Scanning	11-Jul-13		241			
	DOB	09-Sep-13	0				
	Marking	25-Sep-13	16	356			
	WWT	07-Dec-13	89	343	17.6	56.5	31.4
	EPWT1	04-Jan-14	117	347	24.2	52	38.4
	EPWT2	21-Jan-14	134	344	27.4	57.5	43.2
	PSWT1	04-Feb-14	148	100	39.8	57	49
	PSWT2	08-Feb-14	153	94	47.8	51	46.9
PD18	AI	15-Feb-13					
	Scanning	01-Mar-13					
	DOB	01-Jul-13					
	MWT	15-Aug-13	44				
	WWT	11-Oct-13	100	237	12.2	41.0	29.9
	EPWT1	14-Nov-13	133	236	20.3	45.3	33.9
	EPWT2	19-Dec-13	168	236	22.3	48.6	35.7
	PWWT1	06-Jan-14	185	233	24.0	51.2	38.2
	PWWT2	24-Jan-14	203	233	28.9	57.2	42.9
	PWWT3	07-Feb-14	216	222	28.7	58.2	43.9
	PWWT4	13-Mar-14	252	124	33.5	55.5	43.9
	PWWT6	11/04/2014**	280	126	36.0	57.5	46.6
	PSWT1	25/02/2014**	234	234	31.6	62.4	46.5
	PSWT2	10-May-14	309	128	37.0	64.5	48.9

Appendix 1 cont. Summary of key dates, age of measurement and raw liveweight data from all producer demonstration sites.

	Site	Date	Age (d)	Count	Min (kg)	Max (kg)	Ave (kg)
PD19	AI	11/12 Feb 2013		600			
	Scanning	26-Apr-13		600			
	DOB	11-Jul-13	0	311			
	MWT	27-Aug-13	47	308	10.2	26.1	17.7
	WWT	11-Oct-13	92	299	12.7	35.1	23.6
	EPWT1	02-Dec-13	144	295	20.6	47.2	33.3
	EPWT2	30-Jan-14	203	280	14.3	48.5	33.2
	PWWT1	25-Mar-14	257	282	22.7	49.6	36.8
	PWWT2	16-Apr-14	279	159	34.7	60.8	43.8
	PWWT3	06-May-14	299	289	25.5	61.2	40.0
	PWWT4	23-May-14	316	170	22.3	51.2	38.9
	PWWT6	06-Jun-14	330	172	28.4	53.8	42.3
	PSWT1	06-May-14	299	117	38.9	61.2	46.6
	PSWT2	22-Jun-14	346	165	28.3	52.2	42.3
PD20	AI	13-14/3/13		600			
	Scanning	31-May-13	79	589			
	DOB	17-Aug-13	0	210			
	WWT	29-Dec-13	134	193	15.9	40.9	26.5
	EPWT1	25-Feb-14	192	194	16.0	39.0	25.5
	EPWT2	25-Apr-14	251	172	17.2	42.0	29.1
	PWWT1	21-May-14	277	154	22.5	47.0	34.1
	PWWT2	15-Jun-14	302	165	28.5	54.5	40.0
	PWWT3	14-Jul-14	331	166	30.5	53.0	41.2
	PWWT4	13-Aug-14	361	168	33.5	57.5	42.8
	PWWT5	26-Aug-14	374	169	37.0	57.5	45.1
	PWWT6	23-Sep-14	402	52	39.0	59.0	45.8
	PWWT7	07-Oct-14	416	60	37.0	59.0	44.8
	PSWT1	26-Aug-14	374	111	37.0	58.5	46.1
	PSWT2	07-Oct-14	416	57	37.0	59.0	44.5

Appendix 2. Degrees of freedom (number [NDF]; and denomimator [DDF]), F value and probabilites of the fixed effects in the mixed model for LMY, Shear Force and IMF.

		LMY			IMF			Shear force		
		NDF, DDF	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**
Terminal	RBV	1, 2452	11.51	0.0007	1, 1167	35.53	<.0001	1, 1125	21.26	<.0001
	Breed	1, 2452	0.98	0.3231	1, 1167	5.99	0.0145	1, 1125	0.27	0.6033
	FARM	15, 2452	1.36	0.1557	15, 1167	15.13	<.0001	15, 1125	3.16	<.0001
	SEX	1, 2452	2.51	0.1135	1, 1167	17.59	<.0001	1, 1125	5.2	0.0227
	SLDATE(FARM)	12, 2452	8.57	<.0001	6, 1167	1.37	0.2238	6, 1125	15.1	<.0001
	BT(FARM)	12, 2452	4.42	<.0001	12, 1167	1.68	0.0658	12, 1125	1.44	0.1414
	FARM*SEX	15, 2452	2.54	0.001				15, 1125	1.74	0.0379
	HCWT	1, 2452	541.72	<.0001	1, 1167	35.17	<.0001	1, 1125	7.95	0.0049
	HCWT*HCWT							1, 1125	6.57	0.0105
	HCWT*FARM	15, 2452	1.64	0.0562				15, 1125	2.65	0.0006
	HCWT*SEX	1, 2452	9.41	0.0022				1, 1125	4.28	0.0388
Merino	RBV	1, 416	4.42	0.0361	1, 280	2.13	0.1457	1, 247	3.62	0.0584
	FARM	2, 416	0.87	0.4185	2, 280	4.78	0.0091	2, 247	419.37	<.0001
	SLDATE(FARM)	2, 416	27.46	<.0001	1, 280	7.28	0.0074	1, 247	0.97	0.3264
	SEX(FARM)	1, 416	2.81	0.0947	1, 280	0.12	0.7282	1, 247	2.63	0.1063
	BT(FARM)				2, 280	2.42	0.091	2, 247	0.53	0.5901
	HCWT	1, 416	134.02	<.0001	1, 280	26.21	<.0001	1, 247	9.71	0.0021
	HCWT*FARM	2, 416	2.87	0.0577						

Appendix 3. Degrees of freedom (number [NDF]; and denomimator [DDF]), F value and probabilites of the fixed effects in the mixed model for HCWT, Dressing percentage, carcase EMD and carcase CFAT.

		HCWT			Dressing			CEMD			CCFAT		
		NDF, DDF	F Value	Pr > F	NDF, DDF	F Value	Pr > F	NDF, DDF	F Value	Pr > F	NDF, DDF	F Value	Pr > F
Terminal	RBV	1, 2536	5.74	0.0167	1, 2481	8.62	0.0033	1, 2470	9	0.0027	1, 2431	25.01	<.0001
	Breed	1, 2536	5.33	0.021	1, 2481	9.36	0.0022	1, 2470	0.04	0.8484	1, 2431	1.11	0.2911
	FARM	15, 2536	56.27	<.0001	15, 2481	60.19	<.0001	15, 2470	2.8	0.0002	15, 2431	1.9	0.0191
	SEX	1, 2536	52.6.36	<.0001	1, 2481	0.77	0.3817	1, 2470	17.61	<.0001	1, 2431	2.85	0.0914
	SLDATE(FARM)	12, 2536	22.87	<.0001	11, 2481	45.38	<.0001	12, 2470	9.31	<.0001	12, 2431	4.92	<.0001
	BT(FARM)	12, 2536	14.19	<.0001	12, 2481	4.02	<.0001	12, 2470	0.59	0.8543	12, 2431	2.27	0.0073
	FARM*SEX			n.s	15, 2481	2.34	0.0025			n.s	15, 2431	1.97	0.0142
	HCWT	-	-	-	-	-	-	12, 2470	449.59	<.0001	15, 2432	10.89	0.001
	HCWT*HCWT	-	-	-	-	-	-			n.s	15, 2433	3.99	0.0459
	HCWT*FARM	-	-	-	-	-	-	12, 2470	2.44	0.0015	15, 2434	1.72	0.041
	HCWT*SEX	-	-	-	-	-	-			n.s	15, 2435	7.04	0.008
	HCWT*FARM*SEX	-	-	-	-	-	-			n.s	15, 2436	1.95	0.0151
Merino	RBV	1, 472	4.34	0.0379	1, 469	5.74	0.017	1, 415	2.46	0.1177	1, 414	5.36	0.0211
	FARM	2, 472	6.36	0.0019	2, 469	23.98	<.0001	2, 415	0.57	0.5673	2, 414	4.56	0.011
	SLDATE(FARM)	2, 472	0.87	0.4215	2, 469	19.1	<.0001	2, 415	20.34	<.0001	2, 414	10.96	<.0001
	BT(FARM)	2, 472	2.66	0.0707	2, 469	1.02	0.3603	2, 415	1.11	0.3309	2, 414	0.94	0.3932
	SEX(FARM)	1, 472	13.32	0.0003	1, 469	5.95	0.0151	1, 415	3.1	0.0792	1, 414	2.14	0.1442
	HCWT	-	-	-	-	-	-	1, 415	53.26	<.0001	1, 414	14.24	0.0002
	HCWT*HCWT	-	-	-	-	-	-			n.s	1, 414	20.96	<.0001
	HCWT*FARM	-	-	-	-	-	-			n.s	2, 414	5.59	0.004

Appendix 4. Degrees of freedom (number [NDF]; and denomimator [DDF]), F value and probabilites of the fixed effects in the mixed model for HCWT, carcase EMA and carcase EMD with RBV for LMY (LMYR), IMF (IMFR) and SF5 (SHRF5R) included as covariates in the base model in terminal lambs.

	HCWT			EMA			EMD		
	NDF, DDF	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**
LMYR	1, 2535	0.43	0.5113	**1, 2470**	**4.47**	**0.0345**	1, 2468	3.4	0.0655
IMFR	1, 2535	0.03	0.8607	1, 2470	0.06	0.8097	1, 2468	0.53	0.4661
IMFR*IMFR				1, 2470	3.62	0.0572			
SHRF5R	1, 2535	0.03	0.8722	1, 2470	0.02	0.8792	1, 2468	0.06	0.8125
FARM	15, 2535	52.17	<.0001	15, 2470	2.7	0.0004	15, 2468	2.85	0.0002
Breed	1, 2535	5.17	0.0231	1, 2470	0.12	0.7257	1, 2468	0.3	0.5836
SEX	1, 2535	51.91	<.0001	1, 2470	0.37	0.545	1, 2468	17.31	<.0001
BT(FARM)	12, 2535	14.24	<.0001	12, 2470	12.17	<.0001	12, 2468	9.34	<.0001
SLDATE(FARM)	12, 2535	23.03	<.0001	12, 2470	1.3	0.2118	12, 2468	0.59	0.8548
HCWT	-	-	-	1, 2470	621.63	<.0001	1, 2468	448.89	<.0001
HCWT*FARM	-	-	-	15, 2470	2.68	0.0005	15, 2468	2.46	0.0014

Appendix 5. Degrees of freedom (number [NDF]; and denomimator [DDF]), F value and probabilites of the fixed effects in the mixed model for carcase C-Fat, GR thickness (HGRFAT) and loin pH (pHLL) with RBV for LMY (LMYR), IMF (IMFR) and SF5 (SHRF5R) included as covariates in the base model in terminal lambs.

	CFAT			HGRFAT			pHLL		
	NDF, DDF	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**
LMYR	**1, 2429**	**4.52**	**0.0336**	1, 2501	3.58	0.0586	1, 2260	0.02	0.8972
IMFR	1, 2429	3.24	0.0721	1, 2501	2.82	0.0932	1, 2260	1.69	0.1933
IMFR*IMFR							**1, 2260**	**5.75**	**0.0166**
SHRF5R	**1, 2429**	**14.46**	**0.0001**	**1, 2501**	**9.89**	**0.0017**	1, 2260	1.4	0.2376
FARM	15, 2429	1.96	0.015	15, 2501	2.49	0.0012	15, 2260	2.84	0.0002
Breed	1, 2429	1.67	0.1969	1, 2501	4.19	0.0408	1, 2260	3.11	0.0781
SEX	1, 2429	2.53	0.1116	1, 2501	0.83	0.3631	1, 2260	0.08	0.7816
SLDATE(FARM)	12, 2429	4.91	<.0001	12, 2501	13.97	<.0001	11, 2260	30.65	<.0001
BT(FARM)	12, 2429	2.34	0.0055	12, 2501	3.66	<.0001	12, 2260	0.59	0.8533
FARM*SEX	15, 2429	1.98	0.0136	15, 2501	2.21	0.0047			
HCWT	1, 2429	11.2	0.0008	1, 2501	822.56	<.0001	1, 2260	21.08	<.0001
HCWT*HCWT	1, 2429	4.18	0.041						
HCWT*FARM	15, 2429	1.73	0.0389	15, 2501	2.39	0.002	15, 2260	2.28	0.0034
HCWT*SEX	1, 2429	6.6	0.0103	1, 2501	5.78	0.0163			
HCWT*FARM*SEX	15, 2429	1.95	0.0153						

Appendix 6. Degrees of freedom (number [NDF]; and denomimator [DDF]), F value and probabilites of the fixed effects in the mixed model for carcase fresh colour redness (a*), yellowness (b*) and lightness (L*) with RBV for LMY (LMYR), IMF (IMFR) and SF5 (SHRF5R) included as covariates in the base model in terminal lambs.

	a*			b*			L*		
	NDF, DDF	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**	**NDF, DDF**	**F Value**	**Pr > F**
LMYR	1, 2246	0.48	0.4899	1, 2231	1.04	0.3081	1, 2246	0.36	0.5513
IMFR	1, 2246	3.39	0.0655	1, 2231	0.33	0.5654	1, 2246	0	0.9571
SHRF5R	1, 2246	0.1	0.7474	1, 2231	1.17	0.2795	1, 2246	3.23	0.0726
FARM	15, 2246	2.18	0.0054	15, 2231	1.6	0.0662	15, 2246	23.24	<.0001
Breed	1, 2246	1.33	0.2492	1, 2231	0.54	0.4633	1, 2246	1.88	0.1702
SEX	1, 2246	31.78	<.0001	1, 2231	4.87	0.0274	1, 2246	3.03	0.082
SLDATE(FARM)	11, 2246	19.59	<.0001	11, 2231	29.43	<.0001	11, 2246	23.1	<.0001
BT(FARM)	12, 2246	0.62	0.8274	12, 2231	0.58	0.8577	12, 2246	1.04	0.4071
FARM*SEX				15, 2231	1.71	0.0426			
HCWT	1, 2246	0.7	0.4026	1, 2231	12.67	0.0004	1, 2246	15.06	0.0001
HCWT*FARM	15, 2246	2.07	0.009	15, 2231	2.14	0.0066	15, 2246	4.81	<.0001