final report

Project code: B.SGN.0117

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Date published: November 2011

ISBN: 9781741915341

PUBLISHED BY
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Locked Bag 991
NORTH SYDNEY NSW 2059

Lamb Energetics – Red Meat Energetics

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Lamb energetics investigated phenotypic and genotypic factors that impacted on efficiency of lambs during finishing. The study investigated the impacts of a pre-weaning nutritional restriction, and lamb weaning weight and age at finishing on efficiency during a finishing phase. Industry benefits included guidelines related to genetics and on farm management of lambs that optimise lamb efficiency during finishing. A pre-weaning nutritional restriction (twins vs singles) had no impact on feed conversion ratio (FCR) during finishing in wether lambs, but restricted ewe lambs were approximately 3 FCR units less efficient ($P<0.05$) than unrestricted ewe lambs. Decreasing sire PFAT by 1.5mm improved lamb efficiency by about 5 FCR units. In general lambs that were light at weaning gained less weight during finishing than lambs that were heavy at weaning, however the weight gain of these lighter lambs was characterised by proportionately more lean deposition resulting in increased LMY at slaughter. However, this did not result in differences in FCR. Lambs finished at older ages grew slower, deposited proportionately more fat, and had reduced LMY, all characteristics demonstrated by more mature animals. This slower growth was associated with poorer FCR in the older lambs. Awareness of, and interest in the efficiency of finishing lambs, has not been confined to terminal lamb operations. Lamb finishers are best positioned to improve the efficiency of their lamb operations by utilising project recommendations, but lamb breeders are also increasingly aware of their contribution to industry efficiency.

Executive summary

Lamb efficiency is an important consideration for lamb finishers and lamb producers. Producers are often faced with challenges that impact on efficiency of production, yet it remains difficult to quantify these impacts. In the course of their development many lambs are subjected to a period of restricted nutritional intake. Such a restriction in cattle has been shown to impact upon their subsequent growth and performance, compromising their ability to meet market specifications when sold at the same age as unrestricted contemporaries. These animals also require longer periods on feed to reach market specifications, markedly increasing the cost of finishing (Wright et al, 1986), if indeed they are able to reach target slaughter weights at all (Ryan et al, 1993). In addition, producers are often faced with a challenge of managing 'tail end' lambs, these lambs are light at weaning and take longer to reach a given market specification, representing a challenge to the producer. There are numerous questions about the subsequent management of these tail end lambs, i.e. Should they be sold in the saleyards at weaning? Should they be put into a light slaughter market (Muslim kill)? or should they be retained and finished at a later date – and if so, how long should they be retained for? These management questions centre on making the most efficient use of this resource by addressing at what age and stage of development is the lambs' efficiency optimised?

A comprehensive review of available literature on lamb efficiency was conducted. In addition, 350 lambs, representing 21 sire groups were tested for feed intake and efficiency. As a result of monitoring the efficiency of a diverse group of lambs it was possible to develop industry guidelines that outline the key drivers for improved efficiency of lambs during finishing. Identifying the optimum time to finish a specific group of lambs maximises potential returns. Management of lambs prior to finishing must consider the inherent variations within a group of lambs, variations such as genetic potential, weaning weight and age will all influence the optimum time to finish the lambs. To meet the needs of the scientific community two scientific papers "The effect of a pre-weaning nutritional restriction on lamb development and efficiency during finishing" and "The impact of weaning weight and age during finishing on lamb development and efficiency during finishing" are being submitted for publication.

Findings

- Previously restricted lambs were lighter at all time points post the period of nutritional restriction, and it is unlikely that they would have compensated to a point of similar body weights as unrestricted lambs.
- An early nutritional restriction in ewe lambs worsens feed efficiency during finishing (by approximately 3 FCR units). However, the early nutritional restriction had no impact on the later feed efficiency of wether lambs.
- For both light and heavy weaning weight lambs, decreasing sire PFAT by 1.5mm improved lamb efficiency by about 5 FCR units.
- In general lambs that were light at weaning gained less weight during finishing than lambs that were heavy at weaning, however the weight gain of these lighter lambs was characterised by proportionately more lean deposition resulting in increased LMY at slaughter. However, this did not result in differences in FCR.
- Lambs finished at older ages grew slower, deposited proportionately more fat, and had reduced LMY, all characteristics demonstrated by more mature animals. This slower growth was associated with poorer FCR in the older lambs.
- Lambs with low weaning weights can have acceptable FCR for an intensive finishing system, but there is a significant decrease in FCR, irrespective of weaning weight, when lambs are taken out to older ages. In these cases lambs that are light at weaning are best sold at younger ages and targeted at a lighter market specification.

Those sectors of the industry closest to the work (lamb finishers) have already benefited from research outcomes. Lamb finishers (those based on grain or grass) are able to improve the efficiency of their lamb finishing operations by utilising project recommendations. Lamb energetics was specifically developed with a whole of chain approach, and as such awareness of project outcomes has not been limited to lamb finishers. Should seed stock producers have access to technologies or tools such as breeding values that facilitate improvements in feed efficiency, whole of chain improvements are almost assured. Awareness of and interest in the efficiency of finishing lambs has not been confined to terminal lamb operations. Almost unexpected at the start of the project was the surge in interest (towards the conclusion of the project) in maternal efficiency – from a reproduction and metabolic viewpoint. So while those operations that include a lamb finishing component are best placed to take advantage of research findings, seed stock producers and lamb breeders are also positioned to take advantage of flow on benefits.

Contents

1 Glossary of terms

ASBV	Australian Sheep Breeding Values
Cfat	Refers to fat depth at the C site (i.e. subcutaneous fat depth, 40mm from the midline, over the m. longissimus (loin) at the 12th rib)
EMA	Eye Muscle Area
EMD	Eye Muscle Depth
FCR	Feed Conversion Ratio
GBLUP	Genotypic Best Linear Unbiased Prediction
GR	Refers to the GR site for measuring fat depth in a lamb carcass (i.e. total tissue thickness at the twelfth rib, 110 mm from the midline)
HSCW	Hot Standard Carcass Weight
LMY	Lean Meat Yield
MLA	Meat and Livestock Australia

2 Background

Reviewed literature and experimental findings show considerable variation in the efficiency of growth and development of lambs, as well as for the heritability of various measures of efficiency. Causes of variation in animal efficiency can be separated along the lines of genetic and environmental factors, with both having potential to be manipulated for improvements in overall efficiency.

Much of the recent lamb (and more widely ruminant) research that has investigated genotype and environmental considerations has not measured animal efficiency. In part this has been due to differing research priorities, but is also due to the difficulties associated with measuring feed intake, and ultimately animal efficiency. Accordingly, measures of animal efficiency for modern lamb genotypes are scarce. Where measures of efficiency are provided, there is a tendency to report the limited measure of feed conversion ratio, as opposed to residual feed intake (that considers expected feed intake, is independent of growth and does not result in increased mature weight).

This final report identifies a number of opportunities for improving the energetic efficiency of the Australian lamb industry. Key to this is 1) the development of an appropriate target for improvement in feed efficiency, 2) the need to assess the impacts of new selection pressures (such as increasing lean meat yield) on lamb efficiency and 3) the need to assess efficiency for a range of supply chain components, across a range of timeframes (whereas efficiency during finishing may be appropriate for some industry segments, others may require assessment over a whole lifetime).

Recommendations are not just confined to research, with extension and ultimately uptake of research outcomes also required. While new research tools, such as emerging DNA based technologies (particularly for identification of specific gene markers) hold promise for improvements in feed efficiency there remains a need for an understanding of how fundamental elements of on-farm management (eg. weaning weight, growth path and maturity pattern) impact on the efficiency of lambs during finishing. An understanding of how these basic principles affect efficiency during finishing will ideally become key messages for appropriate extension activities.

Market specifications continue to evolve, and vary from traditional concerns such as food safety, and weight and fat thresholds, to emerging credence values that include animal welfare and environmental standards. At the same time as meeting consumer expectations for a range of considerations, production systems need to be highly efficient. Efficiency of resource use is being driven not only by economic imperatives, but also by environmental and social considerations.

Improvements in processing efficiencies have been driven by technological gains within the abattoir and boning room, and by changes in input specifications. Genetic improvement in the lamb industry has been significant (4% per year genetic gain since the 1990s) (Pethick *et al*. 2006) with a trend towards increased lean meat yield with a higher percentage of the carcass in the high value cuts.

Amongst other factors, on-farm efficiency gains have been driven by improvements in reproductive performance as well as by improvements in the growth rates of terminal genetics (Banks 1994). Growth is such a fundamental component of systems efficiency that modelling by Snowden and Van Vleck (1988) has shown a twofold improvement in economic returns from selection based on daily gain versus direct selection for feed conversion ratio. Poor animal growth in young stock (that results in increased mortality, reduced reproductive performance in ewe lambs/hoggets, delayed attainment of market specifications and a reduction in fleece quality) has significant negative implications on animal efficiency in later life (Graham and Searle, 1975).

Clearly there are significant benefits from improving lamb growth and many studies have targeted this goal. Improvements in growth have been achieved through a variety of means including increased nutrition (Hegarty *et al*., 2006a, Hall *et al*., 2002), hormonal manipulation (Lindsay *et al*., 1993) and genetic improvement (Banks, 1994).

While there has been a considerable amount of research focused towards the impact of feed restriction on subsequent growth path, there has been relatively little focus on the impact of restriction on feed efficiency. The efficiency with which feed is converted into product is an important component of on-farm productivity (Grainger and Goddard, 2009). Feed Conversion Ratio (FCR) is a measure of the amount of feed consumed to produce a unit of live weight gain. Due to the ease with which a pen average value for FCR can be generated, it remains the most widely used indicator of animal efficiency in commercial finishing systems (Hennessy and Arthur, 2004).

3 Project objectives

3.1 Objective

To define energetic differences between high and low growth and muscle genotype lambs.

To devise appropriate management interventions that optimise performance on-farm and for subsequent supply chain members.

3.1.1 Primary outcome

Management interventions that are matched to genotypic and phenotypic requirements of lambs.

Such interventions would contribute to improved productivity and compliance to market specifications, giving increased lamb industry performance.

Target audiences for the project outcomes can be divided into three groups, those with the likelihood of receiving a benefit in the short term, the medium term or the longer term. The initial target audience, that is those who are likely to receive a benefit in the short term, will largely consist of lamb finishers. Mid term benefits will be received by lamb breeders (anticipated as within 1 to 2 years of project outcomes being generated). Longer-term improvements will continue to flow to buyers and processors. The time lines associated with these longer-term improvements would be dependent on the structure of the supply chain and the ability of the supply chain to recognise and respond to a change in supply.

4 Methodology

Two experiments were conducted. The first experiment was designed to assess the impact of a pre-weaning nutritional restriction on growth, composition and efficiency during finishing. The second experiment assessed the impact of weaning weight and age at finishing on the same traits of growth, composition and efficiency during finishing. In the first experiment, twin versus single lambs were used to replicate a nutritional restriction. In the second experiment, only twin lambs were used. In both experiments diverse genotypes were evaluated from birth through to slaughter, with feed intake measured during the finishing phase. The experiments were conducted at the Victorian Department of Primary Industries, Rutherglen Centre, Rutherglen, Victoria (Latitude 36.10 °S Longitude 146.51°E).

4.1 Ewe and sire selection, insemination and management during pregnancy

A flock of 3 yr old first-cross (Merino X Border Leicester) ewes (n=292) were selected from a single property of origin. In two subsequent joinings, ewes were inseminated with semen from 21 sires (one link sire was used in both years) with ewes allocated to sires on a random basis. Sires were selected based on their LAMBPLAN ASBVs, targeting extremes in post weaning weight (Pwwt) and eye muscle depth (Pemd). The 21 sires and their associated Pemd, Pwwt, and post weaning fat depth (Pfat) ASBVs are summarised in Table 1. The overall range of sire ASBVs were: Pwwt +3.70 to +16.3; Pemd -0.98 to +3.04; Pfat -1.59 to 0.5.

Table 1. Australian sire breeding values of sires for birth weight (Bwt), weaning weight (Wwt), post-weaning weight (Pwwt), post-weaning fat depth (Pfat) and post-weaning eye muscle depth (Pemd) of sires used.

Sire	Lambplan Identity	Bwt	Wwt	Pwwt	Pfat	Pemd
1	1605452003030097	0.26	9.03	14.28	-1.04	3.04
2	2302862003034156	0.24	9.00	13.23	-1.00	0.69
3	1611432003030091	0.19	8.25	12.67	-0.45	0.74
4	2302862004040231	0.50	8.30	12.66	-1.28	1.16
5	2300902002020079	0.03	7.12	12.4	-1.25	1.27
6	1643062005050176	0.07	6.77	12.35	-1.00	1.45
7	2306362005050716	-0.29	6.90	11.70	0.3	2.3
8	2300902005050481	0.42	7.91	11.55	-1.32	1.5
9	1612352002020462	0.48	7.57	10.58	-0.67	2.43
10	2301001993030015	0.35	4.68	7.08	-1.58	-0.98
11	2300031990900940	0.43	4.97	6.35	-1.22	-0.14
12	1619722003020696	0.12	5.15	5.97	-1.4	-0.14
13	2300902003030806	0.29	3.76	3.70	-1.59	1.31
14	1614832004040107	0.11	9.4	15.2	-1.7	0
15	1644222005050334	0.22	8.2	12.5	-1.4	2.5
16	1603362004040370	0.67	12.3	16.3	-1.1	1.5
17	1644222005050431	0.23	9	15.1	-1.1	2
18	1644222005050437	0.12	8.5	13.9	-1.3	1.6
19	1605452004040454	0.31	8.8	14.2	-1.5	2.2
20	1605452005050603	0.19	9.5	16.1	-1.4	1.2
21	1644222006060666	0.75	11	17.4	-0.4	2.6
22	2306362005050716	-0.17	6.6	11.5	0.5	2.9

In preparation for artificial insemination, intra-vaginal progesterone releasing sponges (Chronogest, Intervet Australia Pty Ltd) were inserted into ewes for 12 days then removed and each ewe injected with 2mls Folligon (Intervet Australia Pty Ltd). Ewes were left without food or water overnight, being inseminated approximately 48hrs after removal of sponges.

Ewes were ultrasonically scanned for pregnancy and litter size 55 days after insemination and non-pregnant ewes removed. All pregnant ewes were run as single flocks, until 10 days before the expected lambing date. On this day ewes were drafted into sire joining groups, and each group then lambed in a separate 1 ha paddock. Ewes were checked twice daily during lambing and each lamb identified to its mother, weighed and ear tagged within 24 hrs of birth. Ten days after the mean lambing day, the sire joining groups were grouped back together into a single flock.

4.2 Monitoring of feed intake

Successful monitoring of individual feed intake was critical to the success of the project. While also ensuring successful data collection, the development of automated feeders also aided in considerable producer interest in not only project findings, but the project methodologies. Such interest stimulated a lot of discussion around project outcomes, and was instrumental in bringing many producers to Rutherglen to inspect the facilities utilised during the project.

Feed intake was monitored at the Rutherglen animal house, a raised shed with mesh flooring equipped with five Ruddweigh automated feeders. Feed intake was measured at a 10 gram level of accuracy using four Kelba S type load cells (Model # KPA 6110) on the feed bins. Physical dimensions of the feeders ensured minimal wastage of the ration.

Feed intake units were hard wired to a desktop computer that acted as a data logger, downloading data every 30 minutes pertaining to the number of feeding events, electronic identification (EID) of animals feeding, opening and closing weight of the feed bin and duration of each feed event (Kearney *et al*. 2004). Each feeder was equipped with a 12v battery backup to retain systems integrity in the case of a power outage. All electrical communication lines were RS485. The desktop computer was equipped with relevant software (Feed Intake Monitoring System V1.13, Gallagher NZ) to collect and manage the data from the feed intake units.

Figure 1. Lamb eating at automatic feed intake unit, showing V race, exclusion zone around the feeder and suspended feed hopper, electronics are housed in the electrical box mounted on top of feeder (with cable looped on its back).

Individual animals were identified by EID tags. Automatic feeders were equipped with EID readers that energise the EID, which in turn transmit their unique identification number as a radio frequency which the reader receives and relays to the computer. The chance of false reads i.e. reading the tag of a non feeding lamb was eliminated by two features, 1) a v race that enabled only one lamb to access the feeder at any one time, and 2) the use of an exclusion zone around each feed bin.

Feed efficiency was measured as Feed Conversion Ratio (FCR), the total kg of feed consumed over the finishing period divided by the change in lamb body weight over the finishing period. Change in lamb live weight was calculated as a linear regression of lamb age and weight.

4.2.1 Animals, management and slaughter procedures

Lambs were weighed at birth, marking, pre-weaning, weaning, twice during backgrounding and weekly during finishing.

To assess body composition all lambs were scanned with a Honda electronics convex ultrasound scanner (HS-1500)™ with a variable 1.5 - 3.5 MHz probe for eye muscle depth (EMD) at the 12th rib and fat depth at the c-site (40 mm from the midline over the 12th rib) at weaning, at the start and at the conclusion of the finishing phase.

After weaning lambs were run as single contemporary groups, and were backgrounded on cereal stubbles and improved pastures prior to finishing.

Prior to entry to the animal house lambs had been introduced to the trial ration over a 15 day period and fed *ad libitum* for 5 days. The trial ration was sourced through Ridley Agriproducts as a pelleted product (13.5 MJ metabolisable energy (ME) per kilogram of dry matter and 16.7% crude protein) with no monensin included.

Prior to transportation and slaughter, lambs undertook a 24hr curfew. Lambs were transported 4.5 hr by truck to a commercial abattoir the evening prior to slaughter, placed in lairage overnight (approx 12hrs) and were the second group of lambs slaughtered in the morning (approx 6:00am). Hot Standard Carcass Weight (HSCW), tissue depth at the GR site and Viascan predictions of Lean Meat Yield (LMY) were collected at slaughter.

4.3 Impact of a pre-weaning nutritional restriction - Experiment 1.

An early nutritional restriction was achieved by assessing the performance of twin versus single born and reared lambs. Allocation of lambs into feed intake groups was based on live weight at weaning but included a stratified randomisation, such that each sire was equally represented in the first and second finishing groups, as were the number of twins and single-born lambs within each sire group. Two groups of lambs were assessed for feed intake; the first consisted of the two heaviest singles and the two heaviest twins at weaning, for each sire, the second group contained the lightest two singles and the lightest two twins at weaning from each sire group.

The first group of lambs entered and exited the animal house at 216 and 250 days of age respectively, the second group entered at 257 and exited at 300 days of age. Lambs were slaughtered in two subsequent groups, group one averaged 252 days (36 weeks), and group two 302 days (43 weeks) of age at slaughter.

4.4 Impact of weaning weight and age at finishing - Experiment 2.

Based on weaning weight, 162 lambs were selected at weaning (14 weeks of age) for feed intake monitoring during finishing. Lambs were ranked from lightest to heaviest, with an equal sample of lambs taken from the lightest, medium and heaviest weaning weight percentiles for each sire group. Lambs from each percentile were then randomly allocated into either the first, second or third finishing group. Selected lambs were all born and reared as twins.

The three groups of lambs to be assessed for feed intake entered the animal house at 21, 29 and 38 weeks of age respectively.

A 3x3 factorial matrix was utilised, with three weaning grades versus three finishing ages. All first order interactions between terms were included and non significant terms were sequentially removed from the model for the final analysis.

Growth of lambs during the test period was modelled by a linear regression of weight against time and regression coefficients were used to calculate average daily gain and live weight at the start and end of the test period.

5 Results and discussion

5.1 Impact of a pre-weaning nutritional restriction - Results

5.1.1 Growth rate, animal efficiency and body composition

Sex had a significant effect on lamb weight at birth, marking and weaning, with wether lambs being 0.3 ($P < 0.001$), 0.7 ($P < 0.008$) and 1.6 kg ($P < 0.013$) heavier than ewe lambs at the three time points respectively. Wether lambs were not significantly heavier than ewe lambs at either entry to or exit from the finishing system for either finishing group one or two.

Birth type had a significant impact on birth weights ($P<0.001$). Birth type alone was not a cause of significant variation in marking weights, however when assessed as a birth type and rear type interaction, the effect was significant ($P<0.001$) for both marking and weaning weights (Table 1).

Table 1. Feed conversion ratio during finishing, and weight (kg) of lambs at birth, marking, weaning, and at entry and exit of the finishing system (standard errors are included in brackets).

	Birth type Rear type	Single Single	Twin Single	Twin Twin	Triplet	Triplet Twin
All lambs	Birth wt	5.6 (0.11)	N/A	4.5 (0.08)	4.0 (0.16)	N/A
	Marking wt	16.0 (0.29)	13.2 (0.5603)	12.3 (0.22)	#	12.2 (0.46)
	Weaning wt	37.1 (0.60)	32.1 (1.2530)	29.1 (0.41)	#	29.0 (1.02)
Finishing group 1	Entry wt	47.5 (0.92)	*	40.4 (0.94)		*
	Exit wt	55.3 (1.20)	*	49.0 (1.23)		*
	FCR	7.4 (1.07)	*	7.8 (1.11)		*
Finishing group 2	Entry wt	48.2 (1.01)	*	42.8 (0.90)		*
	Exit wt	52.6 (1.33)	*	47.3 (1.16)		*

FCR	16.0 (1.28)	*	17.2 (1.01)	*

No lambs were raised as triplets
* Twin lambs reared as singles, and triplet lambs reared as twins were excluded from finishing due to insufficient numbers.

Lamb entry weights to the finishing system were significantly different between multiple and single lambs for both the first and second finishing groups, with single lambs significantly heavier than twin lambs (P<0.001). There were no significant differences between the entry weights of single lambs between the first and second finishing groups, nor between the entry weight of twin lambs from the first and second groups (Table 1).

For both the first and second finishing groups, single lambs had significantly heavier exit weights from the finishing system than twin lambs (P<0.001). For both single and twin lambs, exit weights from the finishing system were greater for the first group of lambs (Table 1).

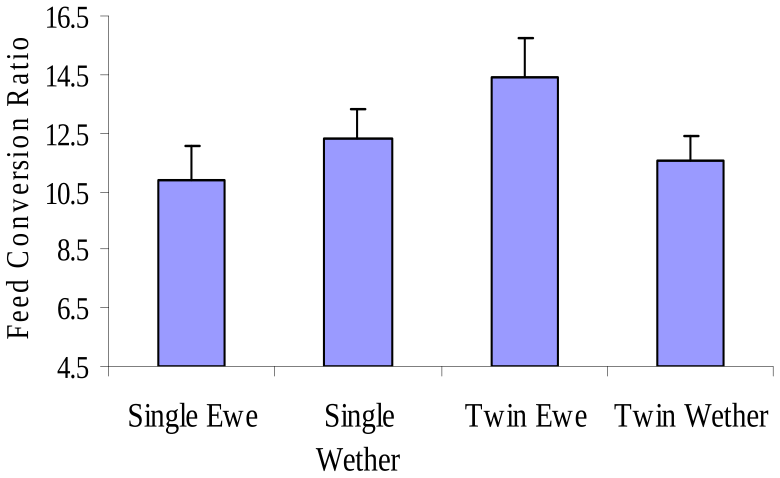

Figure 2. Effect of lamb sex and birth/rear type on feed conversion ratio during finishing.

Single ewe lambs had better FCR than twin ewe lambs (P<0.05) by about 3 FCR units, a difference that was not evident in wethers (Figure 2).

Table 2. Eye muscle depth (mm) and c-site tissue depth (mm) of single versus twin lambs at entry to and exit from the finishing system (standard errors are included in brackets).

Finishing group 1		Single	Twin
Start of finishing	EMD	29.4 (0.63)	28.9 (0.67)
	c-fat	2.8 (0.13)	2.8 (0.15)
End of finishing	EMD	32.4 (0.44)	33.4 (0.42)
	c-fat	4.6 (0.24)	4.5 (0.23)
Finishing group 2			
Start of finishing	EMD	31.7 (0.71)	31.2 (0.58)
	c-fat	3.8 (0.16)	3.9 (0.12)

End of finishing	EMD	34.0 (0.46)	34.1 (0.42)
	c-fat	4.9 (0.25)	5.2 (0.22)

Neither birth type, nor lamb sex had a significant effect on lamb fatness at entry to or exit from the finishing system. However, lamb fatness was significantly affected by live weight, with heavier lambs being fatter (P<0.001). Lamb weight was also a significant factor in lamb muscularity with heavier lambs having significantly greater EMD at both entry to and exit from finishing than lighter lambs (P<0.001).

Interactions between birth type/rear type, and finishing group were significant (P<0.001) for lamb EMD at entry to the finishing system, with both single and twin lambs in the second group of lambs having greater EMD at the start of finishing than lambs in the first group.

For the first and second groups of lambs, singles tended to have greater EMD than twins at both the start and at the end of finishing. There were no significant differences in the c-fat measurements between single and twin lambs at either the start or end of finishing, for either the first or second finishing groups (Table 2).

While single lambs tended towards greater EMD measurements at the start of finishing, the gain in EMD between the start and end of finishing was greater for twin lambs (Table 2). For both single and twin lambs the relative gain in EMD (gain in EMD during finishing as a percentage of EMD at entry) was greater for the first group of lambs (single lambs, grp 1 10.2% v's grp 2 7.3%)(twin lambs grp 1 15.6% v's grp 2 9.3%).

For both single and twin lambs, EMD at exit from the finishing system was significantly greater in the second finishing group than for the first group of lambs (P<0.05) (Table 2).

Lamb sex had no significant impact on fat or the EMD of lambs at either the start or at the end of finishing. However, both fat and EMD measures were significantly affected by lamb live weight. Lamb live weight at entry to and exit from the finishing system was not significantly affected by lamb sex, with wether lambs only trending towards heavier weights than ewe lambs at both entry to and exit from the finishing system (0.23 and 1.66 kg respectively).

Within both groups, decreasing sire PFAT by 1.5mm improved (P<0.05) lamb efficiency by about 5 FCR units. Across all of the tested sires, lambs from group 1 were about 9 FCR units more efficient (P<0.05) than group 2 lambs (Figure 3).

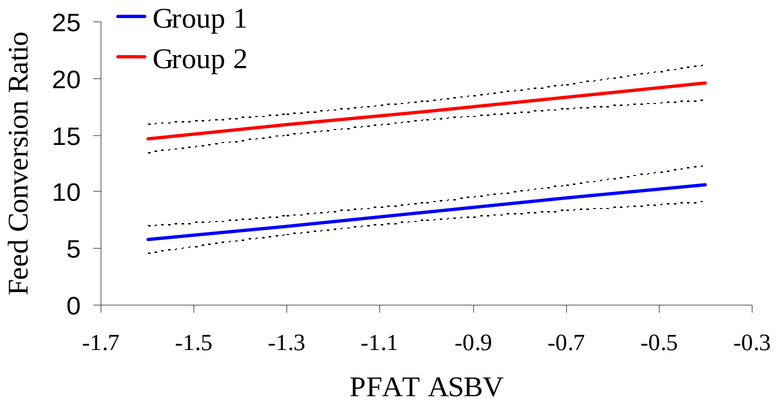

Figure 3. Effect of sire Pfat (Australian Sheep Breeding Value) on feed conversion ratio during finishing.

5.1.2 Carcass data

For both the first and second finishing groups, single lambs had heavier carcass weights than twin lambs (P<0.001) (Table 3). There was no significant difference between carcass weights of single lambs from the first group, versus single lambs from the second group, nor between twin lambs from the first versus second groups.

Table 3. Carcass characteristics of single versus twin lambs, for finishing groups one and two (standard errors are included in brackets).

	Single	Twin
Finishing group 1		
hscw (kg)	26.6 (0.68)	22.9 (0.70)
gr (mm)	18.5 (1.13)	15.1 (1.18)
lmy (%)	53.1 (0.55)	55.1 (0.57)
loin yield (%)	14.5 (0.10)	14.9 (0.11)
Finishing group 2		
hscw (kg)	25.0 (0.76)	23.3 (0.65)
gr (mm)	17.0 (1.24)	16.1 (1.08)
lmy (%)	53.7 (0.60)	54.0 (0.53)
loin yield (%)	14.5 (0.11)	14.5 (0.10)

For both finishing groups wether lambs had significantly (P<0.05) heavier carcass weights than ewe lambs (1.8 kg). Lamb sex did not have a significant effect on carcass fatness (GR), lean meat yield or percentage of loin yield.

While interactions between birth and rear type, and finishing group were not significant for carcass fatness, they were significant for lean meat yield and percentage of loin yield (P<0.05) (Table 3).

5.2 Impact of a pre-weaning nutritional restriction - Discussion

5.2.1 Growth rate, body composition and animal efficiency

Growth rate

The use of twin lambs as a means of replicating a pre weaning nutritional restriction did result in lambs that were lighter through to weaning. However, the impacts of the pre-weaning nutritional restriction were longer lasting than the period of the restriction itself, with previously restricted lambs also lighter at both entry to, and exit from the finishing system.

That twin lambs were lighter at birth, marking and weaning was expected due to the nutritional restriction that twin lambs had been subjected to both in utero and as neonates. That they were still lighter at entry to and exit from the finishing system was not as expected. Despite the faster rate of gain between weaning and slaughter for twin versus single lambs, twin lambs had lower entry weights to the finishing system and lower slaughter weights (and hence carcass weights) than single lambs – hence twin lambs were unable to compensate to a level of equal body weight in the time available.

Our work that shows lower marking weights for multiple lambs, is supported by Hopkins *et al.* (2007) who found that marking weight, adjusted to 20 days of age, depended jointly on whether the lamb was born as a single or multiple ($P<0.001$), rear type ($P<0.001$), and birth weight ($P<0.001$).

Our results are further supported by Hegarty *et al.* (2006) who found that single lambs were heavier at birth than multiple born lambs (5.24 versus 4.24 kg) and had faster pre weaning growth rates (278 versus 212 g/day, sed = 5.3) resulting in greater weaning weights (31.3 v 24.2 kg, sed = 0.80). However, after weaning, multiple born lambs grew faster than single born lambs (109 v 97 g/day, sed = 4.3) but remained lighter at slaughter (40.2 v 45.5kg, sed = 0.90).

While twins, as well as single lambs, had the same entry and exit weights for the two finishing groups, this would be different if assessed on a weight for age basis. Being heavier at a younger age, the first group of lambs to be finished had greater weight for age when compared to the second group of lambs.

For finishing group one, single lambs entered the finishing system at 85.9%, and twin lambs 82.4%, of their exit weights. For the second group of lambs, single lambs were already 91.6%, and twin lambs 90.4% of their exit weights at the start of finishing – hence there was more growth potential in the first finishing group, than for the second finishing group.

Hennessy and Arthur (2004) report similar weight gains during feedlot finishing between calves that had been subjected to either a low or high pre-weaning growth rate. As expected, the low pre-weaning growth rate group were significantly lighter at feedlot entry than those lambs with higher pre-weaning growth rates.

Despite being lighter at weaning, by the time the second group of lambs entered the finishing system they had achieved similar entry weights as the first finishing group, with single lambs again being significantly heavier than twin lambs. Despite similar entry weights between the first and second groups, exit weights differed greatly - with weight gains during finishing for the second group of lambs being less than half that of the first group (Table 1).

Significant differences in weight gain were found between the first and second groups of lambs during finishing. Growth rates for single and twin lambs in the first intake (258 and 208 grams/hd/day) were significantly greater than those of singles and twins in the second intake (68 and 67 grams/hd/day). The low growth rates of the second finishing group were paralleled by poor animal efficiency – to the extent that profitability would be compromised.

The theoretical implication of this result is that by entry to and exit form the finishing system, twin lambs were unable to compensate for a pre-weaning period of reduced nutritional availability.

Such a theoretical implication has considerable practical implications when finishing either twin or single lambs. It appears that despite some periods of higher weight gains, twins will be lighter than single lambs at all time points. Hence, feeding periods to achieve set market specifications (particularly heavy export specifications) will be longer for twins than for singles, leading to greater costs. Additionally, twin ewe lambs have had poorer FCR, which again leads to greater costs.

Given that twin and single lambs of both finishing groups had similar growth rates at the conclusion of finishing, it is unlikely that the twin lambs would have been able to achieve the live weights of the single lambs for either group. This is in agreement with Ryan *et al.* (1993) who concluded that the similar rates of live weight gain between lighter, previously restricted lambs, and heavier, unrestricted lambs, indicated that they would be unlikely to achieve the same body weight.

The greater implication to on-farm management comes from taking lambs that were light at weaning through to similar entry weights (at an older age) and then finishing them. In this case the growth rate of these lambs is poor at best, and unlikely to be profitable.

Body composition

In addition to potential impacts on weight gain, the impact of an animal's growth path prior to entry to a finishing system has been shown to affect carcass composition and retail yield at slaughter (Greenwood and Café 2007). Such differences in carcass composition may then impact on the metabolic efficiency of the restricted versus unrestricted animals.

Entry weights of single lambs were the same in the first and second intakes, as were the entry weights of twin lambs. Despite having the same entry weights, body composition at the start of finishing differed significantly for both twins and singles between the first and second intakes. Both EMD and c-fat levels were greater at the start of finishing in the older, second intake of lambs.

For both singles and twin lambs, despite having the same entry weights between groups one and two, lambs in group two were significantly fatter at entry to the finishing system. The increased fat levels indicate that the group two lambs were more biologically mature at the start of finishing than the group one lambs, and as a consequence have had reduced growth potential, as evidenced by the lower weight gains for these lambs. Given their more advanced biological maturity, fat deposition has been lower in lambs from the second group than for lambs from the first group (lambs from group one had a 62.5% increase in c-fat depth from start to end of finishing, while group two lambs had a 31.3% increase in c-fat).

There are considerable implications when lambs that are light at weaning are taken out to older ages to achieve a predetermined start of finishing weight, as was the case for group two lambs. Lambs in the second intake had higher EMD and c-fat levels at the start of finishing than lambs in the first intake. Their potential for gain in both EMD and c-fat was reduced as both traits were already at levels closer to their biological potential, hence very little change was detected, with accordingly low weight gains.

When comparing EMD and c-fat depths at the conclusion of finishing there were no significant differences between twin or single lambs, nor between the first and second finishing groups for both twin and single lambs. Hence from a fat perspective both twin and single lambs appear equally suitable to fitting market specifications. However, given that twin lambs have proportionally greater levels of carcass fat (given the same carcass weights) there are issues associated with compliance to various market specifications.

There have been many hypotheses (Brody 1945) and work (Puller and Webster, 1977 and Webster 1980) that shows increased energy expenditure in depositing fat than lean tissue. Thus, a possible further implication of lambs from the second group having greater c-fat depths relative to carcass weights, may be a reduction in energetic efficiency.

Energetic efficiency

Twin ewe lambs were less efficient than single ewe lambs. However our results agree with Ryan *et al*. (1993) where nutritional restriction had no impact on FCR in wether lambs.

Lambs that were sired by leaner sires were more efficient during finishing in both groups 1 and 2, and this is likely to be associated with efficiency of lean tissue accretion (Owens *et al.* 1995). These results show that the current practice of selecting rams with low PFAT is energetically sound for finishing lambs, and that an early restriction will impact on the efficiency of twin ewe lambs during finishing.

While in agreement with Ryan *et al*. (1993), who found no difference in feed conversion ratio between restricted and control wethers at any time during their experiment, our work is in disagreement with that of Hennessy and Arthur (2004) who found that British bred cattle that had been subjected to restricted growth from birth to weaning were more efficient (lower FCR) during a period of feedlot finishing than their unrestricted contemporaries. We saw no change in efficiency during finishing for wether lambs that had been previously restricted.

There were however large differences in the efficiency of twin and single lambs from the first finishing group versus twin and single lambs from the second finishing group. The greatest difference in lamb efficiency was not between twin and single lambs, but between lambs of the first and second groups (Table 1). Both single and twin lambs from the second finishing group (where lambs that were lighter at weaning were taken out to an older age to achieve that same finishing entry weight) had greatly reduced efficiency. At this stage the divergence in the efficiency of group 1 and 2 seems likely to be associated with the increased c-fat depths relative to carcass weight, and the related efficiency of lean versus fat tissue deposition.

Contributing to the increased efficiency of cattle that had been subjected to a pre-weaning nutritional restriction, Hennessy and Arthur (2004) found that the more efficient, previously restricted cattle, had low daily feed intakes during feedlot finishing.

There were no differences between voluntary feed intakes of twin and single lambs. However, despite the differences in growth rates for both twin and single lambs between the first and second groups of lambs, the voluntary feed intakes between the first and second groups of lambs was similar. Combined with the reduced growth rates of the second group of lambs, the relatively high feed intake levels has resulted in greatly reduced animal efficiency.

Our work that found no difference in the voluntary feed levels is in general agreement with Ryan *et al.* (1993) who despite finding a short term increase in voluntary feed intakes, found no long term differences in feed intake between restricted and control sheep in the 12 weeks of feeding post a period of restriction. In further agreement with our work Ryan *et al.* (1993) found that previously restricted sheep were unable to compensate to a point of attaining the same body weight as the unrestricted sheep.

While Hennessy and Arthur (2004) cite improvements in FCR for cattle that had undergone a previous nutritional restriction, the significance of an early nutritional restriction upon efficiency of development depended upon the measure used to assess efficiency. When using the simple ratio based indicator of efficiency FCR, an early restriction did result in increased efficiency during the finishing phase. However, when maintenance requirements and animal live weight were taken into account through the use of RFI as the measure of efficiency, the impacts of an earlier nutritional restriction on efficiency during the finishing phase was no longer significant.

The timing of the nutritional restriction prior to unrestricted feeding may have an impact on subsequent animal performance. Graham and Searle (1975), Berge (1991), Tudor and O'Rourke (1980) and Ryan *et al.* (1993) all reported an increase in voluntary feed intake immediately post a period of nutritional restriction. Like Hennessy and Arthur (2004), our work did not monitor feed intake in the period between weaning and entry to the finishing system. Hence, it may be possible that there was a period of increased voluntary feed intakes, but that this increase has occurred during the time when feed intake was not being measured.

5.2.2 Carcass data

As lamb sex had no significant impact on fat or EMD of lambs at either the start or at the end of finishing, there was also no significant sex effect on carcass GR or LMY. Sex did have a significant effect ($P<0.012$) on HSCW with wether lambs 1.8 kg heavier than ewe lambs. This is in agreement with (Hopkins *et.al.* 2007) who found wether lambs had significantly ($P<0.001$) heavier carcasses than ewe lambs (1.39 +- 0.07kg).

For both finishing groups, twin lambs had significantly lighter HSCWs than single lambs. Again, this is in agreement with Hopkins *et al.* (2007) who found that lambs raised as multiples were on average 0.84 ± 0.24 kg lighter ($P<0.001$) than those raised as singles.

In addition to potential impacts on weight gain, the impact of an animal's growth path prior to entry to a finishing system has been shown to affect carcass composition and retail yield at slaughter (Greenwood and Café 2007). When compared at the same age, prenatal and pre-weaning growth and nutrition have been shown to have a significant impact on carcass composition at slaughter. Calves that were subjected to a nutritional restriction have a reduced carcass yield (when compared to calves that have been well grown early in life) driven by a reduction in weight of retail beef (from lighter carcass weight) and an increase in fat trim (Greenwood and Café 2007).

Due to twin lambs having lighter carcass weights they may not be as suited to those export markets with a requirement for heavier carcasses. Twin lambs, or lambs that had been subjected to a pre-weaning nutritional restriction, while having the same fat depths as single lambs had markedly different carcass weights, hence a greater portion of fat per kg of carcass weight. Accordingly, it is less likely that these carcasses would be as suited to a heavier carcass specification that is typically value added through boning rooms.

Despite having greater fat depths relative to carcass weight, there were no differences in the LMY between twin and single lambs, with twin lambs actually trending towards greater LMY.

Findings

- Previously restricted lambs were lighter at all time points post the period of nutritional restriction. Given the similar growth rates between restricted and unrestricted lambs, it is unlikely that restricted lambs would have compensated to a point of similar body weights as unrestricted lambs.
- An early nutritional restriction in ewe lambs worsens feed efficiency during finishing (by approximately 3 FCR units). However, the early nutritional restriction had no impact on the later feed efficiency of wether lambs.
- For both finishing groups of lambs (light and heavy weaning weights) decreasing sire PFAT by 1.5 mm improved ($P<0.05$) lamb efficiency by about 5 FCR units.

5.3 Impact of weaning weight and age at finishing – Results

5.3.1 Growth rate, body composition and animal efficiency

The birth, marking and weaning weight of twin lambs was 4.2±0.18kg, 10.8±0.28kg, and 28.25±0.52kg.

The weight of lambs at entry to and exit from the finishing system, for the three weaning weight groups is shown in Table 2. For all three finishing groups, entry weight to the finishing system was greatest ($P<0.05$) for lambs from the heavy weaning grade and lightest for lambs from the lightest weaning grade. This pattern was followed during the subsequent feedlot period, with heavy lambs showing the greatest weight gain, but only in finishing groups 1 and 2.

For all lambs, sex had no significant effect on entry weight to the finishing system, with wethers only tending to heavier weights (0.8kg; $P<0.15$). However there were marked differences between sex's for exit weights with wether lambs heavier (2.7 kg) than ewe lambs ($P<0.01$).

Table 2. Weight (kg) of twin lambs at entry to and exit from the finishing system for three weaning grades (values are least square means ±s.e.).

	Weaning Weight Group		
	Heavy	Medium	Light
		Finishing group 1	
Entry wt	41.3 ± 1.02a	36.6 ± 1.10b	29.5 ± 1.00c
Exit wt	55.3 ± 1.40a	48.3 ± 1.53b	39.7 ± 1.34c
Difference	13.6 ± 1.20a	11.8 ± 1.31ab	10.4 ± 1.15b
		Finishing group 2	
Entry wt	38.4 ± 1.02a	36.4 ± 1.08b	32.4 ± 0.98c
Exit wt	53.5 ± 1.38a	45.7 ± 1.48b	43.6 ± 1.30b
Difference	15.2 ± 1.18a	9.0 ± 1.27b	11.3 ± 1.18b
		Finishing group 3	
Entry wt	43.5 ± 1.00a	39.5 ± 1.08b	35.9 ± 1.10c
Exit wt	51.1 ± 1.33a	45.0 ± 1.48b	42.6 ± 1.59b
Difference	7.6 ± 1.14a	5.7 ± 1.27a	7.7 ± 1.37a

#Within rows, means followed by different letters are different ($P<0.05$)

Entry fat and EMD were modelled at a standardised entry weight of 36.9 kg, with exit fat and EMD modelled at an average exit weight of 47.2kg. C-site fat depth and EMD increased markedly between entry to and exit from the finishing system (Table 3). For all three finishing periods, the gain in c-fat and EMD was greatest for lambs that were light at weaning. Lambs that were heaviest at weaning had the smallest changes in c-fat and EMD measurements.

For all three weaning grades, the youngest lambs on feed had the lowest increase in c-fat and EMD measurements (Table 3).

Table 3. Eye muscle depth (mm) and c-site tissue depth (mm) at entry to and exit from the finishing system for three weaning grades (values are least square means ±s.e.).

	Weaning Weight Group		
	Heavy	Medium	Light
		Finishing group 1	

Entry EMD	23.0 ± 0.57a	24.5 ± 0.58b	25.6 ± 0.65b
Exit EMD	31.3 ± 0.62a	31.9 ± 0.60a	33.5 ± 0.59b
Difference EMD	6.9 ± 0.87a	7.8 ± 0.84a	10.9 ± 0.82b
Entry c-fat	2.2 ± 0.12a	2.1 ± 0.12a	2.2 ± 0.14a
Exit c-fat	3.6 ± 0.23a	4.1 ± 0.23b	4.3 ± 0.22b
Difference c-fat	1.3 ± 0.24a	2.0 ± 0.23b	2.6 ± 0.22c
		Finishing group 2	
Entry EMD	23.6 ± 0.53a	22.9 ± 0.56a	24.7 ± 0.55a
Exit EMD	31.8 ± 0.58a	32.9 ± 0.58ab	33.8 ± 0.52b
Difference EMD	8.2 ± 0.81a	9.9 ± 0.81b	11.1 ± 0.74b
Entry c-fat	2.0 ± 0.11a	2.1 ± 0.12a	2.3 ± 0.12a
Exit c-fat	3.9 ± 0.22a	4.3 ± 0.22ab	4.6 ± 0.20b
Difference c-fat	1.9 ± 0.22a	2.2 ± 0.22ab	2.5 ± 0.20b
		Finishing group 3	
Entry EMD	22.5 ± 0.62a	23.2 ± 0.57a	23.6 ± 0.59a
Exit EMD	32.5 ± 0.54a	34.9 ± 0.58b	35.3 ± 0.65b
Difference EMD	7.1 ± 0.76a	10.2 ± 0.82b	11.8 ± 0.90b
Entry c-fat	2.2 ± 0.13a	2.4 ± 0.12a	2.2 ± 0.12a
Exit c-fat	4.4 ± 0.20a	4.9 ± 0.22a	4.5 ± 0.25a
Difference c-fat	1.8 ± 0.21a	2.2 ± 0.22a	2.2 ± 0.25a

#Within rows, means followed by different letters are different (P<0.05)

Lamb sex had no effect on fat depth or EMD at either entry to or exit from the finishing system. However, live weight had a significant effect on EMD and c-fat at both entry (P<0.01) and exit (P<0.01) from the finishing system.

In groups one and three there was no difference in FCR between lambs from heavy, medium and light weaning grades, however in group two, medium weaning weight lambs had markedly poorer FCR (P<0.05) than either light or heavy weaning weight lambs (Table 4). Lamb sex did not affect FCR during finishing, with wether lambs only tending towards improved FCR (FCR reduced by 0.49 units) than ewe lambs.

Table 4. Feed Conversion Ratio (x:1) during finishing for three finishing groups, and for the three weaning grades (values are least square means ±s.e.).

Weaning grade	Heavy	Medium	Light
Grp 1 (21 wks)	6.0476 ± 1.017a*	6.62 ± 1.141a*	6.72 ± 0.991a*
Grp 2 (29 wks)	4.95 ± 1.021a*	7.40 ± 1.156b*	5.29 ± 0.966a*
Grp 3 (38 wks)	19.64 ± 1.139a#	21.25 ± 1.320a#	20.17 ± 1.247a#

#Within rows, means followed by different letters are different (P<0.05)
#Within columns, means followed by different ciphers are different (P<0.05)

For all three weaning grades, group three lambs had poorer FCR than groups one and two (Table 4).

5.3.2 Carcass data

As lamb sex had a significant effect on exit weights from the finishing system, it was also significant for HSCW (P<0.001) with carcasses from wether lambs 0.6kg heavier than those of ewe lambs. There were no differences in GR depths or LMY between wether and ewe lambs.

Carcasses from lambs from the heavier weaning grades were generally heavier than those from lighter weaning grades (P<0.05). GR depth was modelled at a standard HSCW of 21.7kg. Lambs that were light at weaning had greater GR depths in finishing group 1 and 3. There were no differences in GR depths between any of the weaning grades in group two lambs (Table 5).

Table 5. Hot standard carcass weight (kg), GR tissue depth (mm) and lean meat yield (%) for three weaning grades, finished at three different time points (values are least square means ±s.e.).

Weaning grade	Heavy	Medium	Light
		Finishing group 1	
HSCW	25.6 ± 0.82a	21.0 ± 0.90b	16.9 ± 0.78c
GR	12.2 ± 1.01a	14.0 ± 1.01a	16.7 ± 1.01b
LMY	53.86 ± 0.524a	55.02 ± 0.567b	56.65 ± 0.50c
		Finishing group 2	
HSCW	23.7 ± 0.81a	21.7 ± 0.87b	21.1 ± 0.76b
GR	12.2 ± 0.92a	12.0 ± 0.97a	13.2 ± 0.85a
LMY	54.43 ± 0.514a	55.30 ± 0.551a	55.38 ± 0.488a
		Finishing group 3	
HSCW	24.1 ± 0.78a	21.3 ± 0.87b	19.3 ± 0.90c
GR	8.2 ± 0.91a	9.8 ± 1.01ab	11.6 ± 1.07b
LMY	54.49 ± 0.499a	55.11 ± 0.570ab	55.74 ± 0.589b

#Within rows, means followed by different letters are different (P<0.05)

In finishing group 1 and 3, LMY was greater (P<0.05) in the light weaning weight group (Table 5). There were no differences in LMY in group two lambs.

5.4 Impact of weaning weight and age at finishing – Discussion

5.4.1 Effect of weaning weight

Contrary to our initial hypothesis, lambs that were light at weaning had the lowest weight gains during feedlot finishing. While their net gain in live weight was less, the light weaning weight lambs did gain more weight as a proportion of their feedlot starting weight compared to those that were heavy at weaning. Furthermore, lambs that were light at weaning also gained proportionately more EMD, and despite accreting greater levels of c-fat tissue finished with greater LMY than those that were heavier at weaning. As previously asserted this would indicate an animal that is less mature and therefore depositing proportionately more lean tissue during growth (Butterfield, 1988). However, the reduced total growth rate suggests that these lambs may be on a growth trajectory towards a smaller mature size.

The reduced weight gain in the lighter weaning weight lambs aligns well with work by Fraser and Saville, (2000), and Selaive-Villarroel et al. (2008). However in either case carcass composition was not measured. Alternatively, Greenwood et al. (2006) demonstrated that lighter weaning weight cattle had greater levels of retail beef and less fat at equivalent carcass weights, also indicating a reduced state of maturity.

Despite the differences in the body composition of light versus heavy weaning weight lambs, this did not manifest itself as a difference in FCR between the weaning weight groups, contrary to our initial hypothesis. While it is likely that the differences in body composition relate to subtle differences in maturity pattern, and the lambs with a lower weaning weight were accreting more lean tissue, these differences were relatively small. Furthermore, in absolute amounts there was no compensatory growth evident, therefore not surprisingly the two groups were no different in their FCR.

A limitation within our study is that we are unable to conclusively say at what point pre-weaning that nutritional restriction occurred, which resulted in the divergence in lamb weaning weights. That there was no compensatory growth evident may indicate that the pre-weaning nutritional restriction occurred at least 12 weeks prior to the lambs being finished (Ryan et al., 1993), potentially prior to marking, or even in utero. Had the restriction occurred post marking, and within 12 weeks of finishing, it is possible that some compensatory growth may have been evident.

5.4.2 Effect of age at finishing

In support of our hypothesis, lambs that commenced finishing closer to weaning demonstrated more rapid growth and improved feed efficiency, compared to lambs that were finished later after weaning. This has considerable implications for producers who traditionally carry lambs over and finish them at older ages. Lambs are often fed at older ages in an attempt to ensure an adequate live weight at the start of finishing, however when lambs are finished at 38 weeks of age their performance is likely to be characterised by low growth rates and inefficient growth.

The low weight gains achieved by the group three lambs indicate that they may have already reached a point of biological maturity. In agreement with our findings, research by Malik et al. (1996) showed declining growth rates as lambs aged. Furthermore, lambs from group three had greater c-fat measurements than group one lambs at exit from the finishing system, again indicative of more advanced maturity (Butterfield, 1988). While there were no differences in FCR between groups 1 and 2, there was a large difference between the FCR of these and group three lambs. Again, this is in agreement with Malik et al. (1996) who found FCR worsened with increasing age. The same association has also been reported in feedlot cattle (Short et al., 1999; Coleman et al., 1995). This relationship was expected, the older lambs being more biologically mature displayed lower growth rates with increasing levels of fatness, with the end result being poorer FCRs.

Findings

- In general lambs that were light at weaning gained less weight during finishing than lambs that were heavy at weaning, however the weight gain of these lighter lambs was characterised by proportionately more lean deposition resulting in increased LMY at slaughter. However, this did not result in differences in FCR.
- Lambs finished at older ages grew slower, deposited proportionately more fat, and had reduced LMY, all characteristics demonstrated by more mature animals. This slower growth was associated with poorer FCR in the older lambs.
- Lambs with low weaning weights can have acceptable FCR for an intensive finishing system, but there is a significant decrease in FCR, irrespective of weaning weight, when lambs are taken out to older ages. In these cases lambs that are light at weaning are best sold at younger ages and targeted at a lighter market specification.

6 Success in achieving objectives

6.1 Communication of project outcomes

Industry based communication of project outcomes has been considerable. The lamb energetics project has been supported by a significant communications program. This communications program (both spoken and written) has been essential to not only increasing the awareness of the project (and MLA and DPI investments) but has provided producers with increased awareness of the efficiency of their own operations. Producer engagement with the project has been most pleasing, with high levels of repeat engagement (groups asking for follow up presentations) and follow up media articles.

6.1.1 Communication activities

Lamb Energetics attracted high levels of industry and media interest. The project leader was often requested to present project findings, and did so to a range of groups outlined below.

Lamb producers and finishers:

- ‘Pepperton’ Poll Dorset breeders workshop, Thorpdale (25)
- South West Prime Lamb group, Hamilton (30)
- Lamb Expo (part of Beef Expo), Hamilton (60)
- Bestwool Bestlamb annual conference, Bendigo (200)
- Bestwool Bestlamb, Sth West group phone conference (15)
- Bestwool Bestlamb group, St Arnaud/Charlton (15)
- Prime lamb producers group, Goorambat (15)
- Boorhaman cropping group, Boorhaman (40)
- Rutherglen Business Networks, Rutherglen (45)
- Rutherglen lamb group, Rutherglen (15)
- ‘Glory’ Poll Dorset breeders and Elders workshop, Newbridge (12)
- Various Bestwool Bestlamb groups; including Hamilton, Charlton and St Arnaud

Seedstock producers:

- National White Suffolk breeders conference x 2, Narracorte (80) Ballarat (100)
- Combined Superwhite and MeatElite conference, Corowa (50)
- National Poll Dorset breeders conference, Hamilton (100)
- Almondvale Bonds and White suffolks, Lochart (25)
- ‘Lambpro’ Poll Dorset and maternal composites, Holbrook (100)
- ‘Leachim’ Merino field day and sale, Snowtown (25)

Next level users ‘Information providers’:

- Elders stock agent workshop x 2, ‘TriggerVale’, Lochart (20 + 80)
- Elders stock agent workshop, ‘Retallack’, Ariah Park (20)
- ‘Glory’ Poll Dorset agent workshop x 2, Newbridge (12 + 20)
- DPI meat and wool team, Rutherglen (10)
- Bestwool Bestlamb annual coordinators meeting, Geelong (12)

Additional to the speaking engagements, a range of media outlets have run articles featuring the work undertaken as part of the Lamb Energetics project. These have included:

- Stock and Land x 2
- Weekly times x 2
- ‘Lambpro’ breeders newsletter

- ‘Farming Ahead’ Kondinin group
- Feedback
- ‘Primary voice’ DPI newsletter
- Border mail
- ABC radio x 2

A one page scientific paper ‘Lambs sired by rams with low Australian Sheep Breeding Values for c-site fat depth have superior efficiency during finishing’ has been reviewed and accepted for online publication in Animal Production Science.

There are also two scientific papers currently being developed in consultation with Graham Gardner 1) The effect of a pre-weaning nutritional restriction on lamb efficiency during finishing. and 2) The effect of lamb weaning weight and age at finishing on lamb efficiency during finishing. The second paper has been internally reviewed within DPI and has been submitted for the Recent Advances in Animal Nutrition conference.

7 Impact on meat and livestock industry – Now and in five years time

7.1 Immediate impact on the lamb industry

The importance of feed efficiency to the red meat industry, and specifically to the lamb industry, is highlighted by economic modelling conducted by Meat and Livestock Australia. This has shown that improving feed use efficiency and decreasing feed requirements by 10% per head would result in a weighted net present value of $159 million per year for lamb and sheep meat production (MLA strategic plan 2006-2011).

Immediate impacts of this project have focused on optimising the efficiency of existing lambs, i.e. making an existing drop of lambs perform to their optimum level. To date, the dissemination of research findings has been focused on the immediate users of the findings – specialist finishers, opportunity finishers and breeders who finish their own lambs.

The extensive industry based communications that have been associated with the project has raised the awareness of DPI and MLA research within industry. Feedback associated with industry based presentations has inevitably been favourable and supportive of the research that has been undertaken in this area.

7.2 Impact on the lamb industry, five years on

Pressures to continue to progress towards more efficient agricultural industries are likely to increase in coming decades, as competition for resources such as high value feed becomes more intense, and social license to operate is increasingly determined by the impact of an industry on the environment. Improvements in feed conversion efficiency from the findings of this project (and possible future selection using GASBVs) will directly improve the efficiency of the industry. The possibility to utilise lambs/sheep with improved feed efficiency optimises the use of resources leading to a reduction in agriculture’s ecological footprint. If a carbon tax is introduced in the future, improved feed efficiency could also provide greater cost savings to the agricultural community.

Longer term impacts of the project will be reliant on not only improving the efficiency of existing lambs, but in breeding lambs in the future that have a greater potential for efficiency during finishing. Integral to this longer term impact is the interest and involvement of the seed stock industry. An awareness that to a certain extent that their own, and more importantly their clients' needs extend beyond just growth and muscle, there is also a need to consider the efficiency of growth. Through the adoption of a supply chain approach to the delivery of project outcomes seed stock producers are aware of the large variations that exist in lamb efficiency.

"If I could have a breeding value for one trait, animal efficiency would be it."
Producer comment to Nick Linden at CRC field day.

The project has generated significant quantities of data that will become a resource to other projects that investigate animal efficiency and feed intake in the future.

8 Conclusions and recommendations

8.1 Improving efficiency within the lamb industry

Findings of the lamb energetics project continue to be incorporated into new extension materials as they are developed.

Longer term benefits from the project are predicated on finding a means by which feed efficiency can be improved within the confines of a normal finishing, breeding or seed stock operation. For lamb finishers there are a series of 'best practice' recommendations' that enable lamb performance, and indeed efficiency to be optimised. It would be appropriate that such findings be incorporated into the development of future extension programs that target the needs of intensive lamb finishers. Such programs would essentially focus on optimising the given efficiency of individual lambs, or a group of lambs.

8.2 Preparing for future improvements in efficiency through GASBVs

Research teams progress appropriate project proposals that address the necessary requirements to develop and validate GASBVs for feed efficiency.

More challenging than optimising the efficiency of existing lambs is to change the potential efficiency of future generations of lambs. Given the inherent costs associated with measuring feed intake and feed efficiency, any potential breeding values for these traits are likely to be generated as genomic breeding values. Genotypic Australian Sheep Breeding Values (GASBV) could be calculated for feed efficiency (FCR or RFI) by the use of Single Nucleotide Polymorphisms (SNP) effects. GASBV = Xu, where X would be a matrix of lamb genotypes, and u is the vector of SNP effects predicted by a variety of methods that could include BayesA, BayesR or BayesS. For GBLUP, GASBV could also be calculated using a similar methodology. Work within the dairy industry has identified large differences in the accuracy of genomic breeding values when calculated via different methods and provides an insight into the most suitable means to generate future GASBVs – BAYESA has given the highest accuracies, followed by BayesR, then GBLUP, with BayesS giving quite poor accuracies (Hayes, 2010).

The generation of genomic breeding values would however be dependant on the ability to phenotype large numbers of lambs for feed efficiency. Doing so is necessary to enable the GASBV to be correlated with the phenotype of the lambs, corrected for a series of fixed effects and the diverse lamb genotypes available within the Sheep CRC INF provides the ideal opportunity to phenotype a large, diverse lamb population for feed efficiency.

8.3 Maternal versus terminal efficiency

Future research activities that focus on feed efficiency need to consider the impacts of selection methods on maternal efficiency.

There remains a need to investigate the relationship between growth efficiency and maintenance efficiency. This has particular relevance for work in this area on maternal efficiency, and combined with genomic breeding values is currently a focus of attention for the dairy industry. It is possible that the most appropriate means of assessment for feed efficiency in terminal lambs is not the same as that which should be used in maternal programs. It is recommended that this becomes a consideration in the development of future efficiency and resilience based programs developed either within or external to the sheep CRC.

8.4 Understanding the relationship between feed efficiency and methane emissions

This area is being addressed within the current Sheep CRC.

Energy lost as methane (CH_4) remains one of the most significant inefficiencies remaining in modern ruminant production systems (Eckard *et al*. 2010), with approximately 10% of total energy intake being emitted as methane. In addition to being a cause of systems inefficiency for ruminants, methane is widely recognized as one of the important greenhouse gases with a global warming potential of 21 currently used for reporting emissions under the Kyoto Protocol (Forster *et al*. 2007).

Improvements in lamb efficiency, if found to align to a reduction in methane emissions, would become a compelling means by which industry methane emissions may be reduced. The ability to select sheep for improved feed efficiency may become a valuable proxy by which methane emissions are improved ie. it is the opinion of this researcher that it would be more feasible in the future to see genetic breeding values for feed efficiency, as distinct to genetic breeding values for methane emissions.

Should there be a favourable correlation between feed efficiency and methane emissions, industry will be well positioned to reduce methane emissions while improving farm system efficiency. At the same time, challenges associated with possible carbon tax systems are able to be quantified and addressed.

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