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The following one-page abstracts summarise papers presented at Animal Production 2018 in addition to those published as peer-reviewed research papers or reviews in the special issue of *Animal Production Science* Volume 58, Issue 8. Their sequence is grouped into 12 major topic areas. These abstracts were independently reviewed by at least one reviewer for merit and clarity before final acceptance by the guest editors.

Analysis of the association between FASN gene polymorphisms ultrasound carcass traits and intramuscular fat in Qinchuan cattle

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Intramuscular or marbling fat is considered very important in the production of beef, because it is the key factor of beef quality and customer satisfaction (Jiang *et al.* 2005; Oury *et al.* 2009). Secondly, fatty acid composition determines the nutritional value of meat and thus has an impact on consumer health (Ntawubizi *et al.* 2010; Sellier *et al.* 2010). However, carcass traits, including back fat and intramuscular fat (IMF) content, are lower than those of imported cattle such as Wagyu. Until recently, there has been a lack of information about the association of bovine Fatty acid synthase (FASN) genotypes with ultrasound carcass traits in Qinchuan cattle. This study aimed to identify polymorphisms of the bovine FASN gene and explore their relationships with ultrasound carcass traits in Qinchuan cattle including; back fat thickness (BF), ultrasound loin muscle area (REA) and intramuscular fat (IMF) content.

In this study, three novel SNP were identified by pool DNA sequencing: g.12740C>T, g.13192T>C and g.13232C>T. The genotype distribution, minor allele frequency, heterozygosity, HWE, and PIC values were calculated, and the results in (Table 1) show a general consensus that the C allele was predominant in the three SNPs at 86.9%, 74.6% and 67.6% for g.12740C>T, g.13192T>C and g.13232C>T, respectively. Genotype distributions of loci were similar with CC (73.7%), CC (57.3%) and CC (47.6%) were dominant in their distribution. According to the PIC values, both g.13192T>C and g.13232C>T possessed intermediate polymorphism (0.25<PIC<0.5) while g.12740C>T possessed low polymorphism (PIC<0.25).

Conclusions

The genotype of TT results in greater backfat thickness, ribeye area and intra muscular fat than TC and CC genotypes. The haplotype combination analysis showed that the haplotype combination H_2H_2 was associated with a preferential increase in backfat thickness however there were no halotype associations for ribeye muscle area and intramuscular fat. These findings imply that the FASN gene may play an important role in defining carcass traits in cattle and will be useful in marker-assisted selection and management of Qinchuan cattle. The H_2H_2 diplotypes (FASN) should be used as molecular markers of combined genotypes in the future for improved prediction of ultrasound carcass traits in Qinchuan cattle.

Table 1. Genotype frequencies of *FASN* gene for the single nucleotide polymorphisms (SNPs)

Locus	Sample	Genotypic frequency			Allele frequency		*He*	*Ne*	PIC	HWE
g.12740C>T	525	CC	CT	TT	C	T				
		0.737	0.263	0	0.869	0.131	0.228	1.296	0.202	12.02
g.13192T>C	525	TT	TC	CC	T	C				
		0.082	0.345	0.573	0.254	0.746	0.379	1.611	0.307	4.34
g.13232C>T	525	CC	CT	TT	C	T				
		0.476	0.400	0.124	0.676	0.3238	0.438	1.779	0.342	3.94

Note: HWE, Hardy–Weinberg disequilibrium; $0.05^2 = 5.991$, $0.01^2 = 9.21$.

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Genomic selection can be used to balance improvement of lean meat yield and eating quality in terminal sire sheep breeds

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Terminal sire sheep breeders in Australia have made substantial genetic progress over more than 20 years, driven largely by the use of a selection index (Carcass Plus) which focuses improvement on growth and lean meat yield (lmy). Due to unfavourable genetic correlations, consumer eating quality of sheep meat has declined. Major advances in genetic evaluation have been made since 2016, with the introduction of 'single-step' genomic analyses (SS-GBLUP) to compute Australian Sheep Breeding Values (ASBVs) for all traits including carcass and eating quality (Brown *et al.* 2018), and a new index (EQ) which balances improvement in lean meat yield and eating quality (Swan *et al.* 2015). This evaluation system is underpinned by a genomic reference population where progeny of industry sires are genotyped and phenotyped for an extensive range of traits. A subset of the reference population were used in consumer eating quality trials, and have data on sensory scores which can be used to identify consumer preferences (Pannier *et al.* 2014).

Ram breeders can now obtain carcass and eating quality ASBVs and indexes with increased accuracy by genotyping selection candidates using high density SNP genotypes. To compare the value of different sources of information a sample of 316 reference population progeny with both genotypes and phenotypes for the traits of interest, and that were also part of the consumer eating quality trial were used. Four SS-GBLUP analyses were conducted on the full terminal sire data set to produce ASBVs and indexes for the validation animals, including and excluding various information sources used to predict genetic merit: 1. validation animals had basic on-farm traits only, replicating a ram breeding flock with no genotypes (No Geno); 2. basic traits plus genotypes, replicating a flock with genotypes and average genomic linkage to the reference population (Geno Av); 3. basic traits plus genotypes on validation animals, and with the inclusion of genotyped half-sibs in the reference population with carcass and eating quality measurements, replicating a flock with high genomic linkage to the reference (Geno High); 4. validation animals had genotypes plus measurements on all traits including eating quality, representing the most accurate scenario (Measured). In addition to standard ASBVs and indexes, these animals had estimated breeding values for the consumer sensory score 'overall liking' (msa, 1–100 points). The top 10% of animals were then selected on Carcass Plus and EQ indexes from each analysis, and their average superiority for individual traits calculated.

Table 1 shows that animals selected on Carcass Plus have below average consumer eating quality (–0.89). When using the EQ index in the No Geno analysis, eating quality can be improved (0.92), in association with a positive change in c-site carcass fat (ccfat) of 0.11mm and a negative change in lmy of –0.25%. Adding genomic information and with closer linkage to the reference, the change in ccfat becomes negative (favourable), and the change in lmy less negative (from –0.25 to –0.07). Two key traits are associated with improved eating quality: intra-muscular fat (imf, mm), which should be positive, and shear force (sf5, Newtons) which should be negative. Results show that flocks who genotype and are more closely linked to the reference achieve a better balance in response between lean meat yield and eating quality.

Table 1. Trait and index superiority of the top 10% of animals selected on Carcass Plus and EQ indexes calculated from different analyses, relative to group mean (*n* = 316) ASBVs and indexes shown in the first row (group standard deviations shown in the second row)

		ccfat	lmy	imf	sf5	msa	Carcass Plus	EQ
Group mean		–0.85	2.12	–0.33	0.44	0.03	123.65	111.07
Group SD		0.66	1.31	0.53	3.07	2.51	11.87	10.54
Select on:	*Analysis:*	*Superiority of top 10% relative to group mean:*						
Carcass Plus	No Geno	0.09	0.68	–0.18	1.17	–0.89	16.71	2.09
EQ	No Geno	0.11	–0.25	0.42	–2.36	0.92	5.8	11.35
EQ	Geno Av	–0.03	–0.11	0.40	–2.53	0.75	8.4	13.37
EQ	Geno High	–0.21	–0.07	0.39	–2.59	1.27	8.54	14.45
EQ	Measured	–0.19	0.05	0.51	–3.44	1.14	8.06	19.12

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How useful are genomic tests for commercial cattle (or, *Should I read the fine print?*)

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Genomic tests are becoming widely available, initially for health conditions but now increasingly as predictors of production merit or value. The principle behind them is simple – take a tissue sample of each animal, send the sample(s) to the appropriate lab, and get back a report which will have some value or ranking of the individual(s) for some purpose. Current examples are tests of the merit of commercial Angus heifers (https://www.angusaustralia.com.au/breeding/animal-selection/angus-heiferselect/) and tests of feedlot merit being trialled now. Such tests offer potential value for commercial producers and others in livestock value chains, but it is worth understanding the determinants of the utility of such tests, which are:

a) The accuracy of the test – how well does it predict performance in the population?
b) How much is it worth testing – what are the differences being predicted?
c) What does it cost?

Accuracy: contrary to widespread perception, tests based on DNA are not automatically 100% accurate. The test may read the DNA (the genotype) with very high precision, but that does not mean it predicts performance at the same level. This prediction accuracy depends mainly on the genetics of the trait being evaluated (how heritable is it), and how large a reference population is the prediction based on. The reference population is a sample of animals of that breed that has been recorded for the trait of interest and genotyped. The prediction accuracy is usually expressed as a %.

How much is it worth testing? this really comes down to 'are there large differences in $ value related to the trait, in this population?' For example, it is not point having a test that is very highly accurate if the range in value amongst animals is only a few cents. It is important to have a good understanding of the range, and if possible the standard deviation, of income, cost or profit due to differences in the trait being tested.

What does it cost? this is obvious – if the test costs more than the range in value, then the test cannot be worth doing, at least for the particular trait. This may become less and less of an issue as the price of genotyping falls.

In practice, these factors interact: a higher accuracy test may cost more; it is possible to obtain value from a lower accuracy test if the range in performance value is very large and/or the test is cheap.

To provide an example of the value of a test, and how accuracy impacts it, we can use a simple but real example. The value of feedlot cattle, in terms of gross margin in the feedlot, depends largely on their growth rate, marbling level and feed intake. The animals in any intake within a breed can be categorised into 8 sub-groups according to whether they are genetically above or below average for each of these 3 traits. Under current prices and using domestic-fed Angus cattle for the example, the 8 groups range in gross margin from \$1,040 to \$1,429 per head, and the bottom quartile generate a loss averaging -\$338 per head (note that these gross margins are <u>before</u> taking into account the purchase price). To cull this bottom quarter, it is necessary to test the entire intake ie if we want to bring in 100 cattle, we need to test 133 – and so we can calculate the profit on testing. If the test is 67% accurate and costs \$45, we spend 133 x \$45, and our return is 100 x (\$1,286–\$1,230) x 67%, so the overall return on the test is -\$385, or -\$16.80 per animal tested. Extending the point, if the accuracy of the test is (for example) 33%, then our return is only 100 x (\$1,286–\$1,230) x 33%, –\$4,137 overall return or –\$31.11 per animal tested. This example shows the impact of accuracy of the test: the other important parameter is the scale of differences in potential gross margin per animal tested. This is illustrated by extending the examples to include long-fed Wagyu cattle and commercial beef heifers (Table 1), with the cost per test at \$45 in each:

Scenario	Mean gross margin prior to selection (standard deviation)	Mean value of bottom quartile	Return on testing (per animal tested) at accuracy of:	
			67%	33%
Domestic-fed steers – 100 days	\$1,230 (\$133.54)	\$1,061	–\$16.80	–\$31.11
Long-fed Wagyu steers – 400 days	\$2,002 (\$258.39)	\$1,695	\$6.61	–\$19.58
Commercial heifers – lifetime	\$5,519 (\$335.71)	\$5,117	\$22.43	–\$11.79

The point here is not to suggest that genomic tests are or are not useful: it is to make very clear that the value of such tests depends on a number of factors, and careful sums are warranted. Producers (including feedlot managers) considering utilising genomic tests to screen animals, whether for culling, or for different management regimes (such as feeding periods) need to understand what traits are being predicted, and what effect the ranges in those traits have on gross margin or profit.

An overview of the Merino Lifetime Productivity Project

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The Merino industry has raised a number of concerns about the current practice of selecting animals at a very young age and its association with lifetime production. Further, with the diversification of the Merino to include a combination of wool, carcase, disease resistance and reproduction attributes, there is a need to create a dataset that will allow the quantification of genetic parameters for lifetime production, and to understand the biological and economic trade-offs between these production elements.

In 2015 Australian Wool Innovation and the Australian Merino Sire Evaluation Association initiated the Merino Lifetime Productivity (MLP) project with strong support from industry including ram breeders and wool growers. This 10-year project has a key aim to generate a unique Merino dataset that can be analysed to better understand how current selection approaches such as MERINOSELECT Australian Sheep Breeding Values and indexes, genomic information, and the use of visual selection relate to lifetime performance and how breeding strategies might be enhanced to deliver better outcomes to industry.

The project involves five sire evaluation sites located across Australia in diverse climates with genetically diverse ewe bases; Pingelly (Western Australia), Harrow (Victoria), Temora (New South Wales), Trangie (New South Wales) and Armidale (New South Wales).

Over the life of the project, 135 industry representative sires will each be joined by artificial insemination to 90 ewes in order to generate 5000 F1 ewes. The repeat use of sires across sites and years will ensure sufficient linkage to allow data to be analysed within each site, across sites and in combination with other industry databases such as MERINOSELECT.

The F1 ewes will be extensively assessed both visually and objectively for 5 to 6 years following an annual recording program outlined in Table 1. Culling will be for welfare purposes only, and DNA will be used to allocate pedigree and to undertake genomic testing. From approximately 18 months of age, every year the F1 ewes will be joined to a syndicate of Merino sires and fertility records collected. The resulting F2 progeny leave the project following the collection of DNA and a weaning weight.

The number of observations generated from the project will enable extensive genetic and economic analysis for the benefit of the Merino industry. The MLP project will form a key reference population for traits rarely recorded by Merino breeders, and as such will contribute to increased genetic gain for lifetime productivity.

Table 1. Visual and measured assessment program per year across all sites used in the Merino Lifetime Project

Wool measurements	Fleece weight, yield, fibre diameter, fibre diameter standard deviation, fibre diameter coefficient of variation, staple strength, staple length, comfort factor and curvature
Growth and carcase	Body weight, eye muscle, fat depth and adult ewe size
Health and welfare	Worm egg count, faecal consistency, dag, urine stain, breech cover, crutch cover, breech wrinkle, and weaner and adult survival
Visual wool traits	Fleece rot, wool colour, wool character, dust penetration, staple weathering, staple structure, fibre pigmentation, non-fibre pigmentation, recessive black and random spot
Visual conformation traits	Face cover, jaw, legs/feet, shoulder/back, body wrinkle
Classing	Two classings with independent sheep classers (flock classing and stud classing approach)
Joining, pregnancy, lambing	Sire, dam, pregnancy scanning, number of lambs weaned (fertility, litter size, lamb survival) body weight and condition score (at pre-joining, pregnancy scanning, pre-lambing, weaning)

We gratefully acknowledge Australian Wool Innovation, nominating Merino breeders, site committees (Balmoral Sire Evaluation Association, MerinoLink, Yardstick Sire Evaluation, New England Merino Sire Evaluation Association, Macquarie Sire Evaluation Association) and site hosts (Tuloona Pastoral, Marty Moses, Murdoch University, the University of Western Australia, the Commonwealth Scientific and Industrial Research Organisation and the New South Wales Department of Primary Industries) for supporting and funding this work.

Phenotypic, environmental and genetic associations between health and growth in the pig

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Genetic improvement of multiple production traits is widely achieved in pig breeding. However, there have been claims that selection for productivity alone has been detrimental to pig health (Prunier *et al.* 2010). This study aims to explore the phenotypic, environmental and genetic relationships between health and growth of the pig.

Performance records from 1998 to 2013 ($n = 31{,}230$) and medication records from 2011 to 2016 ($n = 812$) were obtained from a herd of Large White pigs from the University of Queensland piggery in Gatton, QLD. Average daily gain (ADG) was calculated when pigs were at the average end weight of 90 kg and age of 128 days. A health trait was derived using medication status, with 0 as not medicated (good health) and 1 as medicated (poor health) (Guy *et al.* 2018). The association between ADG and health was explored on 3 levels: 1) phenotypically, using multiple regression to model ADG, with the predictor variables of sex, health status, numbers born alive in the litter, season and birth-month contemporary group; 2) environmentally, using Pearson's correlation between the frequency of medication and the environment, which was quantified through contemporary group estimates of ADG (Guy *et al.* 2017); and 3) genetically, by fitting a bivariate sire model in ASReml (Gilmour *et al.* 2009).

Medication status was a significant predictor of ADG ($p < 0.001$), where healthier, non-medicated pigs grew 27 g/day more than the medicated pigs (Fig. 1A). This association was also found in an alternative model, where a 10 g/day increase in growth estimated breeding values (EBV) decreased the odds of medication by 8% (Guy *et al.* 2018). This suggests that better health is associated with higher growth on a phenotypic level.

Pearson's correlation between the growth environment and frequency of medication was -0.29 ($p = 0.08$) (Fig. 1B). This provides marginal evidence that better growth environments are associated with better health, which is expected as animals in good environments are anticipated to express their true growth potential.

Heritability was estimated at 0.18 ± 0.04 (± *SE*) for ADG and 0.05 ± 0.05 for health. The genetic correlation between ADG and health was estimated at 0.26 ± 0.34 (Fig. 1C). Both positive and negative genetic correlation estimates between health events and various growth traits have been reported in dairy cattle (Brotherstone *et al.* 2007). To the best of our knowledge, there are no similar studies available in pigs. There is insufficient data in this study to provide an accurate estimate of genetic correlation to determine whether or not growth and health are genetically linked.

This study suggests that good growth environments result in positive outcomes for health, which will also result in good growth phenotypes. While more data are required to more accurately estimate of the genetic relationship between health and growth, health should be included as a breeding objective trait in pig breeding programs.

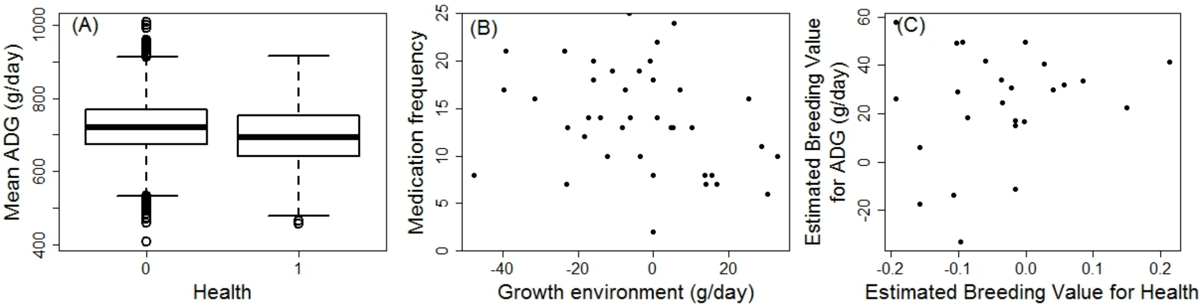

Fig. 1. The relationship between average daily gain (ADG) and health (defined by medication status, where 0 = not medicated and 1 = medicated) on a phenotypic (*A*), environmental (*B*) and genetic (*C*) level.

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Impact of Korean swine genetic improvement network system for a Duroc sire line

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The Korean pig breeding industry has been developed by small and medium sized breeding farms, with variable population sizes and inbreeding frequencies (Seo *et al.* 2011). From 2012, the National Institute of Animal Science (NIAS) has organized a ‘National swine genetic improvement network’ with 17 breeding farms and implemented a nationwide pig breeding program for sire lines of Duroc and dam lines of Landrace and Yorkshire. The aims of this program are selection of superior breeding stock suitable for Korean breeding objectives and increasing the genetic connectedness across the breeding farms by allowingexchange of genetic resources.. This kind of cooperative breeding strategy is inspired by sire referencing schemes in sheep (Lewis and Simm, 2000).

Data consisted of pedigree records of 142,739 and performance records of 57,913 for Duroc from 1987 to 2017 were collected from Korean breeding stock registration system. Performance traits included three point (Shoulder, Belly, Waist) back fat thickness (BF), eye muscle area (EMA), adjusted days to 90kg of live weight (D90kg) and retail cut percentage (RCP). Genetic evaluation has been done every two weeks using multiple traits animal model with WOMBAT program to estimate inbreeding coefficient (F), phenotypic value (PV) and estimated breeding value (EBV). After selecting sires using selection index ‘I = -3×(D90kg EBV) -(BF EBV)’, total 58 selected sires were sent to 4 nucleus herd AI centers and then semen was propagated to joining farms.

From 2012 to 2017, EBV of D90kg in selected semen shared population was improved -3,69 to -7.62 (Fig 1). The accumulated performance data of 1217 shows that the nationwide-selected semen has better EBV of D90kg than farm-base selected semen (Table 1). Next steps of this program are increasing the number of testing traits such as feed efficiency, meat quality and litter size, and including genotype data using high density microarray panel to increase estimation accuracy.

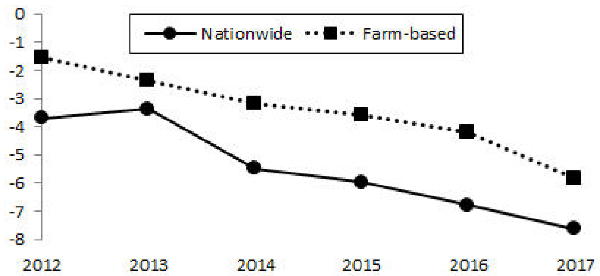

Fig. 1. Trends of EBVs of D90kg form 2012 to 2017.

Table 1. Inbreeding coefficient, phenotypic values, estimated breeding values and differentials in nationwide selected semen used and farm-base selected semen used Duroc sire population in 2017

Population	No. of pigs	F	V	D90kg (day)	BF (mm)	EMA (cm2)	RCP (%)
Nationwide	3,082	0.0248	PV	136.74	13.368	27.790	57.558
			EBV	-5.713	0.6489	-0.5366	-1.0339
Farm-based	27,993	0.0318	PV	137.99	13.147	28.25	58.045
			EBV	-3.850	0.4018	-0.3721	-0.6484
Differential		-0.0071*	PV	-1.25*	0.221NS	-0.467*	-0.487NS
			EBV	-1.863*	0.2470*	-0.1644*	-0.3855*

NS, not significant, **P* < 0.0001.

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Relationship between marbling and marbling fineness in Japanese Black Wagyu

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Marbling is becoming increasingly important in breeding objectives of Australian beef producers. This is due to its association with increased meat eating quality. With marbling becoming more desirable there has been a shift in consumer preference towards finer marbled meat (flecks < 0.5cm^2) which is considered more aesthetically pleasing. AUS-MEAT subjectively assesses marbling using visual scoring systems. This method lacks the precision and range to accurately record high marbling phenotypes in Wagyu and only crudely assesses marbling fleck size. Utilisation of objective measures such as the Meat Image Japan (MIJ) camera are likely to increase accuracy so that both marbling and fineness can be improved simultaneously.

A Full-Blood Wagyu dataset consisting of 878 genotyped animals with AUS-MEAT and MIJ camera records was utilised to estimate genetic parameters of traits. Traits of interest (mean ± SD) were hot standard carcass weight (HSCW, 437 ± 47kg), AUS-MEAT P8 site fat depth (P8, 17 ± 7mm), AUS-MEAT marble score (MARB, scale 0-9, 8 ± 1), MIJ rib-eye area (I_REA, 45 ± 8cm^2), MIJ percentage marbling (I_MARB, 29 ± 7%), MIJ coarseness of marbling index (I_COURSE, 0.3 ± 0.1%), MIJ percentage marbling minus largest marbling particle (I_MARB2, 27 ± 1%) and MIJ fineness of marbling index (I_FINE, 53 ± 11mm/cm) which is defined as the total circumference of marbling particles (mm) divided by the square root of the rib-eye area. Further definitions and methodology for MIJ camera traits can be found in Kuchida *et al.* (2006). Estimations of genetic parameters were calculated using mixed model equations in ASReml-R (Butler *et al.* 2007) with fixed effects of sex (heifer, steer), dam age group (maiden, mature, old), and heterozygosity (21-42%). An additional fixed effect included contemporary group (25 levels), 9 of which had <10 animals with the maximum number being 199. Animals were genotyped with a 30K SNP chip. After filtering for SNPs with a minor allele frequency >0.05, 20955 SNPs were retained to construct the genomic relationship matrix (VanRaden 2008).

Heritabilities were moderate to high for all traits (Table 1). I_MARB was strongly correlated with MARB and given its high heritability, it is likely a superior trait for marbling improvement. Favourable relationships between I_FINE and other traits exist suggesting selection for fineness and marbling combined will not antagonise other important traits. I_COURSE was generally favourably correlated with other traits, but was strongly correlated with I_MARB. However, I_COURSE was lowly correlated with I_FINE suggesting selection on I_FINE will not increase coarseness while selecting for I_MARB might. The results suggest that I_FINE is a better trait for improving marbling than I_MARB and MARB with the added benefit of improving marbling fineness and reducing the appearance of unattractive, coarse marbling particles.

Table 1. Genotypic correlations (below) and phenotypic correlations (above) between AUS-MEAT carcass traits and Meat image analysis (MIA) traits. Heritability* of traits (SE) is presented on the diagonal

	HSCW	P8	I_REA	I_MARB	I_COURSE	I_FINE	I_MARB2	MARB
HSCW	0.56(0.06)	0.26	0.29	0.07	0.24	0.07	0.06	0.15
P8	0.14	0.37(0.07)	-0.02	0.03	0.08	-0.05	0.03	0.01
I_REA	0.33	-0.05	0.42(0.07)	0.15	0.40	0.39	0.16	0.29
I_MARB	-0.09	-0.04	0.23	0.75(0.05)	0.53	0.69	0.98	0.77
I_COURSE	-0.02	0.12	0.31	0.64	0.51(0.06)	0.01	0.43	0.49
I_FINE	-0.03	-0.23	0.48	0.79	0.18	0.55(0.06)	0.72	0.56
I_MARB2	-0.10	-0.06	0.22	1.00	0.61	0.81	0.74(0.05)	0.77
MARB	-0.05	-0.06	0.33	0.97	0.65	0.83	0.97	0.56(0.06)

*h^2 (se) is an average of bi-variate analyses; genotypic correlations SE 0.0001 – 0.14, phenotypic correlations SE 0.02 – 0.04.

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High resolution melt curve analysis to genotype for the Booroola mutation (*FecB*)

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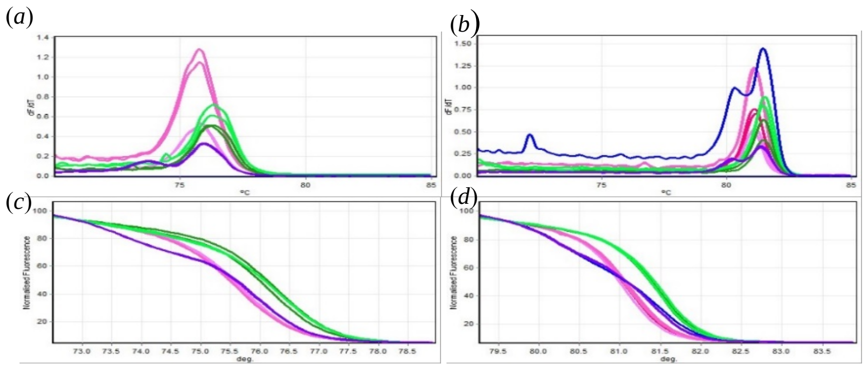
The Booroola mutation (*FecB*) is an allele of a single nucleotide polymorphism (SNP) present in the bone morphogenetic protein 1B receptor gene that causes an increase in ovulations in many breeds of sheep (Souza *et al.* 2001). The Booroola SNP mutation increases ovulation rates in a Mendelian fashion with additive effect (Davis *et al.* 1982). However, the high lamb mortality of the homozygous genotype ($FecB^{BB}$) makes fixing the trait in a sheep population generally undesirable (Walkden-Brown *et al.* 2009). Genotyping is thus required to ensure that the desirable heterozygous ($FecB^{B+}$) is being utilised effectively. The usual method of genotyping using PCR-RFLP are relatively complicated and expensive; therefore, the aim of this project was to develop and validate an one-step high resolution melt curve analysis (HRM) test to differentiate between the non-carrier ($FecB^{++}$), homozygous $FecB^{BB}$ and heterozygous $FecB^{B+}$ Booroola genotypes. Merino sheep DNA or dried blood on cards was sourced from the Sheep CRC, UNE Kirby farm and Booroola Merino flocks of Ross Baldwin and David Wolfenden. A total of 189 samples was used. DNA was extracted from dried blood cards utilising a simple method adapted from Song *et al.* (2013) which was proved suitable for HRM genotyping. Two sets of primers were designed to amplify a 65 bp amplicon and a 110 bp amplicon containing the *FecB* SNP. Sanger sequencing was conducted spanning the amplicons of 8 samples to confirm the site of the mutation within the target. Both primers proved to be suitable for genotyping *FecB* using HRM however the 65bp primer provided an easier interpretation. The SYTO9 was used as the intercalating fluorescence dye and premium ingredients for the PCR master mix were used for PCR amplification and HRM analysis. Forty-six samples from sheep with *FecB* genotypes confirmed by conventional genotyping (GenomeNZ®) were used to determine the accuracy of HRM genotyping. HRM analysis demonstrated clear differentiation between the three different Booroola genotypes. Figure 1 shows the HRM results for 6 samples with known genotypes and these provided positive controls for the remaining samples. Validation against all 46 known genotypes resulted in 100% accuracy. A further 137 sheep of unknown FecB genotype were also genotyped successfully using HRM analysis. Biological support for the genotyping was obtained by analysis of scanned litter size which revealed a significant difference ($P < 0.008$) between the genotypes in the expected direction. The use of HRM method to genotype the Booroola mutation will be more cost effective and quicker than the PCR_RFLP method and competitive with the emerging use of SNP chip testing for this trait. Overall, this project confirmed the hypothesis that the HRM curve analysis can be used effectively to differentiate between $FecB^{++}$, $FecB^{B+}$ and $FecB^{BB}$.



Sample	GenomNZ® Genotype	HRM Genotype
	$FecB^{++}$	$FecB^{++}$
	$FecB^{++}$	$FecB^{++}$
	$FecB^{BB}$	$FecB^{BB}$
	$FecB^{BB}$	$FecB^{BB}$
	$FecB^{B+}$	$FecB^{B+}$
	$FecB^{B+}$	$FecB^{B+}$

Fig. 1. HRM results for samples of known genotypes that were previously genotyped by GenomeNZ®. (*a*) and (*c*) show the results for the 65 bp primer. (*b*) and (*d*) show the results for the 110 bp primer. (*a*) and (*b*) represent derivative melt curve. (*c*) and (*d*) represent the normalised HRM curve. The legend explains the color representation and the genotypes.

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Sheep measles – how can we control its insidious impact on the Australian sheep meat industry?

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Sheep measles is a parasite infection of sheep caused by the cystic stage of the tapeworm *Taenia ovis*. The adult tapeworm resides in the small intestine of dogs whilst the cystic intermediate stage resides in the body musculature, diaphragm and heart muscles of sheep. Dogs become infected by eating sheep measles cysts in sheep hearts or body muscles. Eggs passed in faeces of tapeworm-infected dogs are accidentally ingested by sheep whilst grazing. Neither parasite stage causes pathology in either dogs or sheep and unlike the hydatid tapeworm (*Echinococcus granulosus*) which has a similar lifecycle, the sheep measles tapeworm has no impact on human health. However, the cysts are killed by the immune system of the sheep leading to small abscesses in sheep meat. These abscesses mineralise and develop into hard nodules in the meat that remain for the life of the sheep. Therefore, infection leads to financial losses through down grading of carcasses, total or partial condemnation of carcasses, additional carcass trimming and longer inspection time. Financial losses between $1500–$4500 per day are mainly felt by the processor, but depending who owns the sheep at slaughter, a large proportion of these losses could affect producers.

Sheep measles can also be also be transmitted by wild carnivores. *Taenia ovis* has been reported in foxes (Jenkins *et al.* 2014) but so far, not in wild dogs, however, it is highly likely that in some places in Australia wild dogs are also acting as a host for the tapeworm.

Sheep measles in a farm situation is potentially easy to control; do not feed raw, fresh sheep meat or hearts to dogs, freeze it for 10 days or cook it first, and de-worm dogs every 6 weeks with a de-wormer containing the drug praziquantel. However, when wildlife is a component of the lifecycle, control becomes much more difficult. Certainly, on-farm control through de-worming farm dogs and only feeding them cooked or frozen sheep meat or hearts is still important, but eggs passed onto pasture by foxes or wild dogs may remain viable for up to one year. Therefore, smarter control strategies need to be instigated. The most obvious approach would be to protect sheep from becoming infected.

In late 1980s a highly efficient vaccine for sheep against sheep measles was developed, but for a number of reasons this vaccine has never been commercialised. However, it is hoped this deficiency will be addressed in the future.

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We gratefully acknowledge Meat and Livestock Australia for funding our studies into the role of wildlife in the transmission of sheep measles.

Occurrence of bovine hydatidosis in cattle slaughtered in a northern New South Wales abattoir

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Although a subclinical disease, bovine hydatidosis, caused by *Echinococcus granulosus*, is suspected to have a major financial impact on the Australian beef industry. The disease is characterised by the formation of hydatid cysts in the viscera, most often the liver and lungs. Affected organs are commonly identified and removed from the line of human consumption at slaughter. The prevalence and distribution of hydatidosis in Australian cattle is not accurately known because nationally coordinated data have never been recorded. Prevalence of bovine hydatidosis has been shown to vary geographically; cattle in coastal areas appear to have a higher prevalence of hydatid disease than those in inland areas (Banks *et al.* 2006). The aim of this study was to describe the occurrence of hydatidosis in cattle slaughtered in a northern New South Wales abattoir.

A retrospective study was conducted using data from approximately 1.9 million cattle slaughtered at a northern New South Wales abattoir between September 2010 and December 2016. Hydatidosis reported here refers to the lesion as reported by routine meat inspection at the abattoir.

Although cattle were sourced from all states and territories, most were sourced from New South Wales (56.39%, 95% CI 56.31–56.46%) and Queensland (41.58%, 95% CI 41.51–41.66%). Hydatidosis was diagnosed in 99,182 (5.27%, 95% CI 5.24–5.30%) slaughtered cattle. Annual prevalence of hydatidosis in slaughtered cattle ranged from 4–7%. Prevalence of hydatidosis was highest in New South Wales (6.51%, 95% CI 6.46—6.56%). The prevalence reported in Queensland (3.62%, 95% CI 3.58–3.67%) was higher than that previously reported by Banks *et al.* (2006), but lower than reported by Baldock *et al.* (1985). The regions surveyed in these previous two studies were smaller than the area examined in the current study. Animals of all age groups and both sexes were affected. Consistent with previous studies, the disease was more commonly found in older cattle (7/8-tooth dentition group, 34.76%, 95% CI 34.52–35.00%) compared to younger cattle (0-tooth, 1.30%, 95% CI 1.28–1.32%) (Baldock *et al.*, 1985; Banks *et al.*, 2006). Of all condemned or downgraded organs, 8% were condemned or downgraded due to hydatidosis. Hydatidosis was identified in the liver, lungs, heart, kidneys and spleen (Table 1). Eighty per cent of infected cattle had hydatidosis in both the liver and lungs. Ten per cent had the disease only in the liver and 4% had the disease only in the lungs. In comparison, Baldock *et al.* (1985) found that almost half of the animals in their study had cysts only in the liver and 36% had hydatidosis in both the liver and lungs.

Although the study was conducted in a single abattoir, the large number of animals from a variety of climatic regions throughout Australia demonstrate that bovine hydatidosis remains an endemic disease and a significant form of wastage of meat product in the beef industry. Based on the prevalence reported in this study and given current industry figures (ABS 2017), we can conservatively estimate that approximately 780,000 organs could be condemned or downgraded annually in the beef industry Australia-wide.

Table 1. Proportion of organs condemned or downgraded due to hydatidosis in beef cattle slaughtered at a northern New South Wales abattoir, Australia, September 2010–December 2016

	Total number condemned and downgraded	Proportion affected by hydatidosis (%)
Liver	636611	14.9
Lungs	626921	13.6
Heart	63119	1.5
Kidneys*	11836	0.9
Spleen	70937	2.5

*Kidneys affected by hydatidosis were recorded from May 2016 only.

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Macrocyclic lactone resistance in cattle nematodes in summer dominant rainfall regions of eastern Australia

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Increased reports of anthelmintic resistance in cattle nematodes in Australia (Cotter *et al.* 2015; Lyndal-Murphy *et al.* 2010; Rendell *et al.* 2014) prompted an investigation into the prevalence of macrocyclic lactone (ML) resistance in the summer dominant rainfall regions of eastern Australia where ML's are routinely used to target both internal and external parasites.

This work tested the hypothesis that there is ML resistance on cattle farms in summer dominant rainfall regions of eastern Australia. A Worm Egg Count Reduction Test (WECRT) was used to determine the effectiveness of a number of anthelmintic actives on five farms in southern Queensland and northern New South Wales.

An adequate worm burden was confirmed in young beef cattle prior to commencement of the WECRTs. On Day 0, cattle remained either untreated (on three farms) or were randomly treated with either moxidectin (Cydectin® Pour-On), doramectin (Dectomax® Injectable – on four farms), fenbendazole (Panacur® 100), levamisole (Nilverm® LV) or a combination of actives; abamectin, levamisole and oxfendazole (Trifecta®). Cattle were dosed in accordance to label directions (i.e. treated to the heaviest in the group). The Cydectin® Pour-On group remained separated from other treatment groups for at least seven days after treatment. Faecal samples were collected 10-14 days after treatment for individual worm egg counts (10/group) and group larval differentiation.

Individual WECs were log-transformed to normalise the data and geometric means calculated (VICH 2000). Macrocyclic lactone resistance (WEC reduction: <95% (Coles *et al.* 1992) was evident on 4 out of 5 farms while resistance was suspected to be emerging on the remaining farm. Fenbendazole, levamisole and the combination anthelmintic (abamectin, levamisole and oxfendazole) were effective on all farms. The predominant larval species present were *Haemonchus* spp. and *Cooperia* spp.

These results support the hypothesis of ML resistance on cattle farms in summer dominant rainfall regions of Eastern Australia. This work is on-going and findings will be used to create awareness of anthelmintic resistance in cattle and to determine strategies to ensure the longevity of anthelmintics on farm.

Table 1. Group geometric mean worm egg counts (epg)

Farm	Control	Dectomax® Injectable	Cydectin® Pour-On	Panacur® 100	Nilverm® LV	Trifecta®
NSW – 1	1375^{a}	233^{b}	42^{c}	0^{d}	0^{d}	0^{d}
NSW – 2	33^{a}	Not tested	6^{b}	0^{c}	0^{c}	0^{c}
QLD – 3	2644^{a}	909^{b}	578^{b}	1^{c}	0^{c}	0^{c}
QLD – 4	267^{a}	297^{a}	9^{b}	1^{c}	0^{c}	0^{c}
QLD – 5	202^{a}	5^{b}	5^{b}	0^{c}	0^{c}	0^{c}

Note: Means within rows followed by different letters are different at $P < 0.0001$ as assessed by protected Student's T-test. Dectomax® Injectable – 10 mg/mL doramectin, Cydectin® Pour-On – 5 g/L moxidectin, Panacur® 100 – 100 g/L fenbendazole, Nilverm® LV – 80 g/L levamisole hydrochloride and Trifecta® – 2 g/L abamectin, 80 g/L levamisole hydrochloride and 45.3 g/L oxfendazole, 5 g/L cobalt (EDTA), 2 g/L abamectin and 1 g/L selenium (as sodium selenate).

Table 2. Overall group geometric efficacy (%)

Farm	Dectomax® Injectable	Cydectin® Pour-On	Panacur® 100	Nilverm® LV	Trifecta®
NSW – 1	83.0%	96.9%	100%	100%	100%
NSW – 2	Not tested	81.1%	100%	100%	100%
QLD – 3	65.6%	78.1%	100%	100%	100%
QLD – 4	Ineffective	96.6%	100%	100%	100%
QLD – 5	97.8%	97.5%	100%	100%	100%

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Conflicts of interest: The author is a paid employee of MSD Animal Health at the time the WECRTs were conducted.

Effects of milking machine rate on proteinaceous components and gelatinolytic activity of mammary secretion of dairy cows in Thailand

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The suitability of milking machine management is critical for rapid and efficient removal of milk without damaging the mammary tissues. The dry period before expected calving allows fully remodeling of the mammary gland and nutrient deposition for lactogenesis and intensive growth of the fetus. The extracellular matrix (ECM) is one of the essential components of the cellular microenvironments, which plays a critical role in normal tissue morphogenesis and disease progression in the mammary gland. The ECM is involved in basic cell physiology such as proliferation, adhesion and migration, differentiation, and cell death. Thus ECM integrity is implicated in mammary tissue remodeling. The aim of the study was to investigate the effects of milking machine pulsation rate on the abundance of proteinaceous components and ECM degradation by gelatinases in the mammary secretion around the dry-up of Thai crossbred Holstein cows.

Nine clinically healthy Thai crossbred Holstein cows (75%HF) were kept in the dairy farm of the Silpakorn University Phetchaburi IT campus (Phetchaburi, Thailand). One week after delivery, cows were milked with different pulsation rates (less than 59 cycles/min, 60–69 cycles/min, and over than 70 cycles/min). In late pregnancy, milk and quarter secretion samples (~25 mL) were manually collected from individual quarters 14 days (d –14) and 7 days (d –7) before the anticipated drying off and the day prior to dry-cow treatment (d 0), and after dry-up treatment at day 3 (d 3), 7 (d 7), and day 14 (d 14). A native SDS-PAGE of 7% resolving gel with reducing buffer system was adopted to reveal the soluble protein component of milk and mammary secretion. Routine staining/destaining procedures revealed that gamma-globulin (~150 kDa), albumin (~67 kDa), and caseins (~25–35 kDa) were identified as the most prominent soluble protein components in the milk and mammary secretion. SDS-PAGE with 7.5% resolving gel containing 1% gelatin in Laemmli non-reducing buffer system was used to analyse gelatinase A (MMP-2) and gelatinase B (MMP-9) activity.

The total protein content and protein abundance were not significantly different between the machine rate groups. Gelatinase A (MMP-2) activity in quarter secretion increased up to day 3 but gelatinase B (MMP-9) increased more drastically, especially in cows with milking machine pulsation rate at 60 to 69 cycles/min ($P < 0.05$) (Fig. 1). The results suggest that the milking machine pulsation rate at between 60 to 69 cycles/min may result in more efficient mammary gland renewal during mammary involution and further benefit sustainable milk production and udder health in the long run.

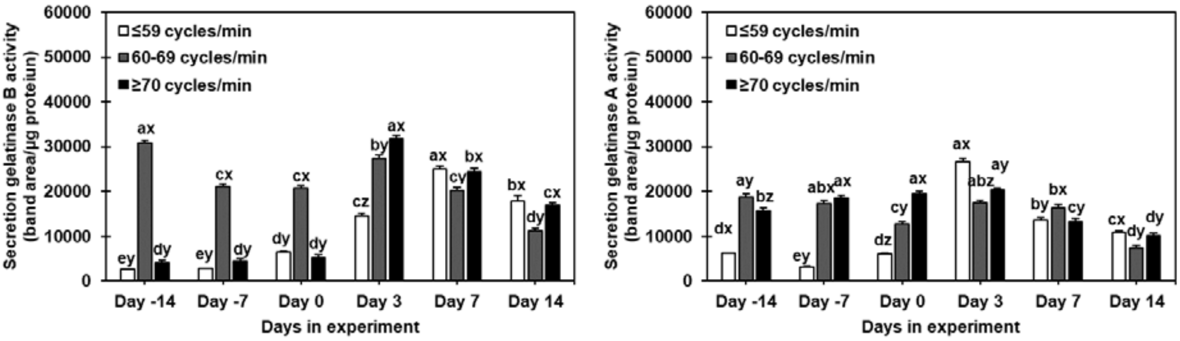

Fig. 1. The abundance of gelatinolytic activity of milk and mammary secretion of experimental Thai Friesian Cows during around dry-up period. [a,b,c]Values with different superscripts differ significantly ($P < 0.05$) among days in experiment within the same animal. [x,y,z]Values with different superscripts differ significantly ($P < 0.05$) in various levels of pulsation rate within the same day in experiment.

We gratefully acknowledge financial support from the Faculty of Animal Sciences and Agricultural Technology, Silpakorn University, Thailand

A comparison of the effectiveness of a single active macrocyclic lactone drench with an abamectin/levamisole combination drench, and the effect on weight gains, in beef cattle in southern New South Wales

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Anthelmintic resistance (AR), a well-recognised problem in sheep flocks across Australia and worldwide, has been assessed less frequently in cattle herds. Combining anthelmintic groups (combination drenches) is recognised as one method of delaying AR (Dobson *et al*. 2011, Leathwick 2013) or reducing its effect (Fazio *et al*. 2014). This study investigated the level of AR in cattle herds, the possible production costs associated with AR and its potential amelioration with an abamectin/levamisole combination pour-on drench.

Young weaned steers in six beef herds in southern NSW were assessed for the level of AR., with 45–50 steers on each property receiving the abamectin/levamisole combination drench, 45-50 steers receiving a macrocyclic lactone (mectin) drench, and 15 steers remaining undrenched (controls). Steers were kept in separate paddocks for 9–11 days following treatment to prevent cross-contamination between groups from animals licking other animals receiving a different treatment (allogrooming). Cattle in the two drenched groups were then weighed, and faecal samples collected per rectum from 15 animals from each of the three groups. Faecal worm egg counts were performed at CSU’s VDL using a similar technique as described by George *et al*. (2017), with multiple McMaster slides being counted and a detection sensitivity of 10 eggs per gram. Cattle in the drenched groups were weighed again 11 weeks later, with differences analysed using appropriate models (JMP 10, SAS Institute Inc., NC, USA).

AR (<95% drench efficacy) was detected to the single mectin drench on 5 of the 6 properties (83%) (Table 1). In comparison, the abamectin/levamisole combination drench was considered effective (≥99%) on all 6 farms (Table 1). Animals treated with the abamectin/levamisole combination drench were significantly heavier 11 weeks post sampling on 2 of the 6 farms (Farms 4 and 5) (Table 1); however on 4 of the 6 farms weight gains between the two treatment groups were not significantly different (Table 1), despite AR being present on these four farms.

Surprisingly, there was weak correlation ($R^2 = 0.39$) between AR and weight gain. The greatest advantage in using a combination drench was on the property with the highest efficacy to mectin drenches (Farm 4); while the property with the highest level of AR (68% efficacy, Farm 6) gained no weight gain advantage from the combination drench, despite it being 100% effective.

The results demonstrate the presence of AR in beef herds in southern Australia, and suggest that AR is likely to be present in many herds. The six herds in this study were not selected on the basis of any suspicion of AR or of any previous or current worm problems; rather they were selected as competent operators who were known to CSU and willing to participate in this trial. Furthermore, given the likelihood of resistance, it would appear prudent for cattle producers to consider using combination drenches even if weight gain advantages are not always apparent, as the continued use of a single active anthelmintic when resistance to that active is present is likely to lead to even greater levels of AR, making anthelmintic failure, weight loss, and clinical parasitism more likely.

Table 1. Anthelmintic efficacy and difference in mean live weights between combination (abamectin/levamisole) and single mectin groups at final weight

Farm Number	Control worm eggs per gram	Anthelmintic efficacy		Weight at drenching (kg)	Weight difference [Combination-mectin] (kg)
		Mectin	Combination		11 weeks
1	523	84%	99%	287	–2.0
2	223	75%	99%	335	4.3
3	90	94%	100%	270	–5.3
4	915	97%	100%	190	20.8*
5	206	83%	100%	265	11.0*
6	94	68%	100%	303	–2.0

*Weight differences between combination and mectin groups significant ($P < 0.05$).

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Buffalo flies: a costly tropical cattle pest and impending threat to southern cattle production

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Buffalo flies (*Haematobia exigua)* are considered the second most costly disease issue in northern Australian cattle (Lane *et al.* 2015). Buffalo flies (BF) live most of their lives on cattle, leaving only to oviposit in freshly deposited dung. If uncontrolled, infestations may reach several thousands of flies per animal, each biting up to 40 times daily, causing production loss, irritating cattle, and causing the development of lesions that are of significant welfare concern (Jonsson and Matchoss 1998).

Buffalo flies entered Australia near Darwin in 1838 and spread relatively slowly to reach Bundaberg in eastern Queensland by 1946. No further spread was recorded for the next 30 years. However with a series of mild winters after 1973 and changes to tick control programs, southward expansion of BF range resumed and BF reached Bonville near Coffs Harbour in NSW by 1982 (Williams *et al.* 1985). Since recommencing their spread from Bundaberg BF have extended their range more than 1000 km southward and in the wet summer of 2011 BF were detected near Maitland in eastern NSW and as far west as Bourke and Narromine (Fig. 1). A warming climate is expected to increase fly activity, the rate of BF population growth and the number of generations each year, with longer seasons of cattle challenge and greater impacts on cattle in most BF-endemic areas. Predicted rises in minimum temperatures and a reduction in the frequency of frosts will favour survival in marginal areas and further extension of the BF range. The results of CLIMEX modelling (Fig. 2) indicate greater impacts from BF in most parts of its current range and the potential for persisting BF populations to establish through much of the moist coastal belt of NSW and in foci as far south as South Australia and southern Western Australia by as early as 2030 (Fig. 2). Increased weather variability and extreme rainfall events predicted under climate change will increase the likelihood of spread of flies across inhospitable areas to new foci suitable for winter BF persistence.

CLIMEX modelling does not account for a changing resource base, microclimate effects or changes in pest biology. In southern areas, the cattle industry is based largely on *Bos taurus* breeds that are more susceptible to buffalo flies than the *Bos indicus* cattle that predominate in northern areas. In addition, many northern cattle are treated to control cattle ticks, which can also impact on BF numbers, whereas most southern cattle receive few parasite treatments. Adaption of insects at the edge of their range can also be an important contributing factor in new pest invasions and the potential for development of a pupal overwintering capacity, as is present in very closely related horn flies (*Haematobia irritans*) in the northern hemisphere and, more recently south America, is a particularly troubling prospect.

Increasing global temperatures and the availability of a large resource base of susceptible and largely unprotected *Bos taurus* cattle suggest that without intervention BF are likely to become a significant parasite issue in Australia's southern beef and dairy industries.

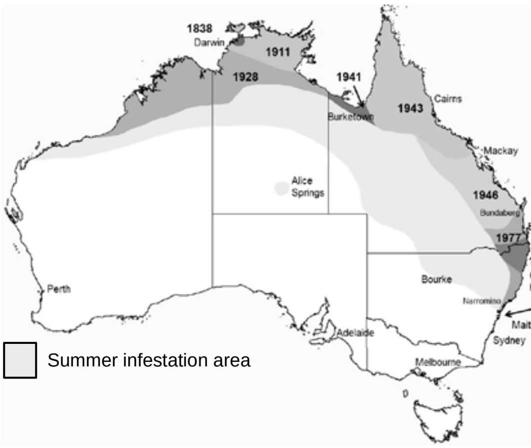

Fig. 1. Spread of buffalo flies in Australia.

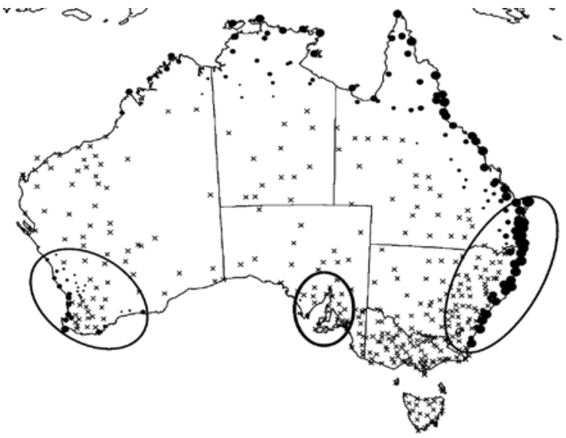

Fig. 2. Predicted favourability for BF by 2030. Ellipses indicate regions of significant potential range expansion

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We gratefully acknowledge Dr Rob Dobson for conduct of the CLIMEX modelling.

The prevalence of health conditions recorded in an Australian sheep abattoir

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The health of an animal can affect the value of its carcase due to trimming and condemnations. Health conditions observed in abattoirs are a valuable source of information about subclinical diseases, which may not be observed in the live animal and should be used to target reduction of specific conditions. While the National Sheep Health Monitoring Program reports on 16 health conditions in sheep, only a subset of carcases are inspected (Animal Health Australia 2017). Therefore, the objective of this study was to use health data routinely recorded in an Australian sheep abattoir to estimate the prevalence of health conditions in lambs.

Monthly records on the number of lambs processed and the health conditions observed were available for lambs procured from VIC, NSW, SA and TAS for Australian Lamb Company. Records were available from January 2015 to December 2017, with over 100,000 lambs processed per month. All carcases were inspected on the slaughter floor by trained staff and audited by veterinarians. The monthly prevalence of health events was calculated as the proportion of lambs processed affected by a health condition.

The monthly prevalence of lambs observed with any health condition ranged from 0.5% to 7.7% of total lambs processed, with an average of 2.4% (Fig. 1). The most prominent health conditions observed over time was grass seed (66% of total affected during the observed period) where monthly prevalence ranged from 0.06% to 7.0%, with an average of 1.6%. Other conditions, such as vaccination lesions, arthritis, pleurisy, sheep measles, bruising and dog bites, had an average monthly prevalence of less than 0.5%. The importance of conditions align with the key issues identified by the National Sheep Health Monitoring Program (Animal Health Australia 2017). While there does not appear to be systematic peaks for health conditions, data from more years is required to more accurately determine seasonal effects.

Abattoir inspections have been noted as a key monitoring tool for multiple endemic diseases in the Australian red meat industries (GHD Pty Ltd 2015). Examination of non-affected lambs can also allow evaluation of risk factors influencing health conditions. In addition to this, if absence and presence of health conditions were recorded on an individual animal basis, and relevant information such as pedigree, sex, and management groups were available, there are opportunities for the genetic improvement of health (for example, Mathur *et al.* 2018). Health feedback can also be provided to producers to allow assessment and improvement of current management practices. Therefore, there are many opportunities to enhance production systems using health data routinely recorded in abattoirs.

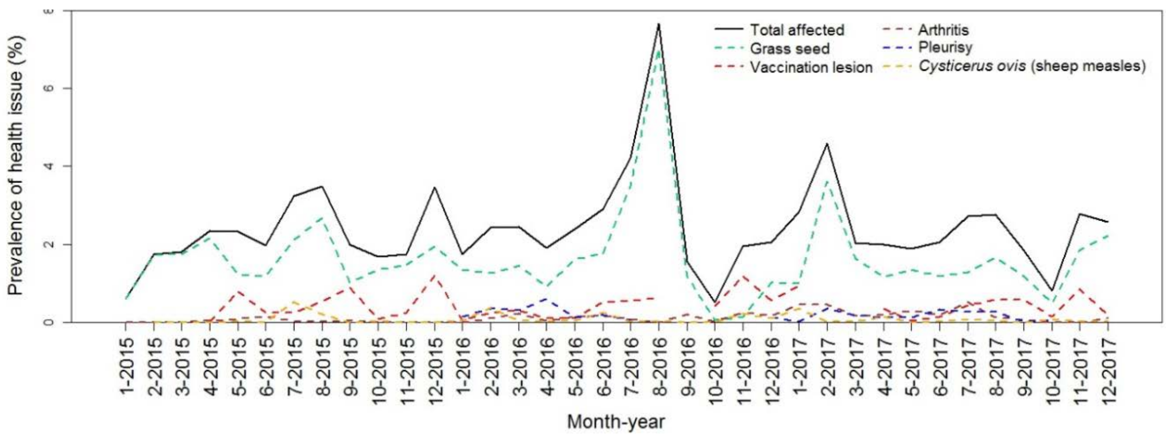

Fig. 1. The monthly prevalence of health conditions observed on the slaughter floor in a lamb abattoir.

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Porcine helminthiasis and the prevalent farm management operations among smallholder pig farmers in the Free State Province of South Africa

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Pork plays a vital role in the nutrition and health status of its consumers in most parts of the world. It is the third highest produced meat in South Africa with increasing domestic demand (South African Government, 2015). The problem of porcine helminthiasis and its zoonotic tendencies have become a major public health concern. This infection can lead to considerable loss of productivity, financial loss to farmers, decline in animal welfare, reduced sustainability in food security especially in subsistence farming systems, and have the potential to cause significant health threats in infected humans (Zoli *et al*. 2003). The highest levels of human neurocysticercosis (NCC), a zoonotic infection caused by *Taenia solium* was reported in the smallholder farming areas of the Eastern Cape Province of South Africa (Krecek *et al*. 2004). Reported incidences (Coles *et al*. 2006) of anthelmintic (AH) drug resistance among worm populations aggravates the problem.

There is insufficient scientific information available on the knowledge of porcine helminthiasis and its attendant problems among resource poor farmers. Therefore, the objective of this study was to determine the level of awareness in smallholder pig farmers with issues regarding their pig health and the prevalent farm practices that militates against productivity. This information aims to form the baseline knowledge to determine farmer's awareness in relation to the above issues.

Questionnaires were issued to 46 smallholder pig farmers in the research region, inferences were drawn from their responses and analyzed using simple statistics. Results show that almost 70 % of respondents were males and majority (60.9 %) possess little or no formal education, giving rise to generally poor arithmetic ability. The semi-intensive system and the continuous flow-barn practice were the most prevalent on-farm management practices. These practices encourage the proliferation and perpetuation of parasites in herds. There was a very high positive correlation ($P < 0.01$) between farm size and number of pigs per enterprise; type of farming method and management system practiced.

On health aspects, more than 70% of farmers vaccinate and deworm their pigs. However, the majority of respondents have never conducted parasitological analyses of their flock's faecal samples. Also, 80.4% of the participants do not employ the services of veterinarians or trained animal health technicians to assess their herd due to high cost, availability and accessibility to farms. Intestinal helminths emerged as the most common (65.2%) herd health problem. Interestingly, 41.3 % believed that the pig's environment can be a source of infection, although only 17.4 % clean their pig stalls daily and the majority did not use disinfectants. Across border, piglets recorded the highest infection and mortality rates, with 53.3 % of mortalities occurring in females. There was a high rate of ignorance towards AH resistance, AH withdrawal periods and zoonoses, even though 67.4 % claimed they know how to prevent human zoonotic infections. Similarly, more than half (53.3%) of the respondents described the cost of AHs as 'expensive'.

On post slaughter practices, 73.9% of respondents do not slaughter their pigs in an abattoir due to high cost of slaughter and transportation, long distances to the abattoir, small scale of production and very few pigs to slaughter at a given period. Unfortunately, half (50.0%) of the farmers reported that their pig production enterprise was not profitable or viable.

Smallholder pig farmers in the study area were faced with several constraints militating against improved pig production and viability. More information and government interventions are still very much needed to increase farmer awareness to the scourge of porcine helminthiasis and to curb the high rate of failed smallholder pig enterprises in the study area.

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Worm problem? What problem?

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The management of gastrointestinal nematode infections is considered a mainstay of animal health, particularly for sheep production where nematode infections are the greatest cause of productivity losses of any disease in sheep. Gastrointestinal nematodes cost the Australian sheep industry $436 million annually, (Lane *et al.* 2015) equivalent to 7% of the industry's total value of $5.972 billion (ABS 2016). Given the impact and importance of nematode infections to the livelihoods of sheep producers, and the amount of information and resources available to farmers, it could be expected that farmers understand the importance of these parasites to their operations, know how to treat these parasites, and do so accordingly.

To develop sheep products that meet the needs of sheep farmers, Virbac set out to understand the processes and the job steps involved in the delivery of sheep drenches and to gain insights into the knowledge, confidence and decision-making processes of farmers as they considered and conducted this task. Using a process called Outcome Driven Innovation, we sought end-user input on the intellectual and physical aspects of the job of drenching sheep. This qualitative and quantitative research revealed insights into the attitudes of farmers towards the information available to them and their actual on-farm practices around gastrointestinal nematode management and animal husbandry.

Preliminary interviews of 20 farmers were performed to identify the critical steps involved in drenching sheep. From the point where the decision is made to drench sheep to the act of cleaning up and disposing of empty product drums, we identified 7 individual steps that formed a job map. Within these steps, we identified 46 individual needs of farmers when completing the job of drenching sheep. These needs were then crafted into pairs of needs statements that were designed to assess the importance of the need and how well that need was currently being addressed when they performed the job of drenching sheep. These pairs of needs statements along with 71 demographic and profiling questions were developed into a survey designed for online completion by a data recorder.

Three hundred and twenty-nine (329) sheep farmers from around mainland Australia participated in telephone interviews guided by the data recorder. The data from these surveys was then analysed using Tableau™ software to identify relationships between demographic data and needs statements.

The farmers who completed surveys were mostly male (89%) and over 55 years of age (59%), and were largely owners of their own properties (85%). The mean flock size was 1200–2000 breeding ewes (32%) with 26% having flocks of 800-1200 ewes, 21% having flocks of 2000–3000 breeding ewes and a further 21% having flocks of >3000 breeding ewes. Farmers with fewer than 800 breeding ewes were screened out of the survey.

Our survey data revealed that the majority of farmers (65%) believe that they do not currently have a drench resistance problem on their property, while 10% did not know whether they had a problem with drench resistance and 25% had knowledge of a drench resistance problem in their flock. These perceptions of farmers are not consistent with data from scientific studies which have shown the prevalence of benzimidazole or levamisole resistance in Australian sheep enterprises to be in excess of 90% and 80% of farms respectively since the early 1990s (reviewed by Besier and Love 2003), and that resistance against macrocyclic lactones can now be found in over 50% of Australian sheep farms (Playford *et al.* 2014).

Key insights from our research revealed that farmers' main needs were the prevention of drench resistance on their property and avoiding bringing drench resistance onto their property. However, despite these concerns, the data also revealed that few farmers were actually implementing the practices required to manage anthelmintic resistance such as the use of combination drenches, appropriate use of quarantine drenches and conducting DrenchChecks or Drench Resistance Tests on their properties. Conversely, farmers who believed they had a drench resistance problem were more likely to use combination drenches, perform faecal egg counts and DrenchChecks, and use appropriate quarantine drenches.

Our presentation will discuss some of the insights we've gained regarding the behaviours of farmers as they approach the challenge of managing gastrointestinal nematodes on their properties and will propose opportunities to improve farmers' management of anthelmintic resistance.

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Effects of post-grazing herbage height and concentrate feeding on protein composition of milk from dairy cows in mid-lactation

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Variations in raw milk protein composition can affect the quality and yield of dairy products such as cheese or milk powder (Dalgleish, 1992). True protein fraction of bovine milk is composed of two major categories: caseins and serum (whey) proteins. Mackle *et al.* (1999) suggested that milk protein composition can be manipulated through both feeding regime and animal genotype selection. The aim of this study was to analyse the impact of grazing management and supplementation on milk protein composition from mid-lactation dairy cows.

This study was carried out to investigate the effects of post-grazing herbage height and concentrate feeding on milk yield (Bryant *et al.* 2013), milk fatty acid composition (Rugoho *et al.* 2016) and milk protein composition. Briefly, the study was conducted at the Lincoln University Research Dairy Farm in Canterbury, New Zealand. Thirty-two mixed-aged, spring-calving, Friesian x Jersey dairy cows in mid-lactation were assigned to one of four feeding systems. These four treatments were a factorial combination of two post-grazing herbage heights (low: 3.5 or high: 5 cm) with or without concentrate feeding (4 kg/cow.d) with two replicates. The concentrate composition on a fresh weight basis was wheat 60%; maize 22%; canola 11%; peas 7%; molasses 1%; and minerals, vitamins and additives 3%. The pasture consisted of *Lolium perenne* and *Trifolium repens*. Milk protein composition was analysed 64 and 87 days after feeding treatments commenced. Milk samples were collected from all experimental cows over consecutive morning and evening milking (16–17 October 2012 and 8-9 November 2012) to determine milk protein composition. Separation, identification and quantification of six major milk proteins were carried out by reversed-phase high-performance liquid chromatography (Bordin *et al.* 2001). The effect of treatments on individual milk proteins was determined by ANOVA (Genstat), with post-grazing height and concentrate as fixed terms and replicate as random term.

There was no effect of post-grazing height or concentrate feeding on milk protein composition (P > 0.10, Table 1). Total casein, α, β and κ-casein were not different in the four feeding systems (P>0.10). Similarly, whey proteins, α-lactalbumin, ß-lactoglobulin-A and ß-lactoglobulin-B were not different. As a result, the ratio caseins/whey proteins was the same for the four treatments. The ratio caseins/proteins for each group was between 83% and 86%, which is in agreement with Dalgleish (1992)'s result. In conclusion, under the feeding system in this study, post-grazing height and concentrate feeding did not influence the milk protein composition.

Table 1. Protein composition of milk from dairy cows grazing herbage at low or high post-grazing height with (+) or without supplementary concentrate feeding

Protein (mg/mL)	Low	Low+	High	High+	SED	P-value[A]
Caseins	34.13	32.76	33.68	34.00	1.521	0,441
α-casein	13.71	13.43	14.11	13.82	0.683	0,993
β-casein	12.68	12.46	12.59	12.87	0.549	0,522
κ-casein	7.74	6.87	6.99	7.30	0.722	0,255
Whey proteins	5.64	6.37	6.89	6.37	0.765	0,257
α-lactalbumin	1.84	1.51	2.00	1.50	0.396	0,759
β-lactoglobulin-A	2.93	4.17	4.05	4.21	0.910	0,405
β-lactoglobulin-B	0.87	0.68	0.84	0.67	0.275	0,979

[A]The P-value presented here refers to grazing height by concentrate interaction effects.

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Residual feed intake in sheep 1: are current models for estimating residual feed intake suitable for mature rams?

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Feed is a major cost of sheep production systems (Cammack *et al*. 2005), therefore, efficient live weight gain per unit of DM intake (DMI) is an important component of a profitable livestock system. Improvements in the feed conversion efficiency of mature animals in the flock will have a greater impact on farm profitability than improvements in efficiency of lamb growth (Jackson *et al*. 2014). The efficiency with which feed is converted to liveweight expressed as residual feed intake (RFI), is the difference between predicted and actual DMI. Residual feed intake is commonly measured in young, growing animals fed medium to high energy density diets, however Reddin *et al.* (2013) suggest RFI measured in young animals does not translate to RFI measured in mature animals. Variation in growth corresponds to differences in body composition and composition of gain. The magnitude of these differences change as the animal matures (Basarab *et al.* 2003) and impacts on the ability to predict RFI in ageing animals. The standard beef model (Knott *et al*. 2008) estimates daily DMI using metabolic mid-point weight (MMWT, weight at the mid-point of the feed intake test^0.75) and average daily gain (ADG). The objective of this study was to examine the feed conversion efficiency of mature rams using RFI estimated by the standard beef model.

Feed DMI and ADG were measured in 61 mature rams (Maternal composite n = 43, White Suffolk n = 11, Merino n = 6, Coopworth n = 1). Rams were aged between 2 and 6 years at the start of the measurement period. Dry matter intake was measured using automated feeders located at DEDJTR Hamilton over 42 days in July/August 2016. Animal liveweights (LWT) were measured 3 times weekly during this period. Residual feed intake was calculated from measured DMI and DMI estimated using 4 approaches. Method 1 estimated DMI based on the equation published by Knott *et al*. (2008). Methods 2-4 used estimates of the animals liveweight to predict DMI, MMWT (Method 2), mean LWT (Method 3) and starting LWT (Method 4). Accuracy of the models in predicting RFI can be explored using the proportion of variance in DMI explained by the model, as RFI comprises the difference between measured and predicted DMI.

The mean (±SD) daily DMI over the 42 days of measurement was 3.74 (±0.678) kg DM/day, ADG was 271 (±73.7) g/day and mean start LWT was 99.8 (±9.14) kg. Daily DMI was highly correlated with average LWT (r = 0.71, $P < 0.001$) and moderately correlated with ADG (r = 0.38, $P < 0.01$). Estimated using method 1, residual feed intake ranged from –1.006 to 1.261 (mean $3.27 \times 10^{-6} \pm 0.439$). Using method 2 residual feed intake averaged -1.64×10^{-6} (±0.479, range –0.876 to 1.454), method 3, 3.28×10^{-6} (±0.478, range –0.872 to 1.429) and method 4 averaged -4.92×10^{-6} (±0.513, range –0.890 to 1.70). Using method 1 explained 51.3% of the variation in daily DMI. However, only MMWT contributed significantly to the model ($P < 0.001$), while ADG approached significance ($P = 0.065$). Using methods 2, 3 and 4 decreased R^2 by 2.1, 1.8 and 9.6 percentage points respectively ($P < 0.001$).

The proportion of variation in daily DMI explained by the MMWT + ADG model was similar to that observed for 6 month ($R^2 = 0.64$) and 13 month ($R^2 = 0.57$) old rams (Knott *et al.* 2008). Although ADG was not a significant component of the RFI model in our study, the increase in variation explained by the model including ADG indicates that it is still an important measure to include in an RFI model, particularly when large gains in liveweight are observed. Completing measurements over a larger number of animals is likely to result in ADG being significant. Where ADG is lower, as may be the case for many mature animals, the importance of ADG to the model may be reduced.

The data suggests that the standard model for RFI, including MMWT and ADG (Knott *et al*. 2008) can be used for mature sheep as well as young growing sheep. However, in mature animals a large proportion of variation in DMI is explained primarily by animal MMWT. It is possible that including measures of body composition may increase variation in daily DMI explained for mature animals.

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Residual feed intake in sheep 2: does incorporating changes in an animal's body composition improve the residual feed intake estimate in mature rams?

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As an animal matures, changes in body composition and the composition of gain become increasingly important in the estimation of RFI due to differences in energy cost to deposit and maintain lean or fat tissue, which affect the efficiency of nutrient utilisation (Basarab *et al*. 2003, Van der Werf 2004). Van der Werf (2004) suggests that to more accurately reflect biological efficiency, measures of body composition need to be known, allowing the RFI model to better represent maintenance and growth. However, Arthur *et al.* (2003) determined that the estimate of RFI was not improved by inclusion of body composition parameters in young beef cattle. Muir *et al*. (2018) suggest that while metabolic-mid-point weight (MMWT) and average daily gain (ADG) could be used to estimate RFI for mature rams, a large proportion of variation was not explained by these parameters and proposed that inclusion of body composition parameters may improve estimates. We examined the effect of including ultrasound scanned muscle and fat depth at the C-site on the percentage of variation explained by the RFI model when compared to the standard RFI model.

Dry matter intake (DMI), ADG and mean body composition and body composition change (as measured using ultrasound scan) were measured in 61 mature rams (Maternal composite n = 43, White Suffolk n = 11, Merino n = 6, Coopworth n = 1). Rams were aged between 2 and 6 years at the start of the feed intake period. Dry matter intake was measured using automated feeders at Agriculture Victoria, DEDJTR Hamilton over 42 days in July/August 2016. Liveweight was measured 3 times weekly during the feed intake measurement period. Residual feed intake was calculated by estimating DMI using equations published by Knott *et al*. (2008, Equation 1, DMI = MMWT + ADG) and Francois *et al*. (2002, Equation 2). Equation 2 (DMI = ADG + mid test weight + mean fat depth + mean muscle depth) was applied as adapted by Knott *et al*. (2008) to include mean fat and muscle depth (adjusted to 50 kg LWT) or to include change in body composition (Equation 3, DMI = ADG + mid test weight + change in fat depth + change in muscle depth). Models estimate DMI, and RFI is calculated as the difference between predicted (modelled) DMI and actual DMI.

The mean (± SD) daily DMI over the 42 days of measurement was 3.74 (± 0.678) kg DM/day, ADG was 271 (± 73.7) g/day and mean start weight was 99.8 (± 9.14) kg. Starting muscle depth averaged 39.8 (± 3.10) mm, end muscle depth averaged 43.5 (± 3.08) mm. Starting fat depth averaged 4.5 (±1.06) mm, end fat depth averaged 7.2 (± 1.59) mm. Daily dry matter intake was highly correlated with average LWT ($r = 0.71$, $P < 0.001$) and moderately correlated with ADG ($r = 0.38$, $P < 0.01$). There was no effect ($P > 0.05$) of ram age or breed in any of the models. Accuracy of the models in predicting RFI can be explored using the proportion of variance in DMI explained by the model. Each model of RFI explained a similar proportion of variance in DMI. Equation 1 explained 51.3% of the variance in DMI, however only MMWT contributed significantly ($P < 0.001$) to prediction of DMI, but ADG approached significance ($P = 0.065$). Residual feed intake ranged from -1.037 to 1.327 (S.D. = 0.465). Including body composition measures (adjusted mean fat and muscle depth, Equation 2) decreased the variation in DMI explained by the model to 50.8%. Only body weight (mid test weight) and growth parameters (ADG) were significant in the model ($P < 0.001$ and $P < 0.05$ respectively). Residual feed intake ranged from -1.020 to 1.256 (S.D. = 0.460). Including the change in body composition (Equation 3) produced a similar result, explaining 50.6% of the variance in DMI. However, only body weight (mid-test weight) was significant in the model. Residual feed intake ranged from -1.00 to 1.335 (S.D. = 0.460). Ranking of rams based on the different estimates of RFI was examined using Spearman Rank Correlation. Correlation between RFI estimates produced by Equations 1, 2 and 3 were very strong ($r > 0.95$) suggesting that re-ranking between equations is very low. This is similar to the effect observed by Arthur *et al*. (2003) for young beef cattle.

In this study, we found the inclusion of body composition did not improve the percentage of variation in DMI explained by the RFI model. Ranking of individuals for RFI did not change significantly with method of estimating RFI. This suggests that inclusion of body composition in the model of RFI for mature animals does not improve the estimate of RFI for mature rams.

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Effect of early weaning using lucerne on ewe and lamb live weight gain

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In New Zealand sheep-production systems, lambs are normally weaned between 10–14 weeks of age onto grass/clover pastures (Geenty 2010). The growth rate of suckling lambs is dependent on milk and herbage intake, and the efficiency of utilisation of the absorbed nutrients. Ewe milk production peaks between weeks 1–2 of lactation and dramatically declines by week 8 of lactation (Paten *et al.* 2014). Consequently, during late lactation the lamb receives little nutrition from the ewe, and the ewe and lamb can become competitors for the same feed resource, thereby restricting lamb growth rates. Lucerne is a high metabolisable energy forage and has been shown to support greater rates of liveweight gain in lambs both pre-weaning and post-weaning when compared to grass (Douglas 1986). Weaning lambs early (at 6–9 weeks of age) onto a high quality lucerne sward has the potential to support high lamb liveweight gain and increase the efficiency of pasture utilisation. Furthermore, if lambs were weaned earlier it would give the ewes more time to gain live weight prior to the start of the next breeding season. Thus, the aim of this study was to determine the impact of weaning lambs early (at approximately 7 weeks of age) onto lucerne on the live weight gain of twin lambs and their dams.

On 3 November 2015 (46 days after the midpoint of lambing; L46), 71 twin-bearing ewes with both lambs at a minimum live weight of 16 kg were allocated to one of three treatments. The treatments were 1) ewe and lambs together on perennial ryegrass/white clover pasture (Grass), 2) ewes and lambs together on lucerne (Lucerne), 3) lambs weaned onto lucerne and ewes on grass (Early weaned). Lambs and ewes in the Lucerne and Early weaned treatments were gradually adjusted to the lucerne diet and then ewes in the Early weaned treatment were removed at L60. Ewes and lambs were weighed at L46, L60 (when ewes were removed from early weaned treatment) and L94 (time of conventional weaning). Herbage masses were monitored throughout the study and maintained to ensure ewes and lambs had unrestricted access to either grass (>1200 kgDM/ha) or lucerne (>1500 kgDM/ha).

There was no difference ($P > 0.05$) in the live weight of the lambs allocated to the three treatments at the start of the study (Table 1). Lambs that were weaned early onto lucerne had a similar ($P > 0.05$) liveweight gain compared to lambs which remained with their dam on grass. While lambs which remained with their dam on lucerne grew faster ($P < 0.05$) than lambs weaned early onto lucerne and lambs which remained with their dam on grass. Ewes weaned early and grazing grass gained more ($P < 0.05$) live weight than unweaned ewes on grass, and had a similar ($P > 0.05$) liveweight gain to unweaned ewes on lucerne.

This suggests farmers could wean lambs 4-5 weeks earlier than normal practice onto lucerne without compromising lamb growth rates. In addition, ewes could be removed onto poorer quality grass and still gain more live weight than if they remained with their lambs.

Table 1. Effect of treatment; ewes and lambs together on grass (Grass), ewes and lambs together on lucerne (Lucerne), lambs early weaned onto lucerne and ewes moved onto grass (Early weaned) on the live weight (mean ± SEM) of twin-reared lambs at day 46 of lactation (L46), L60 (ewe removal from Early weaned treatment), L94 and the liveweight change (mean ± SEM) of lambs and ewes between L60 and L94

Treatment	*n* lambs	Lamb live weight at			Liveweight change (g/day) between L60 and L94	
		L46 (start)	L60 (ewe removal)	L94 (end)	Lambs	Ewes
Grass	48	20.2 ± 0.32	25.2 ± 0.49	32.8a ± 0.49	223a ± 7.9	-5a ± 17.9
Lucerne	48	20.6 ± 0.32	25.2 ± 0.49	35.2b ± 0.47	277b ± 7.7	112b ± 17.9
Early weaned	46	20.2 ± 0.32	26.0 ± 0.47	33.3a ± 0.47	218a ± 7.9	128b ± 17.6

Means within columns with different letters are significantly different ($P < 0.05$).

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Effects of molasses and exogenous enzymes on the fermentation, aerobic stability and nutrient composition of ensiled maize cob and potato hash mixtures

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Affordability of conventional feeds has gone beyond the reach of smallholder livestock farmers in South Africa due to declining grain production and increasing competition with humans for feed ingredients. Availability of agro-industrial by-products have compelled smallholder livestock farmers to use alternative energy sources to in animal diets. These by-products contain essential nutrients and might make excellent animal feed. Maize is a major cereal grown in South Africa and its by-products at harvest, maize cobs (MC), can mitigate into animal feed. Presently, the MC are being thrown away. Potato hash (PH), a by-product of the potato food producing industry is available at an amount of 50 ton per day. However, its high moisture content makes it difficult to incorporate it in animal feed. Ensiling can be considered as an efficient way of preserving PH. It is therefore proposed to ensile MC and PH with the addition of additives such as sugar cane molasses and exogenous enzymes to preserve the PH and MC mixtures. The aim of the present study was to assess the effects of silage additives on the fermentation, aerobic stability and nutrient composition of ensiled maize cob and potato hash mixtures.

An amount of 800 g/kg^{-1} PH was mixed with 200 g/kg^{-1} of MC to produce silage (MCPHS). The mixture was treated with: i) control (no additive), ii) molasses (MOL) and iii) exogenous xylanase enzyme (Natugrain TS L®). Molasses was added at an inclusion rate of 5% and exogenous xylanase enzyme (Natugrain TS L®) was added at an inclusion rate of 100 g/tonne. The treatments were ensiled in 1.5l jars and kept at room temperature for 32 days. After 32 days of ensiling, three jars per treatment were opened and samples were collected and analysed for chemical composition and fermentation characteristics. Further, the silage samples were subjected to an aerobic stability test (CO_2 production) that lasted for 5 days following the procedure of Ashbell *et al.* (1991).

Exogenous xylanase enzyme inoculation improved ($P < 0.05$) DM and CP contents, reduced fibre content and increased lactic acid compared to other treatments, which was consistent to Sucu and Filya (2006). In addition, exogenous xylanase enzyme inoculation had higher ($P < 0.05$) residual WSC, which led to poor aerobic stability of silage (Weinberg *et al.,* 1993) as indicated by higher CO_2 production and lesser hours of aerobic stability compared to other treatments. Inoculation with molasses increased ($P < 0.05$) the content of acetic acid and improved silage aerobic stability compared to other treatments.

The fermentation of WCS was improved with exogenous xylanase enzyme while the silage aerobic stability was improved with molasses inoculation.

Table 1. Fermentation characteristics and chemical composition of maize cob and potato hash silage (*n* = 3)

Parameter	Control	Treatments Mol	EZM	SEM	P-value
Chemical composition					
DM, g/kg	303.7^{b}	228.3^{c}	313.7^{a}	2.08	0.001
CP, g/kg DM	154.6^{b}	142.1^{c}	172.5^{a}	1.85	0.001
aNDF, g/kg DM	474.0^{a}	450.6^{b}	398.5^{c}	1.085	0.001
ADF, g/kg DM	393.4^{a}	393.2^{a}	314.7^{b}	1.037	0.001
ADL, g/kg DM	75.07^{a}	74.57^{a}	62.03^{b}	0.471	0.001
Fermentation characteristics					
WSC, g/kg DM	2.66^{b}	6.47^{a}	7.28^{a}	0.462	0.001
pH	4.40^{b}	5.06^{a}	4.2^{b}	0.1081	0.03
LA, g/kg DM	54.8^{b}	38.2^{c}	69.7^{a}	1.329	0.001
Aerobic stability					
CO_2, g/kg DM	23.63^{b}	6.98^{c}	27.9^{a}	0.724	0.001

$^{a\text{-}c}$Means with different letters in a row differ significantly ($P < 0.05$). DM, Dry matter; CP, Crude protein; aNDF, amylase-treated neutral detergent fibre; ADF, Acid detergent fibre; WSC, Water soluble carbohydrates; LA, Lactic acid; Carbon dioxide; Hrs, Hours

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Enrichment of cardiac tissue of broiler chicken with omega-3 fatty acids: is there potential for inter-generational improvement?

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Cardiac tissue of commercial broiler chickens is dominated by the saturated fatty acids (SFA) and omega-6 polyunsaturated fatty acids (n-6 PUFA) reflecting the dietary fatty acid composition (Kanakri *et al.* 2018). The high SFA and/or n-6 PUFA associate with adverse effects on the birds' health. Conversely, feeding broilers a flaxseed oil-based diet leads to higher omega-3 polyunsaturated fatty acids (n-3 PUFA) and n-3:n-6 ratio in the cardiac tissue (Kanakri *et al*. 2018) and improved productivity performance of broilers (Carragher *et al.* 2016). However, increasing n-3 PUFA types in broiler tissues including heart from dietary flaxseed oil is limited.

This study consisted of two phases. In phase I, roosters and broiler breeder hens were fed maternal diets containing 4% tallow (control), flaxseed oil (high n-3 PUFA, mainly the short chain type, ALA) or fish oil (high n-3 PUFA, mainly the long chain type, n-3 LCPUFA such as EPA, DPA and DHA) to produce fertile n-3 PUFA enriched eggs. In phase II, eggs were hatched and the offspring were grown on either flaxseed oil or tallow progeny diets at 4% for 6 weeks (harvest age).

Broiler breeder hens were able produce high n-3 eggs when fed flaxseed oil or fish oil-based diets; with the composition of total n-3 PUFA in egg yolk reflecting its respective composition in the diet (Kanakri *et al.* 2017). The content and composition of n-3 PUFAs in the cardiac tissue of the newly hatched chicks closely reflected their respective values in the egg yolk (Kanakri et al. 2017). However, the n-3 PUFA content of the cardiac tissue of broilers at the harvest age was only determined by the n-3 PUFA composition of the grow-out diet (Fig. 1). Indeed, there was a non-significant trend for inhibition of n-3 PUFA accumulation in the maternal fish oil diet groups of both genders.

In summary, manipulation of dietary fatty acids can affect yolk composition, but on its own it is not an appropriate strategy for enhancing n-3 PUFA content in the heart of offspring at market age. Therefore, this approach was not successful in increasing the levels of total n-3 PUFA, ALA or n-3 LCPUFAs in broilers' cardiac tissue.

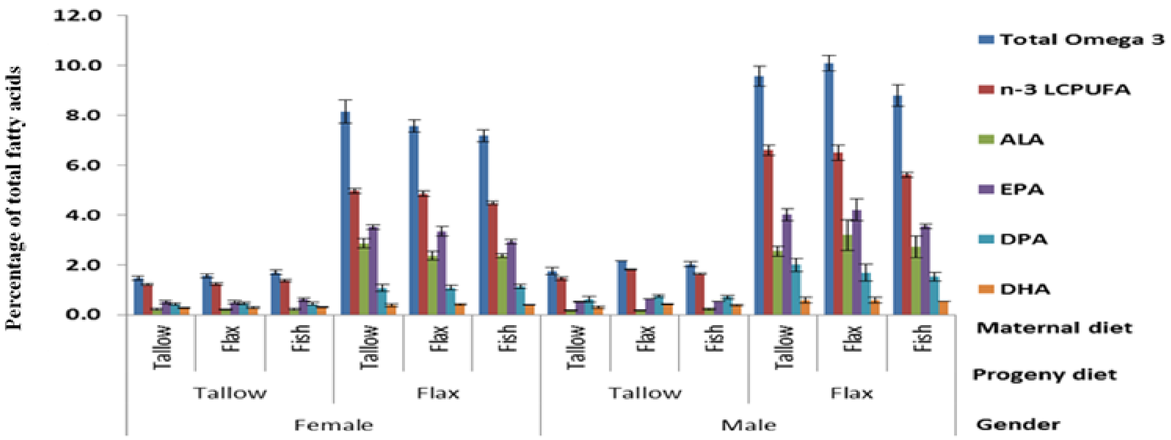

Fig. 1. n-3 PUFA distribution in the cardiac tissue of 6-week-old male and female broilers received 3 maternal by 2 progeny diets (n = 3±SEM).

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Growth and rumen development of kids fed different levels of cow milk

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Introduction

In tropical and sub-tropical regions, high rates of kid mortality affect goat production. The major cause for higher kid mortality is insufficient milk production of the dam. Artificial feeding is required to prevent kid mortality. The actual requirement of milk for artificially fed goat kids is not known well. Therefore, the present study was aimed at determining the amount of cow milk required for optimum productivity of artificially reared kids. Milk was fed at the rate of 10%, 15% and 20% of liveweight daily and the effects on kid growth and rumen development were investigated.

Material and Methods

Three week old Black Bengal (n=16) male kids were separated from their dams and divided into three groups (A, B and C) that were equal for initial weight, litter size of their dam, parity and dam's liveweight. The three groups of kids were fed individually on different milk treatments: A –10% (*n* = 5), B –15% (*n* = 6), C –20% (*n* = 5) of liveweight per day in whole cow's milk. The kids were weighed weekly and the amount of milk being fed was increased weekly on the basis of liveweight. Kids were fed three times daily from 4 to 6 weeks old, twice daily from 7 to 10 weeks old, and once daily from 11 to 13 weeks old. Thereafter, gradual weaning began at 9 weeks old and ended at 13 weeks old. The amount of milk fed to the kids was gradually reduced to zero by the end of week 13, using week 7 intakes as a base @ 2%, 3% and 4% level in 10 %, 15% and 20% milk feeding groups respectively. The kids were supplied equal amounts of roughage and concentrates during the trial. At 16 weeks of age kids were sacrificed to examine rumen development. Data were represented as the mean ± SD (standard deviation). All data were subjected to one-way ANOVA, and the significance of difference among means was determined using Tukey's LSD test. All analyses were conducted in 'SAS/STAT version 9.1.3' for Windows Service Pack 4, 2004 SAS Institute, Cary, NC, USA for Windows. Differences at $P < 0.05$ were considered statistically significant.

Results and Discussion

Increasing levels of milk improved liveweight gain of kids. Kids fed 20% milk were heavier (7.86 ± 0.99 kg) at slaughter than those fed 10% (5.69 ± 0.76 kg) or 15% (6.54 ± 1.61 kg) milk. Total liveweight gain from birth to slaughter was significantly higher in the 20% (5.57 ± 0.97 kg) milk feeding group than the 10% (3.36 ± 0.60 kg) and 15% (4.03 ± 1.69 kg) milk feeding groups. This result is consistent with the earlier studies reviewed by Khan *et al*. (2011). They reported that allotting approximately 20% liveweight per day resulted in improved health, improved growth, and improved later production. The weights of the rumen were significantly higher in the group fed 20% milk (243.39 ± 44.28 g) than in the groups fed 10% (171.40 ± 12.44 g) and 15% (185.0 ± 41.71 g) milk. Histological examination revealed that rumen papillae length (956.0 ± 51.6 µm) and width (417.0 ± 51.4 µm) were significantly higher in 20% milk fed kids than the 10% (380.0 ± 37.4 µm; 152.92 ± 24.2 µm) and 15% (550.0 ± 37.4 µm; 223.2 ± 34.4 µm) groups. In calves, feeding higher volumes of milk had a greater rumen capacity at weaning (Khan *et al*. 2007).

Conclusion

Feeding cow milk to Black Bengal goats at the rate of 20% of their liveweight improved growth and rumen development compared to feeding at either 10 or 15%.

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Mulberry leaf powder level impacts on the development of compound stomach and the antioxidant enzyme gene expression in liver and skeletal muscle of fattening *Hu* sheep

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Oxidative stress can induce diseases and reduce production performance ruminants, whereas antioxidants are needed to protect body against oxidative stress (Zhang *et al.* 2018). Mulberry leaves, used as important protein feed source, are rich in flavonoid polyphenolic antioxidants such as quercetin and rutin, which is known to improve antioxidant capability through upregulating antioxidant enzymes (Agati *et al.* 2012).

The purpose of this study was to investigate the effects of different levels of inclusion of mulberry (*Morus alba* var. multicaulis (Perrott.) Loud. China) leaf powder on organ development and antioxidant enzymes gene expression in fattening *Hu* sheep. Forty 3-month old *Hu* sheep (16.5±0.60 kg) were randomly allocated into 5 treatments (8 for each group), and respectively with concentrate containing either 0% (Control), 15% (T15), 30% (T30), 45% (T45), or 60% (T60) mulberry leaf powder over a 70 d experimental period with a 14 d adaptation. The basal diet consisted of whole plant corn silage. In the first week, concentrate was fed at 375 g/d, followed by an additional 25 g/d per week, and during the first 3 weeks, the whole plant corn silage was fed at 1.5 kg/d, then at 1.75 kg/d. The live body weight (LWT) were measured every 14 d during the experimental period. Three *Hu* sheep were randomly selected and slaughtered from each group at the end of the 70 d feeding. Organs index (for heart, liver, spleen, lung, compound stomach and kidney) was calculated by dividing LWT by total organ weights. The hepatic tissue and skeletal muscle tissue were sampled for measuring the antioxidant enzymes gene expression levels.

There was a significant increase in the index of compound stomach and the ratio of rumen weight to compound stomach weight in Groups T15 and T30. These findings suggested that mulberry leaf powder supplement may promote rumen size as well as feed intake. In addition, the gene expressions of both transcription factor c-Jun and Cu/Zn superoxide dismutase (Cu/Zn SOD) of hepatic tissue were highest in T60 compared to the other treatment groups.The Mn superoxide dismutase (Mn SOD) gene expression was highest in T15 and catalase (CAT) gene expression was highest in T45. These results were similar to those reported for rat liver (Ren *et al* 2015; Andallu and Varadacharyulu 2003). In skeletal muscle tissue, the small mafs (MAFG) gene expression were significantly increased as mulberry leaf powder levels increased. The gene expressions of protein kinase C (PKC), Mn SOD, glutathione peroxidase (GPx), and MAFG were highest in T45 compared to the other treatment groups (Table 1).

Taken together, the mulberry leaf powder, especially when included at 45% in dietary concentrate, improved the development of the compound stomach and the antioxidant enzyme gene expression of liver and skeletal muscle in fattening *Hu* sheep.

Table 1. Effects of different mulberry leaf powder levels in concentrate on antioxidant enzyme gene expression levels in liver and skeletal muscle of fattening *Hu* sheep

Items	Liver					Items	Skeletal muscle				
	Control	T15	T30	T45	T60		Control	T15	T30	T45	T60
c-Jun	1.00^{b}	0.31^{d}	0.41^{cd}	0.53^{c}	2.29^{a}	MAFG	1.00^{c}	2.28^{b}	2.43^{b}	10.31^{a}	2.34^{b}
Cu/Zn SOD	1.00^{c}	1.16^{c}	2.23^{b}	0.91^{c}	3.81^{a}	PKC	1.00^{b}	0.52^{bc}	0.12^{c}	5.02^{a}	0.002^{c}
Mn SOD	1.02^{c}	1.97^{a}	1.08^{c}	1.24^{b}	1.04^{c}	Mn SOD	1.00^{b}	0.54^{c}	0.58^{c}	2.82^{a}	0.04^{d}
CAT	1.03^{d}	1.49^{c}	2.94^{b}	5.20^{a}	1.06^{d}	GPx	1.00^{b}	0.19^{c}	0.04^{d}	8.34^{a}	0.003^{d}

Note: Values with different small letter superscripts in the same row indicate significant differences ($P < 0.05$).

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Effect of canola oil for decreasing methane emissions from dairy cows fed wheat based or corn based diets

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Methane is a potent greenhouse gas and it has been reported that dietary fat reduces methane emissions by decreasing fibre digestion and inhibiting methanogenic function (Grainger and Beauchemin 2011). However, Chung *et al.* (2011) reported the extent of methane mitigation due to dietary fat supplementation is dependent of the type of forage in the diet, but no research has yet reported the effect of type of concentrate. The aim of this research was to study the effect of canola oil supplementation on enteric methane emissions and milk production from dairy cows fed diets supplemented with either corn or wheat. It was hypothesized that the magnitude of the methane mitigation effect due to dietary supplementation with canola oil (designated fat) would not be affected by the type of grain supplement.

This experiment involved 32 Holstein-Friesian dairy cows that produced on average 24.9 ± 4.07 kg milk/day, were 207 ± 13.6 days in milk and had a bodyweight 635 ± 43.3 kg and were allocated to one of four treatment groups and individually fed different diets (n = 8). All animals were offered 11.5 kg/d dry matter (DM) lucerne hay and one of four dietary supplements. These were; 8 kg/d DM of either corn (CRN) or wheat (WHT), or these same treatments with the addition of 0.8 kg of canola oil (CPF and WPF). There was a 1 week covariate period, followed by a 1 week adaptation period, after which cows were fed their full treatment diets for 3 weeks. Milk production and intake were measured daily. During the last week of the experiment, daily methane production was measured using the SF_6 method as described by Deighton *et al.* (2014). Milk production data were analysed by ANCOVA and other data were analysed by ANOVA.

Increasing the fat content in the diet of dairy cows from 2% to 6% had no effect (P = 0.41) on energy corrected milk production (ECM) (Table 1). Cows fed the CRN and WHT diets had greater (P < 0.001) milk fat concentration than cows fed the CPF and the WPF diets, however there was an interaction effect (P = 0.05) of grain type and oil supplementation on milk fat concentration. Feeding canola oil reduced (P < 0.05) methane yield and methane expressed as a percentage of gross energy intake (GEI) in both diets. Methane yield was reduced by 10%, which is greater than the 8% reduction in daily methane production observed by Moate *et al.* (2011) when feeding dairy cows with diets containing dietary fat at 51 to 65 g/kg DMI.

It is concluded that increasing dietary fats by feeding canola oil reduced methane yield in cows fed a wheat based diet and in cows fed a corn based diet.

Table 1. Milk and methane production from cows offered each treatment

Item	CRN	WHT	CPF	WPF	*P* (Grain)	*P* (Oil)	*P* (GrainxOil)
DMI kg/d	20.7[a]	21.3[ab]	21.7[b]	21.8[b]	0.122	0.003	0.458
ECM (kg/d)	23.2	26.1	25.8	21.4	0.29	0.41	0.005
Milk Composition (g/kg)							
Fat	49.1[c]	47.9[c]	39.8[b]	30.3[a]	<0.001	<0.001	0.005
Protein	34.1	34.0	32.8	31.8	0.41	0.05	0.56
CH_4 (% of GEI)	7.6	9.1	7.0	7.7	<0.001	<0.001	0.09
CH_4 (g/kg DMI)	25.5	29.9	24.1	26.2	<0.001	0.004	0.17

Means in the same row with different superscripts differ significantly (P < 0.05).

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Supplementation does not always improve lamb growth rates when grazing lucerne

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Research in New Zealand identified that livestock production from lucerne pastures may be increased by supplementation of livestock with salt (Joyce and Brunswick 1975; Jagusch *et al.* 1977). Lucerne is a natrophobe, which means that it has sodium concentrations in foliage of less than 3 g/kg DM (CSIRO 2007). Studies cited by Minson (1990) had the mean concentration of sodium in lucerne forage at 0.4 g/kg DM and ranged from 0.2–0.8 g/kg DM. Sodium requirements of sheep are in the range 0.7–0.9 g/kg DM and deficiency may result in inappetance, loss in body condition and lowered production (CSIRO 2007). A survey in southern NSW identified that approximately two-thirds of lucerne pastures tested had sodium levels in forage below animal requirements (Hall 1982; CSIRO 2007). It is not routine practice to supplement young sheep grazing lucerne with salt in Australia. Lambs grazing lucerne in these systems are more likely to be supplemented with grain, perhaps with a view to balancing the high protein content of lucerne; however grains can also have low sodium concentration (CSIRO 2007) and therefore may not correct any sodium deficiency.

An experiment studied lamb production on a lucerne pasture near Wagga Wagga in southern NSW in 2017. Poll Dorset x Merino lambs (n = 96, 3–4 months of age) were blocked by sex and randomly allocated to one of 12 lucerne plots (0.7 ha; 8 lambs per plot) in a completely randomised block design with four treatments and three replicates. Lambs were weighed after an overnight curfew at the start of the experiment (15 November), and again on 4 December and 20 December. There were four treatments with lambs supplemented with either coarse salt, barley grain, salt + barley grain (offered in separate tubs) or no supplement (control). Supplementation commenced on 17 November, with supplements offered in tubs and checked and topped up regularly based on consumption, providing *ad libitum* access. Any spoiled supplement (e.g. rain, urine) was discarded and replaced. Lamb weights were analysed using a linear mixed model (Genstat 18th edition) with random effects replicate/plot and fixed effects treatment x date, with starting weight included as a co-variate. Lambs that did not stay in their allocated plots were not included in the analysis, and the salt + barley treatment in replicate three was excluded as lambs could not be contained.

The lucerne sward was flowering and visibly declined in quality during the first three weeks of the experiment; however a large quantity of fresh shoots were available during the second half of the experiment following rain in early December. Consumption of barley was initially low however increased in the second period, with barley fed at 0.2 kg/head/day from 12 December in the relevant treatments. Lamb live weights at the end of growth period 1 and 2 did not differ significantly between treatments (Table 1). The lack of significant difference between treatments may have been due to low or variable supplement consumption, dietary sodium not being deficient in the control, or lamb growth rates being restricted by other factors such as digestibility of the pasture.

Table 1. Lamb live weights (kg) grazing lucerne with *ad libitum* access to different supplements

	Treatment					
	Control	Barley	Salt	Barley + Salt	s.e.d.[A]	*P*-value
15 November	34.1	34.1	34.1	34.1	0.4	0.626
4 December	37.3	38.0	38.1	37.9		
20 December	40.9	41.1	41.1	41.0		

[A]Average standard error of the difference for treatment x date.

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An improved method of estimating pasture intake of grazing lactating dairy cows

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Knowing the intake of pasture of grazing dairy cows would allow farmers to improve feeding efficiency by better matching supplements with consumed pasture. However, quantifying the pasture intake of grazing dairy cows is challenging and problematic. The amount of pasture consumed by a grazing cow depends on a complex mix of animal, feed and climatic factors. There are a number of different methods of estimating pasture intake that vary considerably in their accuracy and commonly involve frequent sampling of pasture and faeces, and detailed, time consuming and expensive chemical analyses (Wright 2017). They are not practical to implement in an on-farm setting.

An alternative to these methods is to predict pasture intake based on observable attributes of the pasture and the animals that graze them. As part of the 'Diet Check' decision support tool, Heard *et al.* (2004) published a series of equations to predict pasture intake (DC-PI) that have since become the benchmark for predicting pasture intake (kg DM/cow.day) for temperate pasture based systems in the Australian dairy industry. Using intake data from a database of grazing plus concentrate supplementary feeding experiments (Heard *et al.* 2017) and additional data from another 25 publications that report intake from grazing plus forage supplementary feeding experiments, we undertook a meta-analysis to determine if pasture intake predictions could be further improved relative to those published in 2004. Of the 375 individual treatment mean data, 155 had core covariates available and these were used in the analysis. The best fit new parsimonious model for pasture intake (N-PI, kg DM/cow.day) was:

$$N\text{-}PI = 6.41 - 10.38 \times 0.95^{PA} + 0.01 \times LWT - 2.16 \times PS - 0.33 \times DMIc - 0.48 \times DMIf + 0.36 \times PH$$

where PA = pasture allowance (kg DM/cow.day), LWT = animal liveweight, PS = pasture species (Paspalum = 1.0, all else = 0), $DMIc$ = dry matter intake concentrate supplements (kg DM/cow.day), $DMIf$ = dry matter intake forage supplement (kg DM/cow.day) and PH = pasture height (cm).

Measures of predictive success for both the N-PI equation and the DC-PI models were calculated. Comparison was made between pasture intake measured experimentally and pasture intake predicted using either the DC-PI model or the N-PI model (Fig. 1).

Based on measures of predictive success, the new pasture intake model was better (Lin's concordance coefficient = 0.81) than the Diet Check model (Lin's concordance coefficient = 0.60) at predicting pasture intake. Assuming these observations can be repeated for independent data, the replacement of the DC-PI equation with the N-PI equation within industry should be considered.

a. b.

Fig. 1. Relationship between experimentally measured (DMI_Pas) and predicted pasture dry matter intake (kg DM/cow.day) using (a) Diet Check (DC-PI) and (b) the new pasture intake model (N-PI).

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Effect of maternal mineral supplementation from lamb marking to weaning on live weight gain in lambs

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Cereal crops can provide a valuable forage source for animals during winter and may be grazed by different livestock species and classes depending on the production system. However, mineral content of these crops is not in balance. Studies have shown that around 14% of barley forages are deficient in sodium (Na) and 30% are deficient in magnesium (Mg) compared to animal requirements (Dove *et al.* 2016). Also, the K concentration in dual-purpose crops are high which consequently reduce Mg absorption (Dove *et al.* 2016). Previous studies have shown that supplementation with Calcium (Ca), Mg and Na improved live weight gain in weaned sheep and suckling new born twin lambs grazing dual-purpose wheat (McGrath *et al.* 2015). For production systems based on autumn lambing, ewes and lambs may graze cereal crops from lamb marking to weaning. The current study sought to assess the effect of mineral supplementation to ewes grazing barley on live weight gain in lambs from lamb marking to weaning.

The experiment was conducted in 2016 at Charles Sturt University, Wagga Wagga, NSW. Dual-purpose barley (cv. Moby) was sown in a 10 hectare paddock at a rate of 60 kg/ha and the paddock sub-divided into 8 x 1.25 ha plots. Merino ewes (n = 104; 3–5 years old) raising single and twin lambs (n = 164, 4–5 weeks old) were randomly allocated to plots after blocking for single or twin lambs at foot (13 ewes/plot). Ewes in each plot were provided either *ad libitum* access to a loose-lick mineral supplement containing calcium carbonate (limestone), magnesium oxide (Causmag® AL7) and sodium chloride (coarse salt) at a ratio of 2:2:1 (30 g/head/day) (supplemented) or no mineral supplementation (control). Lambs were weighed at lamb marking, 2 weeks after lamb marking and at weaning. Data were analysed using IBM SPSS statistics for windows. A linear mixed model was used for analysis of the data and the fixed factors were treatment, time points, rearing status and their interaction. Ewe and plots were random factors.

Calcium, Mg and Na levels in barley forage appeared adequate for animal requirements (data not shown). The live weight of twin raised lambs in the treatment group was significantly greater than the control group at weaning time (Table 1). This result shows that mineral supplementation of ewes grazing barley forages from lamb marking to weaning may improve the live weight of twin raised lambs at weaning despite the concentration of key minerals in forage appearing adequate. Ewes with multiple lambs generally produce more milk than single bearing ewes and have increased requirements for minerals such as Ca and Mg, and this may explain why superior growth rate occurred in twin raised lambs when ewes had a free access to minerals. Lamb management at weaning has important impact on post weaning mortality, lifetime productivity and profitability. Therefore, higher weaning weights may improve weaner survival and performance, increasing farm production (Kenyon *et al.* 2004).

Table 1. Lamb weights at lamb marking, two weeks after lamb marking and four weeks after lamb marking

Time	Raising status	treatment	Control	*P*-value
Marking (Start)	Singles	12.3	13.9	n.s.
	Twins	13.5	13.1	n.s.
Marking+2W	Singles	16.3	17.9	n.s.
	Twins	17.8	16.8	n.s.
Weaning	Singles	19.8	20.5	n.s.
	Twins	21.5	19.2	0.026

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Diet selection and growth rates of lambs fed second generation legumes or lucerne oversown with forage oats in the winter

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Pasture legumes can improve the nutritive value of cereal forage and grass swards due to their higher digestibility. Primary photosensitisation (PP) has been reported in sheep grazing biserrula (Kessell *et al.* 2015), but providing other plant species in the sward may enable animals to reduce negative experiences such as PP through selective grazing. No studies to date have investigated growth rates or diet selection of lambs grazing second generation legume pastures sown with forage oats.

Cross-bred lambs were grazed in replicated (n = 3) plots (0.2 ha in size) from 10 Jul to 22 Aug 2016 (43 d). Oats were oversown at 30 kg/ha into regenerating pasture stands of arrowleaf clover (ACO; *Trifolium vesiculosum* Savi), biserrula (BO; *Biserrula pelecinus* L.), bladder clover (BCO; *T. spumosum* L.), French serradella (FSO; *Ornithopus sativus* Brot) and lucerne (LO; *Medicago sativa* L.). Lambs were allocated randomly (on block) to plots on stratified LW (based on an overnight fast). Swards were assessed/sampled weekly for feed on offer (FOO; kg DM/ha; data not reported for all swards) and quality. Lambs were weighed weekly after an overnight fasting. Diet compositions, using *n*-alkane based estimates were determined on days 28 and 42 from four core animals/plot, whereby faecal samples were taken and bulked (on an equal dry weight basis) to form one representative sample/plot. Legume and oat samples were taken from each plot on the same day as faecal samples for alkane analyses. Diet composition was calculated based on the method of Dove and Mayes (2006). A linear mixed model using REML was used for statistical analyses.

Forage quality. Mean digestible organic matter digestibility (DOMD) and crude protein (CP) is reported in Table 1. The interaction between sward type and date was significant ($P < 0.01$) for DOMD and CP. LO had lower DOMD than all other swards at 15, 21 and 28 d, and overall. The CP of the swards declined at a similar rate, with the exception of LO. *Lamb growth rates.* There was no difference in start or end LW of the lambs fed the varying swards; however, the interaction between sward type and date was significant ($P < 0.05$) for LWG. Overall LWG was lowest at 8 d (12 ± 18.8 g/d) and highest at 16 d (317 ± 19.3 g/d) for lambs on all swards. *Diet composition.* Results are reported in Table 2. Lambs grazing BO consumed a lower proportion of legume than those grazing ACO, BCO and LO at 28 d; however, at 42 d the proportion of legume in the diet increased (>4 times), whilst those fed ACO, BCO and LO did not vary. The proportion of legume in the diet of those grazing FSO was lower at 42 d grazing than for all other swards due to the much lower biomass of legume compared to the oats (267 vs. 3067 kg DM) at that time. There was no PP observed in lambs grazing BO.

Despite the lower DOMD, lambs grazing LO had similar LWG to those grazing the other swards. It is likely that the pasture sampling did not represent the quality of the selected diet and may have underestimated the proportion of legume being consumed by the lambs, which would explain why lambs performed similarly to the other swards of higher DOMD. Based on *n*-alkane estimates, lambs grazing BO may have developed an aversion to biserrula earlier in the grazing period that was overcome by 42 d, likely due to the absence of PP. Lambs grazing BO appeared to be able to mitigate PP via diet selection.

Table 1. DOMD and CP of varying legume + oat swards

	ACO	BO	BCO	FSO	LO
Sward quality					
DOMD (%) *S.E. = 0.41*	77.3^{b}	76.7^{b}	76.1^{b}	77.3^{b}	71.1^{a}
CP (%) *S.E. = 0.55*	28.1^{bc}	25.5^{a}	29.0^{c}	25.3^{a}	26.4^{ab}

Differences ($P \leq 0.05$) indicated by differing superscripts.

Table 2. Diet composition (%) based on *n*-alkanes estimates of lambs fed varying legume + oat swards

	28 d (7 Aug)		42 d (21 Aug)	
S.E. = 5.14	Legume	Oat	Legume	Oat
ACO	42.2^{cd}	57.8	39.4^{cd}	60.6
BO	13.5^{ab}	86.5	59.6^{d}	40.4
BCO	43.1^{cd}	56.9	37.7^{bcd}	62.3
FSO	33.6^{abc}	66.4	10.7^{a}	89.3
LO	47.4^{cd}	52.6	32.5^{abc}	67.5

Differences ($P \leq 0.05$) indicated by differing superscripts.

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Does stocking rate of singleton ewes during lambing and lactation affect performance?

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The lambing percentage of the New Zealand flock has increased over time resulting in more multiple-bearing ewes. Given New Zealand sheep producers have an aversion to the use of supplements during lambing and lactation, the increased number of multiple-bearing ewes increase the demand for pasture. A possible tactic to meet this extra demand, without increasing whole-flock demand, is to restrict the intake of singleton-bearing ewes by increasing their lambing paddock stocking rate (SR), thus freeing space and pasture for multiple-bearing ewes. With prolific ewes, SR has been shown to affect performance (Keady *et al.* 2009, Earle *et al.* 2016, 2017*a*, 2017*b*), although there may be a ceiling after which further increases in performance are not observed.

Pasture sward mass and ewe and lamb live weights (LW) and ewe body condition score (Jeffries 1961, BCS) were recorded from an experiment designed to measure the impact to weaning of SR in singleton-bearing ewes (11, 13 and 15 ewes per ha). Each year, different (2014, n = 96 ewes; 2015 n = 98 ewes in total) singleton-bearing ewes were randomly allocated to a SR treatment a week prior to lambing, with each treatment replicated twice within year. Ewes were weighed and their BCS recorded at set stocking and weaning. Lamb LW was recorded within 12 hours of birth and at weaning. Pasture mass at set-stocking and on four occasions during lactation was recorded with a rising plate meter (Jenquip, Feilding, New Zealand). Weaning occurred 90 and 73 days after the midpoint of lambing in 2014 and 2015 respectively. Due to the differences in the timing of weighing events, each year was analysed separately with replicate included as a random effect. The effect of stocking rate on pasture mass and ewe and lamb live weight were analysed within year using a generalised linear model (SAS 9.4).

Pasture mass at set stocking did not differ (P > 0.10) between SR in either 2014 or 2015 (average covers in 2014 and 2015 were 1702 and 941 Kg DM/ha respectively). In 2014, pasture mass in lactation was greater (P < 0.05) with lower SR (1952 ± 107, 1592 ± 107, 1271 ± 107 Kg DM/ha for 11, 13 and 15 SR respectively), but was not in 2015 (P > 0.10). SR had had no effect (P > 0.10) on ewe LW at set stocking or lamb birth weight in either year (Table 1). At weaning SR had no effect (P > 0.10) on ewe and lamb LW in 2014. In 2015 at weaning, SR 11 ewes were heavier (P < 0.05) and SR tended (P = 0.08) to affect lamb LW. Ewe BCS was not affected (P > 0.10) by SR in either year. In 2014, when pasture masses at set stocking were high, SR had no impact on ewe and lamb performance. In contrast, when pasture masses at set stocking was low in 2015, ewe LW at weaning was greatest with the lowest SR and SR tended to affect lamb LW at weaning. Combining these results suggests that over the range of SR tested, that the impact of SR is affected by available pasture mass and when masses are low there is a ceiling SR above which ewe weight loss in lactation is negatively affected. However across years ewe live weights also differed, which makes drawing clear conclusions difficult. Therefore, further studies are now required to verify the apparent effect over a range of pasture masses and ewe live weights at set stocking.

Table 1. The mean ± SE of ewe live weight and body condition score (BCS) (kg) at set stocking and weaning and lamb live weight at birth and weaning for stocking rates of 11, 13 and 15 ewes/ha

Stocking rate		Ewe live weight (kg)			Ewe BCS		Lamb live weight (kg)	
	n	Set stocking	*n*	Weaning	Set stocking	Weaning	Birth	Weaning
2014								
11	25	56.6 ± 0.9	23	53.7 ± 2.1	2.5 ± 0.3	2.8 ± 0.3	5.1 ± 0.3	24.3 ± 1.5
13	31	56.0 ± 0.9	28	50.4 ± 2.0	2.5 ± 0.3	2.7 ± 0.3	4.8 ± 0.5	23.4 ± 1.4
15	35	57.1 ± 0.9	29	51.7 ± 2.1	2.5 ± 0.3	2.7 ± 0.3	5.1 ± 0.2	24.1 ± 1.5
2015								
11	29	77.1 ± 1.1	23	77.6^{b} ± 2.0	3.6 ± 0.4	3.5 ± 0.3	6.7 ± 0.3	29.8 ± 1.3
13	34	76.2 ± 1.0	29	71.3^{a} ± 2.0	3.3 ± 0.3	3.3 ± 0.3	6.5 ± 0.4	28.0 ± 1.3
15	35	76.8 ± 1.0	31	69.5^{a} ± 1.9	3.5 ± 0.3	3.2 ± 0.3	6.4 ± 0.2	27.6 ± 1.3

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Lambs grazing second generation annual pasture legumes arrowleaf clover, biserrula and bladder clover have similar growth rates in spring as lambs grazing lucerne pasture

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Second generation annual legumes, such as arrowleaf clover (AC; *Trifolium vesiculosum* Savi), bladder clover (BC; *T. spumosum* L.) and biserrula (B; *Biserrula pelecinus* L.) can maintain quality and high biomass production for extended periods (Hackney *et al.* 2013), so should support higher liveweight gain (LWG) than traditional species such as subterranean clover. However, studies comparing lamb growth rates of these legumes to traditional legumes are limited. The aim of the experiment was to assess the growth rates of lambs grazing pastures of AC (cv. Arrotas), BC (cv. Bartolo) and B (cv. Casbah) compared to lucerne (L; cv. SARDI 10).

Merino and White Suffolk x Merino lambs were grazed in replicated (three/treatment) plots (0.4 ha in size) sown to either, AC, B, BC or L pastures for 42 d in Spring 2015. Lambs were weighed (LW: fasted overnight) and grouped into breeds and allocated randomly (on block) to plots on a stratified LW to ensure an even distribution of breeds and LW across each pasture. Pastures were sampled (pluck) once weekly (in replicates) to estimate the likely quality diet of the lambs and analysed via NIR spectroscopy. Lambs were weighed weekly. A linear mixed model using REML was used for statistical analyses. Pastures were maintained >2000 kg DM/ha (data not shown).

Forage quality. The interaction of pasture type and date was significant (P < 0.001) for DOMD and CP of pastures (Table 1). Overall the pastures showed a gradual decline in DOMD and CP as grazing proceeded, although increased at 42 d. AC had relatively consistent DOMD and CP throughout the experiment whilst the quality for the other pastures was more variable. *Lamb growth rates.* Lambs grazing AC, B, BC and L had similar (P > 0.05) LW (Fig. 1).

The high quality of the AC, B and L pastures resulted in high LWG of lambs; whilst those grazing BC performed better than expected based on the DOMD and CP. Based on the results presented, it is unclear why lambs grazing BC grew at a similar rate to those grazing the other pastures, given the lower quality of the pasture, which concurs with McGrath *et al.* (2015). This questions whether DOMD is an accurate predictor of LWG for lambs fed BC and this requires further investigation. Although similar in growth rates in the spring, BC is unlikely to maintain similar growth rates later in the season due to earlier pasture senescence affecting both pasture quality and biomass, compared to later maturing species such as AC (cv. Arrotas).

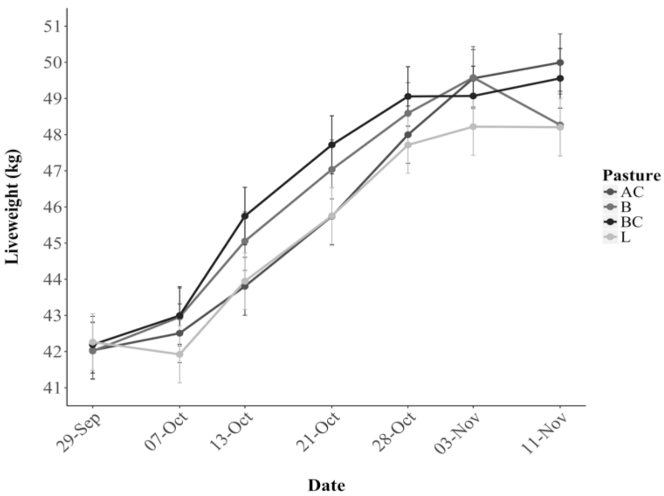

Fig. 1. Liveweight change of lambs fed the varying pastures.

Table 1. Mean digestible organic matter digestibility (DOMD) and crude protein (CP) of pastures

	AC	B	BC	L
DOMD (%)		S.E = 1.1		
28 Sept (-1 d)	78	79	73	77
6 Oct (8 d)	79	77	73	79
12 Oct (14 d)	80	78	72	78
19 Oct (21 d)	76	73	69	73
26 Oct (28 d)	73	68	66	65
2 Nov (35 d)	74	65	61	67
9 Nov (42 d)	77	70	61	79
CP (%)		S.E. = 1.0		
28 Sept (-1 d)	32	28	25	31
6 Oct (8 d)	35	26	24	37
12 Oct (14 d)	30	24	20	29
19 Oct (21 d)	32	22	17	28
26 Oct (28 d)	31	19	14	23
2 Nov (35 d)	26	17	14	23
9 Nov (42 d)	28	21	16	38

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Inorganic nitrogen promotes rumen hydrogen redirection under methanogenesis inhibition

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Strategies to manage metabolic hydrogen accumulation in the rumen should be considered when reducing ruminant methane (CH_4) emissions. Recently, a study has demonstrated that a phenolic compound as a supplement would act as a hydrogen (H_2) sink when methanogenesis was inhibited thus preventing accumulation of gaseous H_2 and formate (Martinez-Fernandez *et al*. 2017). It was hypothesised that nitrogen (N) supplements may also modify the rumen microbiota and facilitate metabolic hydrogen use in the CH_4 inhibited rumen. The current trial examined the effect of different N sources on H_2 flow and rumen fermentation when CH_4 is inhibited in cattle fed a tropical grass/concentrate diet.

Twelve rumen-fistulated Brahman steers (*Bos indicus*) were allocated in three experimental groups receiving Rhodes grass hay and grain at a ratio of 60:40. Each group was treated with a different N supplement: urea, casein or no supplement (Doses: urea 130 g/animal/day; casein 300 g/animal/ day). The doses were calculated to provide a similar amount of N (50 g of N each source). After 14 days animals were placed into open-circuit respiration chambers for measurement of CH_4 and H_2 production and collection of rumen samples. Following the initial control period the three groups received an antimethanogenic compound (chloroform) during 21 days (1.6 g/100 kg LW) with the last two days in open-circuit respiration chambers as previously described.

No significant effects ($P > 0.05$) were observed on dry matter intake (DMI), CH_4 and hydrogen production between treatment groups during the control period. A significant ($P < 0.05$) increase in ruminal ammonia concentration was observed in those animals treated with urea or casein compared with the animals fed just the experimental diet. Dry matter intakes were significantly decreased in animals treated with chloroform without N supplement compared with animals treated with chloroform and fed the diet containing urea. A range of 65-50% reduction of CH_4 (g) per kg of DMI was observed with the chloroform treatment across the three groups compared with the control period. Hydrogen expelled (H_2; g/kg DMI) from the animals treated with urea and chloroform was significantly ($P < 0.05$) lower than the other two groups treated with chloroform. The study of the rumen fermentation parameters showed a significantly ($P < 0.05$) lower ruminal ammonia concentration in animals treated with chloroform without N supplements compared with the groups treated with chloroform plus casein or urea. Although total SCFA were not significantly ($P > 0.05$) affected between supplements, a significant ($P < 0.05$) reduction was observed in animals treated with chloroform without any supplement or casein compared with the control period. Our results suggested that a H_2 redirection occurred with the urea supplement, also the rumen function and fibre degradation was not impaired under methanogenesis inhibition when N additives were provided. Further experiments should be designed to confirm the results observed with the N supplements and their role in H_2 flows under antimethanogenesis conditions.

Table 1. Control and Chloroform effects on DMI, CH_4 and H_2 production, daily weight gain and rumen fermentation parameters on steers fed no supplement (Grain), urea (Grain + U) or casein (Grain + C)

Parameter	Control period (Untreated)			Chloroform (21 days)		
	Grain	Grain + U	Grain + C	Grain	Grain + U	Grain + C
DMI, kg	7.4^{A}	7.5	7.8	3.2^{bB}	7.1^{a}	6.5^{ab}
CH_4, g/kg DMI	20.0^{A}	20.1^{A}	19.5^{A}	5.8^{B}	11.2^{B}	9.4^{B}
H_2, g/kg DMI	0.00^{A}	0.00^{A}	0.00^{A}	2.6^{aB}	1.0^{bB}	2.4^{aB}
Formate, mM	2.0^{B}	2.8^{B}	2.5^{B}	20.1^{A}	18.7^{A}	18.4^{A}
NH_3, mg/100mL	8.0^{b}	19.0^{a}	25.7^{a}	10.6^{c}	15.6^{b}	21.4^{a}
Total SCFA, mM	75.9^{A}	88.3	83.6^{A}	43.5^{B}	84.2	62.2^{B}
Acetate, mol/100 mol	64.9^{aA}	67.1^{aA}	61.5^{bA}	51.8^{B}	55.1^{B}	48.4^{B}
Propionate, mol/100 mol	18.0	18.1	21.6	23.7	25.1	23.8
i-Butyrate, mol/100 mol	0.88^{b}	0.80^{b}	1.46^{a}	1.8	0.9	2.2
Butyrate, mol/100 mol	12.5	10.7	10.4^{B}	14.5	13.6	16.7^{A}
i-Valerate, mol/100 mol	2.0	1.8	2.5	5.1	2.8	4.6
Valerate, mol/100 mol	1.5^{b}	1.3^{b}	2.5^{a}	2.2^{ab}	1.9^{b}	3.3^{a}
A : P	3.6^{aA}	3.7^{aA}	2.9^{b}	2.2^{B}	2.2^{B}	2.1

[a–c]Within a row, treatment means (control or chloroform) for each supplement without a common superscript differ, $P < 0.05$.
[A,B]Within a row, means for each treatment and respective control without a common superscript differ, $P < 0.05$.

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Effect of feeding varying levels of extruded rice polishings on intake, growth performance, structural development, and feed efficiency of Lohi lambs

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Rice polishings is a by-product of rice processing industry containing approximately 12% CP, 12–18% fat, 16–21% NDF and 21–28% starch contents. Practically, inclusion of rice polishings in concentrate diets of fattening lambs > 20% lowers feed intake. Depression in intake is associated to rancidity of raw rice polishings due to lipases. The process of extrusion has been found to increase nutrient digestibility and stabilize fats through deactivation of lipases (Ramezanzadeh *et al*. 1999). To date, limited published information is available on the use of extruded rice polishings (ERP) as an energy source in the diet of fattening lambs. Therefore, the aim of this experiment was to evaluate the effects of increasing level of ERP on intake, growth performance, feed efficiency and structural development of Lohi lambs.

Thirty-six lambs with an average 34.9 kg BW (SD = 3.26) were assigned to one of the three dietary treatments in a randomized replicated-pen design (4 pens per treatment; n = 3 lambs/pen). Total duration of experiment was 14 weeks including a two week adaptability period. Treatments assigned were: (1) Control (C) without ERP, (2) ERP25; containing 25% ERP and (3) ERP50; containing 50% ERP in the concentrate diets. Formulated concentrates rations were iso-caloric and iso-nitrogenous. Lambs were fed at 4% of their body weight (BW) twice daily, at 08:00 and17:00 h, as TMR with a forage to concentrate ratio of 45:55. Extruded rice polishings was replaced with energy ingredients including corn grain, molasses and wheat bran. Water was provided free choice in each pen. Body weights, body measurements; withers height (WH) and heart girth (HG) were determined at the start and then on weekly basis. Fecal scoring was performed on a daily basis. Data for DMI and fecal score were analyzed using repeated measures ANOVA using (SPSS version 21). Model included treatment, week, week × treatment and pen. However, BW change, structural measurements and feed efficiency data were analysed using one way ANOVA. To determine effect of increasing level of ERP in the concentrate diet polynomial orthogonal contrasts were included.

The results revealed that average daily DMI, gain in structural measurements (HG and WH) and fecal score were not affected ($P > 0.05$) by increasing level of ERP in concentrate diet. However, body weight gain tended to be highest for the ERP50 (Linear P=0.080) and lowest for the C fed lambs. Numerically higher DMI in the ERP50 lambs may be related to improved palatability through stabilization of rice polishings. One possible explanation for maintaining DMI at 50% inclusion could be the inactivation of lipases during the process of extrusion. Furthermore, tendency for higher weight gain in ERP50 may be related to increased surface area and consequent greater availability of nutrients to the animals fed on the ERP50 diet. Hence, ERP can successfully replace the energy ingredients in the concentrate diets of fattening lambs up to 50%.

Table 1. Intake, growth performance, and feed efficiency of Lohi lambs fed varying levels of extruded rice polishings in a fattening experiment

	Treatments				*P*-value		
Parameters	C	ERP25	ERP50	SEM	Linear	Quadratic	Treatment x week
Average daily DMI, kg/day	1.32	1.36	1.40	0.070	0.487	0.993	0.788
Initial BW (kg)	34.8	35.3	34.9	1.796	0.950	0.855	
Final (kg)	40.4	41.2	42.1	2.193	0.603	0.986	
BW gain (kg)	5.640	5.940	7.160	0.50	0.080	0.508	
Feed efficiency	0.078	0.080	0.090	0.005	0.107	0.550	
Average daily fecal score	1.20	1.09	1.16	0.024	0.269	0.012	0.687
Gain in withers height, cm	4.10	3.05	4.27	0.610	0.858	0.191	
Gain in heart girth, cm	2.26	1.77	4.48	1.178	0.366	0.448	

Treatments: C (without ERP), ERP 25 and ERP 50 containing 25% and 50% ERP in concentrate feed.

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The omega-3 content of mixed pastures and pasture species of southern New South Wales

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The omega-3 (n-3) fatty acid content of the diet of livestock can affect the level of n-3 in the blood or meat of the animal (Scollan *et al.* 2001). Altering the amount of n-3 in blood may influence the reproductive potential of livestock, while enhancing the level of n-3 in red meat may have health benefits for consumers (Gulliver *et al*. 2012). The amount of n-3 in crops and pastures has been investigated in several countries including the United Kingdom and Canada but not in Australian grazing systems. The aim of the current study was to assess the availability of n-3 in common pasture systems in southern NSW.

Samples of pasture, at varying stages of growth, were collected from two beef cattle properties at Jugiong and Bowna at regular intervals during each season from winter 2016 until spring 2017. Individual species and mixed samples of native or improved pastures, representative of material available to grazing livestock, were collected at each property. Samples of species included: mixed clover (n = 7 on each property), phalaris (Jugiong n = 7, Bowna n = 16), and lucerne from Jugiong (n = 7). Samples were analysed for crude protein (CP) using the Dumas combustion method and fatty acid content by direct methylation.

The mean, minimum and maximum percentages of n-3 in clover, phalaris and lucerne, sampled at Jugiong or Bowna, are presented in Table 1. The n-3 percentages found at both locations were numerically higher than values found in the UK and Canada (Clayton 2014). The n-3 percentage was positively correlated with the CP content of mixed pasture samples taken from Jugiong (R^2 = 0.82) and Bowna (R^2 = 0.54, Fig. 1).

The relationship observed between n-3 content and CP was expected given the relationship between nitrogen in the leaf material and presence of n-3 in leaf chloroplasts (Boufaied *et al.* 2003). The range in values observed for individual species and pasture mixes demonstrates the need for further investigation into the level of n-3 in Australian pastures, including a wider range of species and variations with season and phenology, and the impact of pasture n-3 on reproduction outcomes and health attributes of red meat.

Table 1. Omega-3 (n-3) content (% fatty acids) and omega-6 (n-6) to omega-3 ratio of pasture species at two locations

			n-3 (% Total)
Species	Location	Mean	(Min-Max)
Clover	Jugiong	59.8	(42.3 – 64.5)
	Bowna	57.4	(38.4 – 65.1)
Phalaris	Jugiong	60.8	(51.9 – 68.7)
	Bowna	64.6	(50.7 – 70.7)
Lucerne	Jugiong	51.3	(28.5 – 67.9)
			n-6:n-3 Ratio
Species	Location	Mean	(Min-Max)
Clover	Jugiong	0.24	(0.19 – 0.39)
	Bowna	0.23	(0.17 – 0.28)
Phalaris	Jugiong	0.21	(0.15 – 0.32)
	Bowna	0.16	(0.12 – 0.26)
Lucerne	Jugiong	0.35	(0.15 – 0.63)

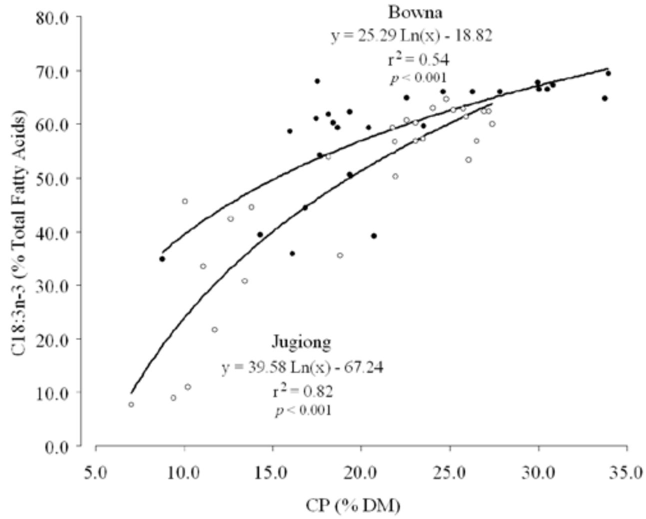

Fig. 1. Relationship between mixed pasture crude protein (CP) and omega-3 (C18:3n-3) content at two locations.

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Growth and eye muscle area of cross-bred Boer goats fed Desmanthus cultivar JCU 1 hay

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Rhodes grass (*Chloris gayana*) hay (RGH) is an improved tropical pasture species used for livestock production in the Australian tropics and sub-tropics, however, RGH contains low crude protein, low metabolisable energy and high neutral detergent fibre relative to improved temperate pasture species and tropical legumes leading to low productivity of goats unless supplemented with a source of crude protein. Supplementation tropical grasses with urea (Uza *et al*. 2005), cottonseed meal (CSM) (Solomon *et al*. 2008) or the tropical legume species *Desmanthus* (Ngo 2012) is reported to increase dry matter intake and liveweight gain of goats and sheep. The objective of the present study was to compare rate of liveweight gain and accretion of eye muscle determined at the 12^{th} rib of twenty female Boer goats (19.84±2.21 kg) fed RGH supplemented with either urea, urea + CSM, CSM or only fed Desmanthus (cultivar JCU 1) hay over 138 days. Total crude protein concentration in the diets was 185 to 195 g/kg DM. Each diet (Urea, Urea + CSM, CSM and Desmanthus) provided 144, 130, 139 and 112 g/kg DM of rumen degradable protein (RDP) and 42, 56, 59 and 83 g/kg DM of undegraded dietary protein (UDP), respectively. The urea and CSM in the Urea + CSM diet supplied equivalent amounts of crude protein. All animals received a complete mineral supplement (Rumevite® Fermafos). The diets were offered in equal amounts twice a day at 08:00 h and 16:00 h. Eye muscle area was estimated by counting the number of 1 × 1 mm squares marked on a clear plastic grid that covered a transverse section of the longissimus dorsi muscle (including fascia) on the caudal side of the 12th rib.

All diets supplied sufficient crude protein, RDP and minerals to maintain normal rumen function at high levels of DMI (NRC 2007). The Desmanthus diet resulted in the highest total dry matter intake (DMI), crude protein intake (CPI) and metabolisable energy intake (MEI) while the diet supplemented with urea produced the lowest total DMI, CPI and MEI (Table 1). The diets supplemented with urea + CSM or CSM showed intermediate values for total DMI, CPI and MEI. The rates of liveweight gain across all diets were consistent with those predicted by NRC (2007) based on metabolisable energy intake for a 20-kg Boer goat.

This intake pattern can be explained by both palatability and the amount of UDP supplied by the diets. In particular, the high palatability and UDP supplied by the legume likely promoted intake and liveweight gain while the low palatability (Tadele and Amha, 2015) and lower UDP supplied by the diets containing urea likely limited intake and liveweight gain. Importantly, once requirements of the rumen for RDP (and minerals) are met, diets with the most UDP in dry matter (CSM and Desmanthus) supported the highest dry matter intakes, rates of liveweight gain and eye muscle area. Supplementation strategies for diets based on tropical grasses must provide sufficient UDP to support high levels of intake and growth.

Table 1. Intake of dry matter, crude protein, and metabolisable energy as well as live weight gain and eye muscle area of supplemented growing Boer goats

Item	Dietary treatments				sem
	Urea	Urea CSM	CSM	Desmanthus	
DMI total (g/d)	443^{a}	573^{b}	636^{b}	1027^{c}	43.10
CPI (g/d)	98^{a}	125^{b}	151^{c}	206^{d}	8.46
MEI (MJ/d)	3.8^{a}	4.5^{a}	5.9^{b}	10.1^{c}	0.46
Average LW gain (kg)	0.7^{a}	5.6^{b}	6.7^{b}	9.6^{c}	0.64
Eye muscle area (cm^2)	2.4^{a}	3.5^{ab}	3.9^{b}	5.5^{c}	0.25
Hot carcass weight (kg)	6.5^{a}	8.2^{b}	10.1^{c}	12.6^{d}	0.50

Different letters in the same row differ significantly; $P < 0.05$.

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Supplementing nitrate as a non-protein nitrogen source for sheep consuming a protein-deficient chaff increases salivary and plasma levels of nitrate or nitrite without risking nitrite toxicity

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Nitrate is an effective additive to reduce enteric methane emissions and can replace urea as a non-protein nitrogen (NPN) source for ruminants (Nolan *et al.* 2010). A completely randomized study including 24 Merino sheep (27.5 ± 0.77 kg) was conducted over 35 d to investigate the effect of nitrate as NPN source on plasma or saliva nitrate or urea profiles and blood methaemoglobin (MetHb) levels. Sheep were assigned to one of 3 dietary treatments consisting of 600 g of wheaten chaff (crude protein, CP: 2%; metabolisable energy, ME: 4.9 MJ/kg DM) plus 200 g wheat grain fed alone (control, Con) or with 2 % calcium nitrate (NO_3) or urea (Ur) iso-nitrogenously to the NO_3 diet. An adaptation period was included to prevent nitrite (NO_2) toxicity in NO_3-fed sheep. Animals were fed once daily at 09.30 hours. Blood MetHb concentration was measured once weekly 1.5 h after feeding (AF) throughout the experiment. Blood plasma (P) and saliva (S) samples were collected pre-feeding (PF), 1.5 h and 8 h AF on week 7. Saliva (5 mL) was collected by aspiration with a vacuum pump. Nitrate and NO_2 concentrations were determined in P (P-NO_3 or P-NO_2) and S (S-NO_3) as described by de Raphélis-Soissan *et al.* (2017). Urea-N was analysed in P (P-urea) and S (S-urea) by spectrophotometric analysis (Dade Behring Dimension Xpand Plus, USA).

Averaged blood MetHb concentrations 1.5 h AF in NO_3-fed sheep were 6.74%, below the concentration indicative of NO_2 toxicity (Brunning-Fann and Kaneene 1993). The lowest and highest recorded values were 1.7% and 22.7% of total haemoglobin as MetHb.

In NO_3 treatment, P-NO_3 and P-NO_2 concentrations were greater at 1.5 h AF than for PF and 8 h AF (Table 1; P<0.05). Overall, S-NO_3 was higher than P-NO_3 in all dietary treatments and at all sampling times, suggesting that NO_3 was concentrated and recycled via saliva (Leng 2008; Benu 2016); except for PF levels in NO_3-fed sheep in which P-NO_3 was greater than in S-NO_3 (P=0.03). However, P-NO_2 was greater at 1.5 h AF (P=0.02) but had returned to PF levels by 8 h AF (P=0.18) and no visible signs of methaemoglobinaemia were exhibited by sheep. There was a large variation in P-NO_2 between sheep fed NO_3 diet (min=0.4 µM and max=77.9 µM).

Urea concentrations PF and 1.5 h AF were greater in P than in S (P<0.001) whereas no differences were observed 8 h AF for all dietary treatments (P>0.14). Across sampling time, supplementing sheep with NO_3 or Ur increased P-urea and S-urea concentrations compared to Con-fed sheep (P<0.03), illustrating both supplements would increase salivary N supply for microbial protein synthesis.

We conclude that the addition of 20 g NO_3/kg DM to a protein-deficient diet in ruminants provided advantage through additional N without exposing animals to risk of NO_2 toxicity, even if animals were fed once daily. Our results demonstrate that NO_3 absorption from the rumen into the blood stream increased P-NO_3 and P-NO_2 concentrations and that NO_3 was concentrated in and would be recycled to the rumen via saliva.

Table 1. Nitrate, nitrite or urea concentrations in plasma (P) and saliva (S) measured pre-feeding (PF), 1.5 h or 8 h after feeding in sheep fed a protein-deficient diet supplemented with nitrate (NO_3) or urea (Ur)

Diet	Con			NO_3			Ur				Significance			
Time (h)	PF	1.5	8	PF	1.5	8	PF	1.5	8	SEM	Diet	Time	Site*	DxT
Site-parameter														
P-NO_3 (µM)	4.19	3.82	4.28	25.5	51.8	21.2	3.82	3.76	4.12	2.60	<0.01	<0.01	<0.01	<0.01
P-NO_2 (µM)	1.78	1.68	1.20	4.63	22.9	7.41	2.91	2.42	1.86	0.29	<0.01	<0.01	-	0.01
P-urea (µM)	2063	2081	725	3206	3763	2617	3420	3795	2723	154	<0.01	<0.01	<0.01	<0.01
S-NO_3 (µM)	7.26	12.2	9.97	10.6	165.4	61.1	7.58	8.90	10.3	6.46	<0.01	<0.01	<0.01	0.07
S-urea (µM)	1439	1285	596	1835	2270	1614	2302	3035	1810	111	<0.01	<0.01	<0.01	<0.01

* Site: plasma (P) or saliva (S).

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Increasing inclusion rates of cassava waste in concentrate based diets for fattening cattle

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The nature of the relationship between increasing inclusion rate of cassava (*Manihot esculenta* Crantz) waste (CW) in diets of fattening cattle, and causes of reduced animal performance at high inclusion rates were evaluated. Previous research by this group (unpublished) has found lower than expected performance at high levels of CW inclusion. It was therefore hypothesised that CW has a dose-response effect on cattle performance, and that a quadratic relationship could be established between CW inclusion and liveweight gain and/or feed intake.

Thirty growing Madura (*Bos indicus* x *javanicus*) bulls (mean initial starting weight 236 ± 29 kg and BCS 2.45 ± 0.32 (1–5 scale)) were allotted to a randomised block design, and individually housed and fed concentrate-mixes with five levels of CW inclusion at 20 g DM/kg liveweight and elephant grass (*Pennisetum purpureum*) at 5 g DM/kg liveweight, at the University of Brawijaya, East Java, Indonesia. Treatment concentrate mixes contained increasing inclusion rates of CW, at the expense of the protein meals palm kernel cake (PKC) and copra, which were added in equal quantities. The five tested CW inclusion rates were 30, 40, 50, 60 and 70% of total diet dry matter. Limestone and a multi-mineral mix were added at a set inclusion rate of 0.8 and 1.6%, respectively. Quadratic regression lines were fitted to the relationships of animal performance and CW inclusion rate.

Intake of dry matter and concentrate demonstrated a quadratic relationship with increasing CW inclusion, both maximised at 40–50% CW inclusion. When concentrate intake was regressed against dietary composition, the best fitting model was a linear relationship with terms for CW inclusion (CW; %; $F = 3.1$; $P = 0.09$), crude protein content (CP; g/kg DMI; $F = 9.9$; $P < 0.01$) and organic matter content (OM; g/kg DMI; $F = 14.8$; $P = 0.001$): Concentrate intake (g/kg W.d) = 291.6 + 0.178 CW + 0.2449 CP – 0.3559 OM. This model had an R^2 of 45%. Liveweight gain and change in body condition score both demonstrated a quadratic dose-response relationship with increasing CW inclusion, with maximal performance achieved at 40 % inclusion of CW. Liveweight gain was most strongly affected by crude protein intake, which was a function of both crude protein content of the diet, and reduced voluntary intake of concentrate at high levels of CW inclusion. When liveweight gain was regressed against dietary descriptors for intake and chemical composition, the best fitting model was a linear relationship with terms for CP intake (g/kg W.day; $F = 30.1$; $P < 0.001$) and MEI (MJ/day; $F = 9.7$; $P < 0.01$): Average daily gain = -0.886 + 0.01382 MEI + 0.3532 CPI. This model had an adjusted R^2 of 78%.

Above 50% CW inclusion, the consumed diet CP content was less than 7.5%, at which level rumen function may be impaired (Freer *et al*. 2007). However, there was no relationship between CW inclusion and indicators of the digestibility of the diet consumed (OMD or M/D (MJ/kg DM)), even at the highest levels of CW inclusion. This research demonstrated that inclusion of CW up to 40% of the diet does not have a detrimental effect on liveweight gain. Future research should consider the effect of CW on NDF digestibility and protein supply.

Table 1. Dose-response of feed intake of Madura bulls to increasing cassava waste inclusion rate (CW%) in simple feedlot diets (μ ± s.e.)

Parameter	Inclusion rate of cassava waste in diet (%) 30	40	50	60	70	Relationship	R^2	P
Total DMI (g DM/ kg W. day)	19.79 ± 1.09	20.40 ± 0.17	21.00 ± 0.54	20.53 ± 0.26	18.31 ± 0.41	Y = 10.65 + 0.4425 CW% - 0.004736 CW%^{2}	30.7 %	**
OM intake (g/kg W.day)	17.4 ± 0.95	17.7 ± 0.15	18.2 ± 0.47	17.4 ± 0.22	15.8 ± 0.35	Y = 10.06 + 0.3581 CW% - 0.003942 CW%^{2}	33.2 %	**
Liveweight gain (kg/day)	0.72 ± 0.12	0.83 ± 0.05	0.61 ± 0.05	0.40 ± 0.04	0.14 ± 0.05	Y = 0.1566 + 0.03493 CW% – 0.000507 CW%^{2}	69.8 %	***
CP intake (g CP/ kg W.day)	2.5 ± 0.15	2.4 ± 0.02	2.1 ± 0.06	1.5 ± 0.02	1.3 ± 0.03	Y = 3.598 - 0.03307 CW%	86.8 %	***
NDF Intake (g/kg W.day)	12.3 ± 0.64	12.3 ± 0.14	12.5 ± 0.31	11.9 ± 0.15	9.9 ± 0.20	Y = 6.479 + 0.2952 CW% - 0.003484 CW%^{2}	57.5 %	***
Estimated ME intake (MJ/day)	57.1 ± 4.0	54.7 ± 1.4	55.6 ± 2.0	53.1 ± 2.4	44.1 ± 2.2	Y = 38.33 + 0.9743 CW% - 0.01257 CW%^{2}	22.4 %	**

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We gratefully acknowledge the Australian Centre for International Agricultural Research for funding this work.

Bacillus amyloliquefaciens H57 alters diet preference and ruminal pH in steers

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The novel probiotic *Bacillus amyloliquefaciens* strain H57 (H57) is a spore-forming bacterium originally used to reduce the risk of fungal spoilage in hay (Brown and Dart 2005). Le *et al*. (2016) demonstrated that the preference for weaned dairy calves for calf pellets inoculated with H57, compared to Control pellets, was approximately 70:30. In ruminants, dietary preference is controlled by the interaction between food sensory characteristics and post-ingestive feedback (Forbes 2007). That feedback could include rumen pH, which may increase when probiotics are fed (Seo *et al.* 2010) and higher rumen pH can improve intake rate (Giger-Reverdin 2018).

A 4×4 Latin square design was applied to separate pre and post-ingestive effects of H57 on rumen pH and diet preference for feedlot pellets in mature rumen-fistulated steers. *Bos-indicus* cross steers were offered a set amount of feedlot pellets (0.35% of liveweight), manufactured with (H57) or without (C) the H57 probiotic. Half of the total pellets amount were put into the rumen via the fistula (r), and then the remaining, of either H57 or C pellets, were orally consumed (o) over 15 minutes, to giving four treatments: H57o/H57r, H57o/Cr, Co/H57r and Co/Cr. Rumen fluid was sampled at 0, 2, 4 and 6 hours after feed offering and then preference was tested immediately after 6 hours measurement by simultaneously offering the steers 4kg of the each H57 and C pellets in adjacent troughs for 5 minutes and relative intakes recorded. Each treatment period was applied for 6 consecutive days, with rumen pH sampled and averaged of the last 3 of those days. Each period was followed by 10 day rest period and this cycle was repeated until each animal had experienced each treatment. *Ad libitum* tropical grass hay was offered throughout.

There was no treatment effect on subsequent preference, indicating that post-ingestive effects did not override pre-ingestive effects, or visa versa, (P = 0.89). When the data was combined across all treatments, the steers preferred the H57 compared to the C pellets (56:44; P < 0.01). Overall, no treatment effect was observed on ruminal pH (P > 0.05; Fig. 1). However, when the H57 pellets were introduced to the rumen directly, ruminal pH at 4h was higher for the H57 compared to when the C pellets were introduced (6.20 vs. 6.12, P =0.04). This trend began by 2h (P = 0.08) and continued to 6h (P = 0.06). In conclusion, H57 can improve preference but that could be driven by a combination of pre- and post-ingestive signals. It is also possible for H57 to alter ruminal pH. However, since an increase in ruminal pH *per se* was not sufficient to alter diet preference, alteration of ruminal pH may not be an over-riding mechanism by which H57 improves preference.

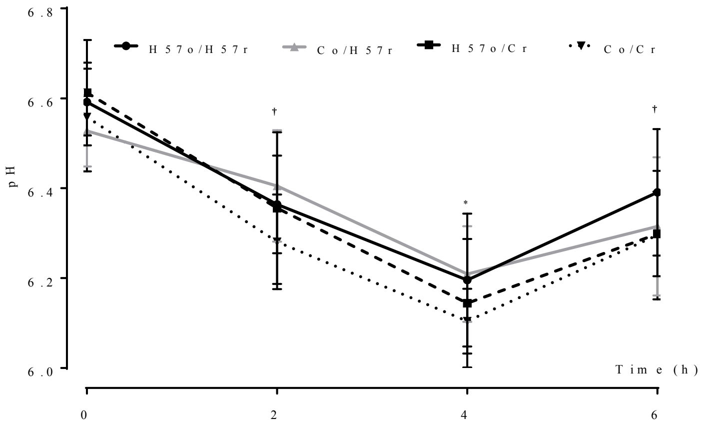

Fig. 1. Evolution of ruminal pH following the short term addition of pellets ether orally (o) or through a rumen fistula (r) (†: P < 0.10; *: P < 0.05; P indicate significant contrast effect of introducing the H57 (H57o/H57r & Co/H57r) compared to the C (H57o/Cr & Co/Cr) pellets into the rumen).

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Nuclear magnetic resonance to detect rumen metabolites as potential proxies for enteric methane emissions from beef cattle

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With animal production increasing rapidly in order to meet the needs of a growing population it is necessary to understand the negative effects this can have on the environment. Ruminants contribute significantly to the global greenhouse gas budget, producing ~80 million tonnes of methane (CH_4) per year and contributing to 25-30% of anthropomorphic emissions (Beauchemin *et al*. 2008). The CH_4 is produced inside the rumen by two distinct pathways: hydrogenotrophic and methylotrophic methanogenesis. The hydrogenotrophic pathway is characterised by the utilisation of hydrogen and carbon dioxide, made during the production of volatile fatty acids (VFAs), as substrates for CH_4 production, and is the most commonly studied pathway. The methylotrophic pathway is characterised by the use of methylamine, methanol and other methyl compounds as substrates and is less studied (Poulsen *et al.* 2013). These metabolites associated with CH_4 emissions may be used as proxies to quantify emissions and so provide a less invasive, less expensive and higher throughput alternative to current techniques. The aims of this study were: to assess how effective nuclear magnetic resonance (NMR) is at detecting rumen metabolites; to assess if CH_4 emissions can be accurately predicted from metabolite concentrations; and to detect methylotrophic methanogens in rumen fluid from animals offered different diets.

The study was conducted at the Beef and Sheep Research Centre laboratory of SRUC. A total of 211 rumen samples were obtained, of which 128 gave metabolite signals and were analysed from previous studies, conducted between 2015 and 2017. The samples came from 3 different diet types: forage, mixed or concentrate. Samples were stored frozen and subsequently thawed, centrifuged at 13000 rpm for 5 minutes and filtered through 2μL Whatman filters. The prepared samples were then analysed using a 1H-NMR instrument (4 channel instrument, 5mm TCI, CryoProbe). The spectra were then converted to data and a principal component analysis (PCA) and a partial least squares (PLS) analysis was done to validate the data (Fig. 1).

Results indicated that the largest peaks were attributed to the VFAs as expected with acetate and butyrate being associated with the forage/mixed diets whilst propionate was higher in the concentrate diet. The predictive modelling of CH_4 emissions showed an $R^2 = 0.59$ and an RMSE = 0.16. When using metabolites alone. But when the model used metabolites plus the diet-related factors the $R^2 = 0.72$ and an RMSE = 0.13. Metabolites associated with the methylotrophic pathway were also identified and were present in higher levels in the concentrate diet.

When relating these results to the study aims: NMR can be used as a method to detect metabolites; metabolites associated with the methylotrophic pathway are more abundant with diets containing higher levels of concentrate. However, further research is required to fully quantify the ability of metabolites as CH_4 predictors.

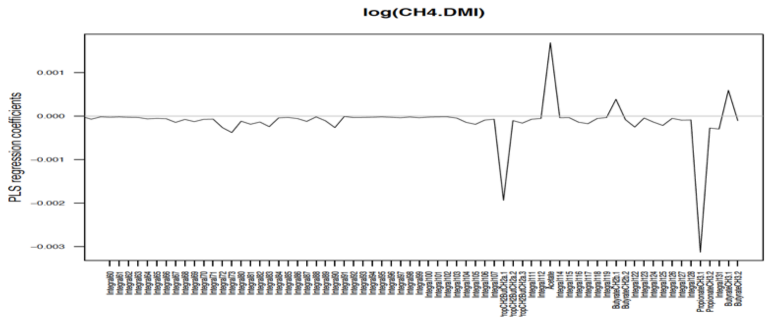

Fig. 1. PLS analysis using rumen metabolites. X-axis showing metabolites, Y-axis PLS regression coefficients.

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The relationship between liveweight-for-hip height and compensatory growth in cattle

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There is variability in the physiological adaptation of the skeleton and muscles of cattle to both nutritional restriction and the observed response when the subsequent level of nutrition is increased. During nutritional restriction bones cannot decrease in physical dimensions, in particular length, but may decrease in weight and mineral composition. Increases in bone length, albeit a slower rate of elongation, can still occur in situations of liveweight (LW) loss and maintenance (McLennan 2014). Muscles decrease in diameter and weight during severe nutritional restriction and increase protein accretion during compensatory growth (Lehnert *et al.* 2006). This worked aimed to investigate the relationship between hip height and liveweight on compensatory growth.

Liveweight and hip height (HH) data ($n = 4201$) from seven different experimental groups of castrated male *Bos indicus* cattle were combined in order to generate a LW-for-hip height (LW-for-HH) relationship for unrestricted cattle. The data was sorted in order to exclude treatments in which animals suffered any type of nutritional restriction. Initially, six models were generated and then Akaike information criterion was applied to select the best-fit model. The model selected to describe the LW-for-HH of unrestricted cattle was later utilized to compare the effect of the difference between the LW predicted by the model to the observed LW during the compensatory growth phase. The observed mean HH at the end of each restricted phase was used to predict the expected LW according to the selected LW-for-HH model. The difference between the predicted and the observed LW was designated as the LW gap. The relationship between LW gap and LWG during compensatory phases was investigated by a regression analysis. Data used in this analysis was sourced from Silva (2017) and McLennan (2014) selecting treatment groups that were subjected to nutritional restriction. These different treatment groups within these studies were named group 1 to 5.

The results show that during nutritional restriction cattle deviate from the LW-for-HH relationship (Figure 1 a) with greater increases in HH than in LW. The greater the difference between the expected LW to the observed LW at the end of a restricted period the more potential thee is for compensatory growth (Figure 1 b). The results presented suggest that the potential for compensatory growth may be defined by the difference between the measured LW and the expected LW based on the animals LW-for-HH at the end of a period of nutritional restriction.

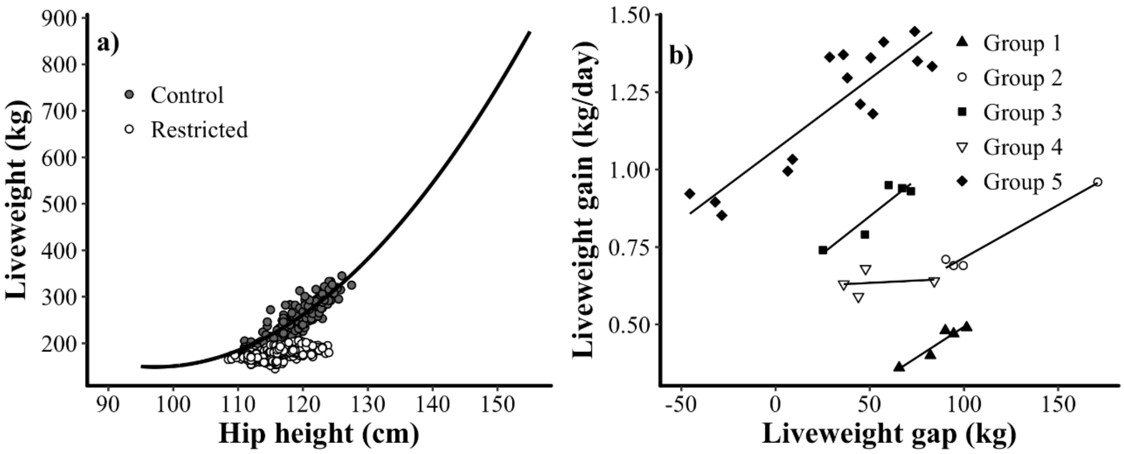

Fig. 1. (a) Liveweight is plotted against hip height to generate the liveweight-for-hip height relationship for unrestricted cattle ($Y= 1896.2 - 37.9X + 0.199X^2 + 39.6$, $R^2=0.97$, RSE=22.4, $P<0.001$). In addition, the liveweight-for-hip height relationship of cattle during nutritional restriction (restricted) and high levels of nutrition (control) is included using data from two experimental groups sourced from Silva (2017). (b) Relationship between the liveweight gap (difference between predicted liveweight by liveweight-for-hip height model and observed liveweight at the end of nutritionally restricted phases) and liveweight gain observed during the subsequent compensatory growth period when the level of nutrition was increased.

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Peri-natal *ad libitum* feeding increases gestation length and the number of piglets born alive

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Improper sow nutrition can have multiple negative effects to the overall productivity of a farm. With reproduction associated with sow body condition and nutrient supply, one of the major causes of poor reproductive performance is insufficient feed intake and reduced nutrient absorption, limiting the sow's ability to meet her maintenance and lactation requirements (Yang *et al*. 2008). Under-feeding throughout gestation will result in greater back fat losses throughout lactation and consequently a delayed return to oestrus and low conception rate. Overweight (also known as overfed) sows are often culled earlier due to locomotive problems and poor performance during lactation (Dourmad *et al.* 1994).

For the past 50 years, the Australian industry standard for lactation feeding has been a stair-step feeding program, which provides the sow with a maximum of 1 kg of feed on the day of farrowing with the quantity increased by 0.5 kg increments daily until day 7 post-farrowing. Since 2013, PIC Australia has implemented *ad libitum* feeding in late gestation (3 d prior to expected farrowing date) and throughout lactation to try to counteract the adverse effects of mobilisation of sow body stores during early lactation.

Using data collected from 6 genetic lines from 1 year prior (when a stair– step feeding program was used during lactation) to 1-year post- feeding regimen change, the objective of this study was to determine if there were significant improvements in gestation and farrowing parameters in response to the *ad libitum* feeding. Over the 2-year period, a total of 14,543 matings were recorded at the piggery. Of these, 7,203 matings occurred during the restricted diet phase. From these values, non-farrowing, abortions, culls and deaths were removed from the sow data leaving a total of 9,742 farrowings (4,714 recorded in the restricted feed period). Using the statistics program 'R', data were subjected to analysis of variance. Multiple linear mixed models were used to determine statistical differences between groups; genetic line, parity and feed. Season, feeding program, parity, line and sow genetics in the farrowing and gestation data and parity, lactation length, numbers weaned and line were included in the analysis to minimise the skewing of data.

Sows fed *ad libitum* for the last 3 d of gestation had a significantly longer (P = 0.001) gestation length than those on feed restriction. Gestation length also varied between genetic line (P = 0.032), parity (P = 0.001) and season (P < 0.001). During summer, sows fed *ad libitum* had a significantly (P < 0.05) longer gestation length (116.4 d) than restricted fed sows (116.1 d). However, neither the weaning to oestrus interval nor conception rate varied (P > 0.05) between the feeding programs. The sows fed *ad libitum* had a significantly higher (P = 0.011) number of piglets born alive (PBA; 10.84 ± 3.21) compared to those sows on feed restriction (10.60 ± 3.35), resulting in an additional 0.24 PBA per sow per litter. The increase in PBA was a consequence of the significant reduction (P = 0.001) in stillbirths. The feeding regimen of the sows had no effect (P > 0.05) on piglet birth weight.

There was no significant improvement in total litter size in response to increased feed intake; however, there was a significant increase in the number of PBA. Gao *et al.* (2012) reported in increase in PBA in response to L-arginine supplementation of sows during gestation. Given that, by default, *ad libitum* feeding results in an increased intake of amino acids, including L-arginine, it is possible that the increase in PBA may have been the result of an increase in the supply of L-arginine. The increase in gestation length in response to *ad libitum* feeding from 3 d prior to the expected farrowing date was an unexpected finding. Gestation length has been associated with genetics, parity, litter size and season, but has not been previously associated with feed intake (during late gestation). While the exact series of events is not fully understood, it is known that piglets trigger farrowing (Rydhmer *et al.* 2008). The question then arises as to whether the foetuses or the sow was the cause of the extended gestation length. While there is uncertainty as to why the gestation length has increased, there is the possibility for stillbirths to be significantly reduced with increased gestation length (Vanderhaeghe *et al.* 2011) and this may be a possible explanation for the significant increase in PBA.

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Nutritional modelling for enhanced livestock productivity in the rangelands of northern Ghana in response to pasture improvement with an adapted tropical legume species

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Low digestibility and crude protein concentrations in native pastures compels some nomadic livestock herders in the rangelands of northern Ghana to burn mature and dry forage to encourage regrowth with better nutritive characteristics. This practice, however, typically leads to pasture scarcity in the dry season (Nov-Apr) so that animals lose weight sometimes leading to mortalities. One possible solution to this problem is to introduce an adapted legume with the aim of increasing protein and dry matter intake during the dry season. Currently, there are no data to support this proposition and provide estimates of likely responses of livestock to the introduction of a legume in this grazing system. The main objective of this study was to use the Grazfeed® program to estimate the potential increase in productivity of lambs in response to incorporation of an adapted tropical legume in native *Hyperthelia dissoluta* (Yellow thatching grass) pastures typical of northern Ghana.

Modelling was conducted for unimproved pasture (0% Legume) and improved pasture (30% legume) for both the dry season (November –April) and wet season (May–October). Values for crude protein (CP) and dry matter digestibility (DMD) were as reported by Skerman and Riveros (1990) (Table 1). Values used for green and dead pasture mass of unimproved pasture ranged from 0 to 1.5 and 1.0 to 1.5 T DM/ha, respectively, in the dry season and 1.0 to 3.5 and 0.5 to 1.0 T DM/ha, respectively, in the wet season. Values used for green and dead pasture mass of improved pasture ranged from 0.5 to 3.0 and 1.0 to 2.0 T DM/ha, respectively, in the dry season and 1.0 to 4.0 and 0.5 to 1.0 T DM/ha, respectively, in the wet season. Lambs were classed as 'small Merino' at 20kg liveweight and an average age of 6 months with 1.5 cm fleece as this was the closest match to the Djallonke breed commonly farmed in Ghana.

Modelling suggested acceptable weight gains from native pastures could be expected in the wet and early dry seasons, but with weight loss occurring late in the dry season. This is consistent with observations. Modelling suggested that pasture improvement would result in positive weight gains year round with the largest benefit occurring in the dry season. The study concluded that improving native pastures by incorporating an adapted legume at an average 30% of total dry matter would significantly enhance the productivity of livestock in the rangelands of northern Ghana and would avoid the need for the burning of native pastures in the dry season.

Table 1. Crude protein (CP) and dry matter digestibility (DMD) values of unimproved pasture and improved pasture for during dry and wet seasons

Season	Unimproved pasture (0% Legume)				Improved pasture (30% Legume)			
	DMD (%)		CP (%)		DMD (%)		CP (%)	
	Green	Dead	Green	Dead	Green	Dead	Green	Dead
Dry	50	45	7	4	65	50	8	5
Wet	60	40	10	5	70	40	16	6

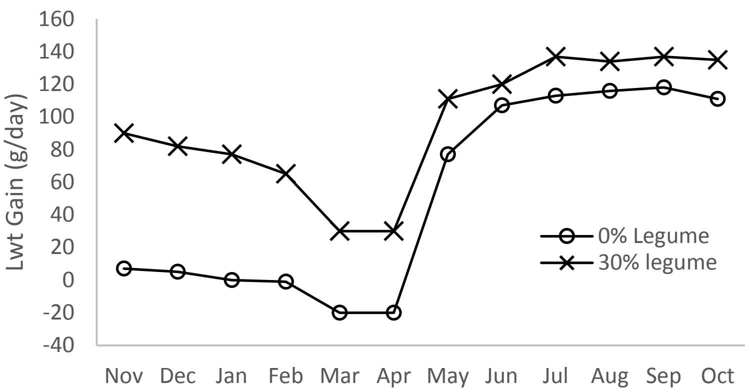

Fig. 1. Daily weight gain in 20kg lambs grazing native pastures with 0% and 30% legumes in the dry and wet seasons of northern Ghana predicted using the Grazfeed® Program.

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The effects of supplementary P in the diet on the concentration of P in faeces

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Phosphorus (P) deficiency often occurs in cattle grazing pastures growing on very low P soils and may have severe adverse effects on animal productivity. Nutritional management (e.g. by P supplementation) of grazing cattle requires estimation of P intake from pasture. In cattle ingesting forage diets the diet P concentration (DP) can be estimated from faecal P concentration (FP), or more satisfactorily from the P and N concentrations of faeces and diet N concentration measured by near infrared spectroscopy of faeces (Dixon and Coates 2011; Dixon 2016). The present study examined whether the relationships to estimate DP from FP developed with cattle fed forages without P supplements can also be used to estimate DP in cattle given P supplements.

The relationships between the FP and DP were examined in a grazing experiment at Springmount, Mareeba, N Qld, Australia (Miller *et al.* 1998). Groups of 6-8 *Bos indicus* cross breeder cows grazed six paddocks with native grass – *Stylosanthes spp* pastures where soil P ranged from acutely deficient to adequate. Two of the paddock groups were fed P supplement (sodium monophosphate) through the drinking water. Chromic oxide markers and P tracer were used to measure P intake on six occasions (in the late dry season, and the early and late wet seasons in each of two years) in four of the cows in each paddock group. At each of the six measurement periods diet digestibility was measured with oesophageally fistulated animals. A pooled linear regression of DP on FP using paddock means compared the relationships of cows obtaining all of their diet P from pasture with cows obtaining a substantial proportion of their DP from P supplement.

The pooled regression explained 88% of the pooled variation ($R^2 = 0.88$). The relationships had similar slopes but differed in elevation ($P < 0.001$) with DP relative to FP greater for cattle fed P supplements in the drinking water than those grazing pasture in the absence of P supplements over the range of FP studied. As shown the range in FP was considerably less for the P supplemented than the unsupplemented cows. An additional consideration is that in P supplemented animals the relationship may be affected by the form, and the frequency and timing of ingestion, of the P supplement. Importantly, regression relationships between DP and FP developed from measurements in cattle ingesting diets of forage alone are not directly applicable for estimating DP when cattle are given P supplements.

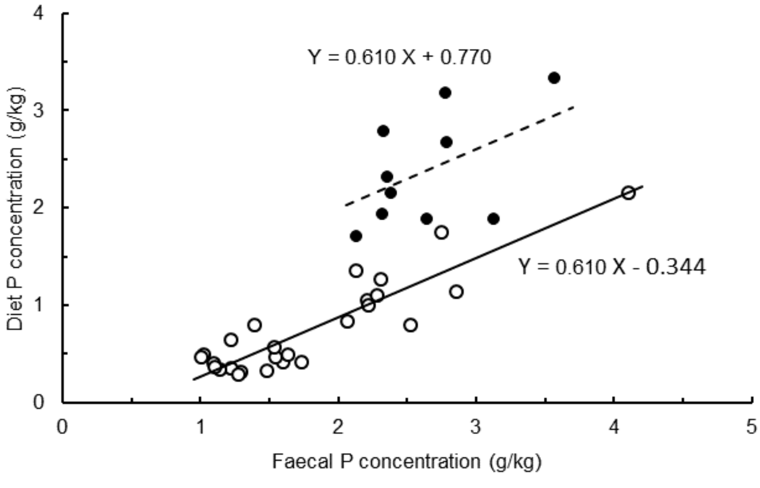

Fig. 1. The relationships between the concentration of P in the diet and the concentration of P in faeces of breeder cows grazing tropical pasture without supplements (○) or supplemented with P (●).

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Response to meat and bone meal, phytase and antibiotics on gut permeability, nutrient digestibility and caecal microflora in broiler chickens during a necrotic enteritis challenge

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Necrotic enteritis (NE) is an enterotoxaemia of poultry with a significant economic effect on poultry production. Currently, antibiotics effectively prevent NE, but there is a global push for reduced reliance on the use of in-feed antibiotics (Castanon, 2007). Preventative treatments focus on the predisposing factors that instigate the disease. One such factor is meat and bone meal (MBM). The ingestible proteins in MBM (Kim, et al., 2012) cause production of toxic metabolites via proliferation of putrefying bacteria, such as highly proteolytic *C. perfringens* (Sharma, et al., 2017). Supplementing broiler diets with a ‘superdose’ of phytase has previously been shown to improve performance in NE challenged birds. The aim of this study was to investigate the effects of phytase in NE challenged birds fed MBM based diets, on gut permeability, nutrient digestibility and caecal microflora.

Wheat, SBM, canola meal diets were fed as starter (S) to d 14, grower (G) from d 14–28 and finisher (F) from d 28–42 to Ross 308 male birds (n = 672) allocated to 8 dietary treatments in a 2 × 2 × 2 arrangement in completely randomized design with 6 replicates per treatment and 14 birds per replicate. Factors were: MBM (0 g/kg or 60g/kg S 50g/kg G/F); AB (0 g/kg or zinc bacitracin, 100 mg/kg S/G, 50 mg/kg F plus salinomycin, 60 mg/kg; and phytase (500 or 1500 FTU/kg) (Quantum Blue^{TM}, AB Vista Feed Ingredients, UK). All birds were challenged with 5000 unattenuated sporulated oocysts each of *E. acervulina*, and *E. maxima and 2,500* sporulated oocysts of *E. brunetti* on d 9, and 10^8 CFU of *C. perfringens* Strain EHE-NE18 on d 14 and d 15. Two birds per pen were gavaged with fluorescein isothiocyanate dextran (FITC-D) solution on d 16 post-hatch, to evaluate permeability of the intestinal tract; FITC-d was measured in the blood serum approximately 2 ½ hours following the gavage. Quantitative real-time polymerase chain reaction (PCR) of the bacteria were assessed using the methods of Kheravii *et al.* (2017). The apparent ileal digestibility of energy, crude protein, carbon, Ca and P were also determined on d 16 and d 28.

Meat and bone meal increased (P = 0.043) the level of the FITC-D marker in the serum, indicating damage to the gut lining. This positively correlated with apparent ileal digestibility of calcium (r = 0.323; P = 0.025). Antibiotics significantly reduced the level of FITC-D in the serum (P = 0.028) and increased nitrogen retention on d16 (P = 0.048). Presence of meat and bone meal increased the apparent ileal digestibility of Ca and P on d 16 (P = 0.008 and P = 0.011, respectively), but decreased Ca digestibility on d 28 (P < 0.004). The high level of phytase supplementation increased P digestibility on d 28 (P = 0.001). No significant treatment effects were detected for caecal *Lactobacillus spp., Ruminococcus spp., Bacteroides spp.*, and *Bifidobacterium spp.* (P > 0.05). Counts of *Bacillus spp.* were lower in birds fed the treatment with high phytase and no-antibiotic (P = 0.038). *Clostridium perfringens* counts tended to increase with dietary inclusion of MBM (P = 0.059).

In conclusion, nitrogen retention was improved by antibiotics during NE while meat and bone meal increased intestinal permeability, Ca and P digestibility and *C. perfringens* counts in chickens during NE.

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In vitro digestibility of fermented rice straw supplemented with cassava (*Manihot utilissima*) tuber and leaves

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A synchronized protein-to-energy ratio indicates optimal fermentation efficiency (Charbonneau *et al*. 2007). This study aimed to determine the best ratio of cassava tuber and leaves added into fermented rice straw to improve *in vitro* digestibility. In a 4 × 4 factorial design, cassava tuber (0, 5, 10, or 15% of total DM) and cassava leaves (0, 5, 10, or 15% of total DM) were added to fermented rice straw. The organic matter digestibility (OMD) and crude protein digestibility (CPD) was predicted using the first stage of the 2-stage *in vitro* technique (Tilley and Terry 1963). Results showed that addition of cassava leaves or tubers to fermented rice straw improved OMD and CPD without changing the culture pH (6.93 to 7.10). The greatest improvements in digestibility of the diets were detected at the highest levels of cassava addition, when 15% tuber or 15% leaves was included with the straw. A combination of supplementing 15% tuber and 15% leaves of cassava yielded the greatest OMD and CPD. Addition of 15% tubers or leaves improved digestibility to levels closer the maintenance requirement of mature ruminants (49.9 and 47.6%, respectively) while addition of both resulted in a diet where modest growth was achievable (57.1%).

Table 1. *In vitro* organic matter digestibility of fermented rice straw supplemented with cassava tuber and leaves

Cassava leaves levels (% as fed)	Cassava tuber levels (% as fed) T0	T5	T10	T15	Means
L0	36.0^{p}	41.1^{q}	49.6^{st}	49.9^{st}	44.4^{x}
L5	44.1^{qr}	45.2^{r}	50.5^{st}	51.9^{tu}	48.8^{y}
L10	46.7^{rst}	46.5^{rs}	51.1^{t}	55.4^{uv}	51.5^{z}
L15	47.6^{rs}	49.7^{st}	51.4^{t}	57.1^{v}	53.1^{z}
Means	42.9^{a}	46.0^{b}	50.7^{c}	54.0^{d}	

Table 2. *In vitro* crude protein digestibility of fermented rice straw supplemented with cassava tuber and leaves

Cassava leaves levels (% as fed)	Cassava tuber levels (% as fed) T0	T5	T10	T15	Means
L0	25.5^{n}	26.5^{no}	27.5^{no}	30.9^{op}	27.6^{w}
L5	33.1^{pqr}	34.5^{pqrs}	31.3^{opq}	36.5^{qrs}	33.9^{x}
L10	34.7^{rst}	37.8^{rst}	39.4^{qrs}	44.5^{uv}	38.4^{y}
L15	39.6^{stu}	42.1^{tu}	43.9^{uv}	47.4^{v}	43.2^{z}
Means	33.2^{a}	35.2^{a}	35.8^{a}	39.8^{b}	

T0 = without cassava tuber supplementation, T5 = supplemented with 5% cassava tuber, T10 = supplemented with 10% cassava tuber, T15 = supplemented with 15% cassava tuber, L0 = without cassava leaves supplementation, L5 = supplemented with 5% cassava leaves, L10 = supplemented with 10% cassava leaves, L15 = supplemented with 15% cassava leaves.
^{a,b,c,d}Means in the same row with different superscripts differ at $P < 0.05$.
^{w,x,y,z}Means in the same column with different superscripts differ at $P < 0.05$.
^{p,q,r,s,t,u,v}Means in the same row and column with different superscripts differ at $P < 0.05$.

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The effect of season of kidding on milk yield of commercial dairy goats in Australia

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Milk production in goats is affected by various non-genetic factors (i.e. kidding season, parity and litter size) (Assan 2015). Predictions of how kidding season influences cumulative milk yield in commercial dairy goats can assist farmers in making management decisions and contribute to increased efficiency of animal selection. This study aimed to investigate the effects of kidding season on milk yield in three phases of lactation and cumulative milk yield in Australian commercial dairy goats.

This experiment was conducted at Meredith Dairy commercial farm (Meredith, Australia, 37°50′S; 144°04’E), during four consecutive kidding seasons, from June 2016 to March 2017. In total, 1000 (~250 per kidding season) Saanen and Saanen-cross goats (1–7 years, LW; 66 ± 17.0 kg, and BCS; 2.5 ± 0.3) were enrolled in the study. Goats were housed in a single barn and were *ad libitum* fed a total mixed ration (TMR) (9.7 MJ/kg ME and 160 g/kg CP DM). Does were machine milked twice-daily in a 2 × 36 parlor with electronic milk meters (De Laval, SE). Does were culled in line with commercial practice and only the does that achieved 270 days in milk (DIM), (MAR, n = 149; JUN, n = 180; SEP, n = 175; and NOV, n = 173) were analyzed. Lactation was divided into three phases: early-lactation (from kidding to 90DIM), mid-lactation (91 to 180DIM), and late-lactation (181 to 270DIM). Data obtained was analyzed using the Linear Mixed Models procedure of GenStat (version 18.1). Kidding season, litter size, parity and age were included as fixed effects and goat was included as a random effect.

The herd average for cumulative milk at 270DIM (C270DIM) was 773 ±29.0 L. Milk yield per goat per day was higher (P < 0.001) in early-lactation than it was in the other lactation periods for goats kidded in MAR, JUN and NOV. The C270DIM was decreased (P<0.001) for goats kidding in autumn and winter (MAR and JUN) (Table 1). Although C270DIM did not differ between NOV and SEP, and between MAR and JUN kidded goats, C270DIM was more evenly distributed along the three lactational phases for lactations initiated in SEP and JUN. Our findings are in agreement with recent studies demonstrating that stage of lactation is an important factor affecting dairy goats' responses to environmental variations (Russo *et al*. 2013; Salama *et al*. 2014).

The herd’s average milk production peaked in December (3.0 ±0.04 L/goat/day) and was lowest in June (2.3 ±0.05 L/goat/day). The peak production coincided with summer in the Southern hemisphere and seasonal variations in environmental factors including food quality, temperature, humidity, rainfall, day length (photoperiod) and radiation can influence animal performance (Nardone 2010). In this experiment, the flock was housed in open-sided sheds and fed a TMR year-round. Therefore, changes in food quality presumably did not contribute to variation in milk yield. Thus, higher herd milk yield in summer was more likely driven by the longer photoperiod which has been shown to increase milk yield in dairy goats (Garcia-Hernandez *et al*. 2007; Russo *et al*. 2013).

These results demonstrate that season of kidding affects cumulative milk yield and the distribution of the total milk between the three stages of lactation. The determination of the impact of season of kidding on milk yield and lactation curve of commercial goats can contribute to the design of commercial management plans aiming for a relatively constant supply of milk throughout the year.

Table 1. Mean (± SED) milk production (L/goat/day) and cumulative milk (L) at 270DIM of Australian commercial goats kidded over four periods per year (March, June, September and November)

	Month of kidding					
Lactation Stage	MAR	JUN	SEP	NOV	SED	P-value
Early	3.3	3.1	3.2	3.5	0.13	<0.001
Mid	2.7	2.6	3.1	3.2	0.13	<0.001
Late	2.3	2.4	2.6	2.4	0.12	<0.001
Cumulative milk 270DIM	744	733	794	821	31.0	<0.001

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Nutrient intake of Holstein-Friesian crossbreed male calves fed calf starter

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It has been common practice on dairy farms in Central Java to focus their business on raising their male calves. One of the reasons was the low price of milk compared to the high cost of feed. The high growth rate of the Holstein Friesian crossbred calves makes growing them out attractive to the farmer. Typically calves are raised for two months approximately and sold to other farmers for further fattening. Farmers have limited experience with using a nutrient calf starter, thus this study investigated a commercial calf starter compared with wheat pollard in the calves ration. By providing more palatable feeds used in commercial calf starters palatability and feed intake in growing calves should be increased (Fathi *et al*. 2009).

The research was conducted in Boyolali, Central Java, Indonesia using 10 male Friesian Holstein crossbreed calves (75–95 kg body weight). The calves were divided into 2 treatment groups and fed individually a diet of 20% *Panicum muticum*, 48% tofu waste together with 32% wheat pollard (as practised by farmers, control diet) or with a 32% commercial calf starter (treatment diet). The nutrient intake data were collected at 60 days after a two week adaptation period. The data from the two groups were analysed using an independent sample t-test.

The dry matter (DM), organic matter (OM), crude protein (CP), and crude fibre (CF) intake were significantly different between groups ($P < 0.01$) (Table 2).

The different nutrient composition (Table 1) was one of the reasons the nutrient intake of calves differed between treatments. While the treatment calves had slightly higher crude protein intake, organic matter intake was slightly lower, suggesting there may be no benefit in using the calf starter, although further work is required to understand why intake of the treatment diet was lower than the control. The high ash content of the treatment diet also warrants further investigation.

Table 1. Nutrient ration composition of Control and Treatment rations

Group	Dry matter (%)	% DM				
		Ash	CP	CF	EE	NFE
Control[a]	77.00	7.30	17.60	18.70	5.48	51.06
Treatment[b]	77.17	11.31	18.92	10.30	6.15	46.32

[a]Control = 20% *Panicum muticum*+80% Concentrate (32% *wheat pollard*+48% tofu waste)
[b]Treatment = 20% *Panicum muticum*+80% Concentrate (32% *calf starter*+48% tofu waste)
EE = extract ether; NFE = nitrogen free extract.

Table 2. Nutrient intake of male calves fed with calf starter substitution on concentrate (%)

Item	Control	Treatment
Dry matter		
Intake (g/head/day)[ns]	3317.44±87.49	3389.99±132.56
Intake (g/kg bodyweight $^{0.75}$)*	97.74±3.96[b]	83.41±9.84[a]
Intake (% bodyweight)*	3.02±0.15[b]	2.44±0.41[a]
Organic matter		
Intake (g/ head/day)*	2976.24±79.32[b]	2818.65±110.08[a]
Intake (g/kg bodyweight $^{0.75}$)*	87.69±3.62[b]	69.36±8.18[a]
Crude Protein		
Intake (g/ head/day)*	509.09±16.19[a]	574.06±25.12[b]
Intake (g/kg bodyweight $^{0.75}$)[ns]	15.00±0.77	14.12±1.62
Crude fibre		
Intake (g/ head/day)[ns]	581.73±14.36	585.81±20.80
Intake (g/kg bodyweight $^{0.75}$)*	17.14±0.54[b]	14.42±1.74[a]

[a,b]Significant ($P < 0.05$) difference between treatment and control. [ns]Not significant.

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Mineral supplementation with salt, magnesium oxide and lime increases steer growth rates when grazing a failed wheat crop during early spring

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Dual-purpose wheat forage is below animal nutritional requirements for sodium (Na) and marginal for magnesium (Mg) (Dove and McMullen 2009). Supplementation with minerals can improve growth rates of young sheep grazing wheat crops by 20-60% (Dove, Masters and Thompson 2016). It has been suggested that improvements in growth rates of young cattle in response to mineral supplementation may be even greater than those in sheep (Dove 2018) although no results from replicated studies have been reported in beef cattle in Australia.

Growth rates of beef steers grazing a wheat crop with or without access to a mineral supplement were compared near Wagga Wagga in southern NSW in 2017. Angus steers (n = 36, 12-13 months of age) were allocated to one of six wheat plots (0.78 ha) in a completely randomised block design with two treatments (+/ minerals) and three replicates. The loose-lick mineral supplement consisted of salt (NaCl), Causmag® (MgO) and lime ($CaCO_3$) (1:1:1 by weight), offered *ad libitum* in tubs. Grazing started in late August when the main stem of the wheat plants had elongated (GS32; Zadoks *et al.* 1974). This was later than the normal grazing window for dual-purpose wheat, analogous to grazing a failed wheat crop due to drought. At commencement, steers were yarded at 8am in the morning for animal health treatments, weighed four hours later and then randomly allocated to plots (6 steers per plot). Animals were re-weighed on day 21 and 34 after the start of grazing following a similar four hour morning curfew. Some cattle moved plots at the commencement of the experiment; these were recorded and subsequently remained in their new plots. Average daily gain (ADG) was calculated by dividing the weight gain for each animal during period 1 (days 0–21) or period 2 (days 21–34) by number of days grazing in the period. Results were analysed using a linear mixed model (Genstat 18th edition) with the random effects replicate/plot/animal and fixed effects treatment x date.

Feed on offer (FOO) at the commencement of period 1 was 3.8 t/ha, reducing to 3.2 t/ha at the commencement of period 2. Residual wheat biomass at the end of the experiment was 1.6 t/ha. There was no difference between treatments at any of the sampling times. The crop had continued to elongate when FOO was measured at the commencement of period 2 and there was a decrease in the available leaf blade. The residual crop at the end of the experiment was primarily stem and leaf sheath with very little leaf blade remaining. Weight gain of steers was 32% higher in the treatment receiving mineral supplement during period 1 but did not differ significantly between treatments in period 2 (Table 1). Steer ADG was lower in period 2 compared to period 1.

Mineral supplementation of steers increased growth rates during period 1 when the leaf availability in the crop was highest and wheat plants were at an earlier growth stage; however mineral supplementation did not have a significant effect during the second period of grazing, characterised by lower leaf availability and lower ADG. The lack of response due to mineral supplementation during period 2 may be due to differences in dietary mineral composition, associated with the changed proportion of leaf:stem or plant maturity, and/or weight gains being restricted in both treatments by lower forage quality. The results indicate mineral supplementation of young cattle grazing wheat is beneficial when leaf availability is high.

Table 1. Average daily gain (kg/day) for steers grazing wheat during period 1 (days 0–21) or period 2 (days 21–34), with steers having *ad libitum* access to mineral supplements or no supplements. Different letters indicate significant differences. *P*-value and s.e.d. are for treatment x period interaction

	Days			
Treatment	Period 1	Period 2	s.e.d.	*P*-value
Mineral	2.5a	1.7c	0.14	0.007
Nil	1.9b	1.6c		

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A role for renal adaptation in driving voluntary intakes of low dry matter forages

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Fodder beet (*Beta vulgaris*) grazing systems for cattle and sheep have been pioneered in New Zealand over the past decade (Gibbs *et al*. 2011, 2014). The annual crop has increased from 100 ha to >60 000 ha on the productivity resulting from high yields (15–35 t DM/ ha) enabling high stocking rates (cattle: 20+/ ha; sheep: 200–350/ha). Moreover, the high metabolisable energy (ME) of the crop has resulted high liveweight (LWT) gains in cattle (Gibbs et al 2015). The DM% of the crop is low (<15%), but both intakes and LWT gains are reported for dairy and beef cattle, where a maximum of 2.1–2.3% LWT daily for DM intake has resulted in LWT gains above 1 kg/d in weaner steers fed *ad libitum* FB and 10% supplement (Saldias and Gibbs 2016; Gibbs *et al*. 2014). This suggests that intakes are not adversely impacted by the low DM% of the diet in cattle. There is no information available for sheep.

Methods. This trial used eight 35-40 kg entry LWT Coopworth hogget rams with individual pen feeding to establish maximum intakes of industry standard FB and fibre supplement diets (*ad libitum* intakes at 90% FB: 10% fibre supplement), with a long diet adaptation period through rising FB diet %. All rams were thus fed one of three diet treatments, sequentially: Diet A – FB 0%: grass silage (GS) 100%; Diet B – FB 30%: GS 70%; Diet C – FB 90%: GS 10%. Each diet was fed for 14–21d, with 7 d stable intake, before a 7 d collection period for total faeces and urine in a metabolism crate with recorded differential intakes and water consumption. LWT gains for each 21 d period were calculated, along with DMD% and water balance.

Results and Discussion. The maximum intake for sheep for diet A was 3.4% of LWT daily and 3.1% for diet C. The calculated DMD% were 82.8% for diet C, which with methane chamber assessments (data not shown) represents an ME value for the FB component of *c*.12 MJ/ kg DM, identical to previous ME estimates from NZ digestibility trials in cattle and sheep (Gibbs et al 2011). The mean urine output rose from 29 mL/ kg LWT daily in diet A to 162 mL/ kg LWT daily in diet C, with a corresponding mean LWT gain at <50g/ d at diet A and B but160g/ d for diet C.

Water balance calculations demonstrated urine volumes followed water consumed in feed rather than imbibed, as recorded water drinking intakes were effectively zero on diet C (<100mL/ d), resulting in periods of approximately 60 days with effectively no water drinking, but urine volumes above 100mL/kg LWT daily. The highest recorded daily urine outputs were >200 mL/kg LWT, approximately fourfold above the current published reference range maximum for sheep. The strong LWT gain for diet C amply demonstrated there is no diuresis effect for this diet, simply a high water loading.

It was noted that transitioning from diet A to diet B took less than one week, but diet B to diet C took almost 12 days to establish a maximum intake. Intakes increased approximately every three days then remained stable again for this period. Given that sheep had been on the FB diet for *c*.50 days by diet C, it is highly unlikely this is rumen adaptation. Instead, we suggest it reflects renal adaptation to the high water loads eaten, as previous studies have reported very low rumen ammonia despite high microbial protein production on identical FB rations in steers (Prendergast and Gibbs 2015), suggesting high rumen water absorption. The absence of an ammonia 'brake' on rumen epithelial blood flow (Reynolds and Kristensen 2008) enables maximal rumen water absorption, and we suggest it then requires direct intake control to avoid subsequent haemolysis, unless renal water excretion can be up-modulated to cope. This may explain why typical transition to *ad libitum* FB diets are at least 14 d, while similar energy density concentrate diets can be 7 d.

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Diurnal rumen pH patterns in cattle fed fodder beet *ad libitum* or as restricted intakes

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Fodder beet (FB: *Beta vulgaris*) is an annual forage crop that has been widely adopted as a dairy, beef, sheep and deer grazing feed in New Zealand (Gibbs and Saldias 2014). The crop is characterised by high yields (15–35 t DM/ha), high utilisation (90%+), and high feed value (ME: 12 MJ/kg DM) (Gibbs 2011; Saldias and Gibbs 2016). Typically diets of high water soluble carbohydrate (sugar) content and NDF are considered at risk of producing acidosis, which has associated health and production consequences (Owens *et al.* 1998).

The historic literature on rumen pH of such diets with low DM% as well is effectively limited to molasses feeding systems. In New Zealand industry standard grazing systems for dairy and beef are <20% fibre supplement and *ad libitum* grazed FB, and are associated with high intakes and liveweight gains (Saldias and Gibbs 2016; Gibbs and Saldias 2013), which does not suggest acidosis is common. Experienced operators do, however, avoid restrict feeding FB as this is commonly associated with rumen dysfunction. This project collated and compared diurnal rumen pH patterns via measurements from dairy cows and beef steers fed FB *ad libitum* or as a restricted diet, with 20% or less fibre supplement in the ration.

Methods. Seven experiments were used, four of *ad libitum* and three restricted (*c.*75% *ad libitum* intake), all with 20% or less fibre supplement included in the ration. Animals were fed a single daily allocation between 0800–1000 h each day. Experiments A, B, and C were pregnant, non-lactating cows grazing *ad libitum* FB; D was yearling beef steers beef steers pen-fed whole FB *ad libitum*; E, F and G were yearling beef steers pen fed whole FB at restricted ration (*c.*75% *ad libitum*). The pH measurement was by indwelling sensor (Ionode, IJ44, Australia) inserted via the fistula on a weighted paddle in the ventral sac floor, logged every 15s for 24h, meaned for 10 min intervals across experiments.

Results. The diurnal patterns of rumen pH and feeding times are displayed in Fig. 1. In general, rumen pH for ad libitum fed cattle remained above 6.0 for the day, and declined <0.5 units within 2 h of daily feeding. Restricted fed cattle were observed to have a greater decline in pH after feeding, and in each experiment were observed to have periods below 5.5 pH, which were not present in *ad libitum* fed cattle.

Discussion. The lower rumen pH values in restrict fed cattle despite lower daily energy intakes than *ad libitum* fed cattle is notable, and we suggest it reflects an intake behaviour adaptation to *ad libitum* feeding. Prendergast (2015) and Saldias and Gibbs (2016) observed intake patterns for *ad libitum* fed beef steers grazing FB, reporting significant time eating after dark and before dawn, and suggested that a flatter diurnal intake pattern may be an adaptation to unlimited high quality feed to increase intake. We propose that the rumen pH pattern of restrict-fed cattle, compared to *ad libitum*-fed, reflects a stronger pre-allocation appetite and competitive eating behaviour.

Conclusion. Cattle fed *ad libitum* FB with 20% or less fibre supplement did not have diurnal rumen pH patterns associated with acidosis, while such values were observed in restrict fed cattle. Changes in intake behaviour may be the cause of this, and caution should be taken when feeding cattle in this manner.

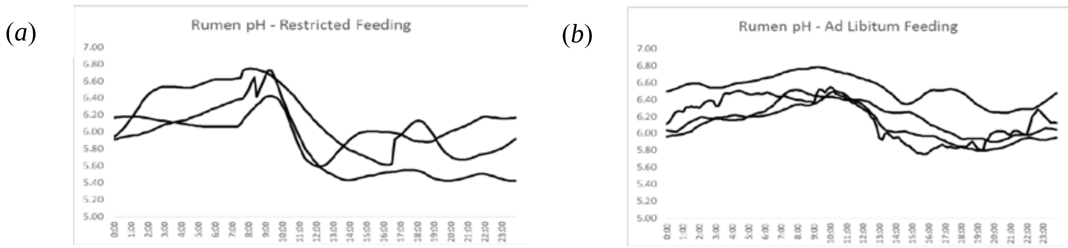

Fig. 1. (*a*, *b*) Diurnal rumen pH in cattle with restricted feeding and *ad libitum* feeding of fodder beet.

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The effect of protein synthesis inhibitors on gas production by rumen fluid from faunated and defaunated sheep

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Measurement of nitrate (NO_3^-)- and nitrite (NO_2^-)-reductase activity by rumen microbiota typically relies on quantification of appearance or disappearance of nitrite alone (McNally *et al*. 1997), however it is hypothesized that production of ammonia (NH_3) could serve as a measure of nitrite reductase activity, removing the requirement for high nitrite concentrations in the assay that are toxic to microbial populations. Measuring NH_3 production would require that incorporation of NH_3 by microbial growth be inhibited as is performed in protein degradability studies (Broderick 1987) without adversely affecting fermentation. A study was conducted using gas production by rumen fluid from faunated or defaunated (protozoa-free) sheep to assess the effect of microbial protein synthesis inhibitors on ruminal fermentation, prior to including these inhibitors in further assays for nitrate- and nitrite-reductase activity determinations.

In vitro incubations were conducted using whole rumen fluid samples (70 mL) collected from two crossbred female sheep (defaunated; *n* = 1; 87.6 kg) and faunated (*n* = 1; 71.8 kg) by oesophageal intubation three hours post-feeding. Both sheep had been acclimated to dietary NO_3^- (2 % of diet DM) provided as calcium nitrate ($5Ca(NO_3)_2$. $NH_4NO_3.10H_2O$), Bolifor CNF, Yara, Oslo, Norway, sprayed on blended lucerne/oaten chaff.

Each 70 mL rumen fluid sample from the faunated (F) and defaunated (D) sheep was subsampled (2 x 30 mL) into 50 mL plastic syringes containing ground samples of NO_3^- supplemented dietary chaff (301 ± 6.6 mg DM chaff/syringe) and fitted with three-way luer-lock taps. Protein inhibitor was added (3.9 mg hydrazine sulphate ($H_6N_2O_4S$) and 0.9 mg chloramphenicol ($C_{11}H_{12}Cl_2N_2O_5$;+I) to one syringe tube from each sheep, with no inhibitor added to the remaining tube (-I). Incubations were run for 4h with headspace gas quantified after 1, 2, 3 and 4 h.

A repeated measures analysis over time indicated that there was no effect of protozoa on gas production (P>0.05) and the effect of inhibitor was dependent upon time (P<0.01). Although protein synthesis inhibitors increasingly repressed gas production over time, the suppression of gas production after 1h was minimal (Fig. 1). As incubations for nitrate reductase assays are typically conducted for 15 min only, it was determined that inclusion of protein synthesis inhibitors would not significantly affect short-term fermentation, so could be used to enable estimation of nitrite reduction based upon the accumulation of ammonia within the incubation.

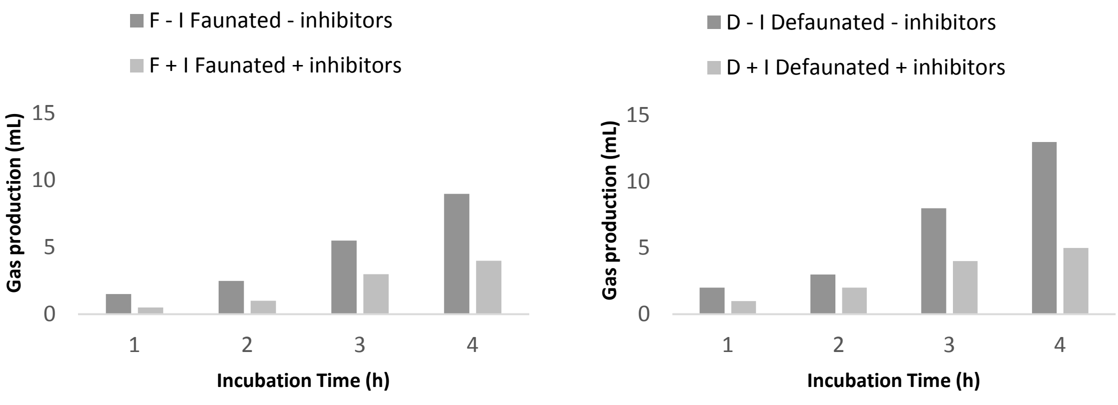

Fig. 1. Gas production over time by whole rumen fluid collected from faunated and defaunated sheep acclimated to 2 % dietary NO_3^- in DM. Incubations were conducted at 39˚C with or without protein synthesis inhibitors (3.9 mg hydrazine sulphate + 0.9 mg chloramphenicol).

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Microbial protein production in steers grazing *ad libitum* ryegrass or fodder beet

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Fodder beet (*Beta vulgaris*) has low concentrations of crude protein (CP), fibre and minerals, high water-soluble carbohydrates (WSC) concentrations and high levels of fermentable metabolisable energy (FME) (Gibbs 2011; Gibbs *et al*. 2015). The New Zealand fodder beet grazing approach for beef is as a finishing system, using minimal fibre supplementation. Commercial scale trials have measured liveweight gains of 1–2 kg/day for 260–530 kg steers fed fodder beet for 90-150 d at stocking rates above 20 animals/ha, resulting in a mean liveweight production of greater than 3000 kg/ha in that period (Gibbs *et al*. 2015). These liveweight gains are achieved with comparatively low CP concentration (<14%DM) of the feed, suggesting metabolisable protein supply may be optimised in this diet. The objective of this research was to establish if there was a significant difference between the microbial protein production in steers fed a diet of *ad libitum* winter ryegrass (cv Bealey) compared with a diet of *ad libitum* fodder beet (cv Brigadier, Seedforce) with 1 kg DM fibre supplementation.

Four rumen fistulated, yearling Charolais steers were housed in metabolism crates for two experiments comparing *ad libitum* diets of winter pasture (ryegrass (*Lolium perenne*) and clover (*Trifolium repens*)) and with fodder beet. For each experiment there were three rumen function trials carried out. Trial one was a ten day digestibility trial where intake was allocated to ensure 20% feed refusal. Microbial protein production was determined using the urinary purine method of Chen and Gomes (1992). In trial two, the diurnal pattern of rumen pH was measured for 24 hours, with a rumen probe placed into the ventral sac of the rumen. Trial three involved a 24 hour period of two hourly rumen samples taken from the ventral sac for ammonia, urea, and volatile fatty acid (VFA) concentration and pH.

The winter pasture treatment resulted in lower ($P < 0.05$) dry matter intake than the fodder beet treatment (Table 1). The microbial protein production was lower ($P < 0.001$) in the winter pasture diet, and the efficiency of microbial protein production (g N/kg DMI) was higher ($P < 0.05$) for the fodder beet treatment than the winter pasture treatment (Table 1). The pH recorded was higher for the fodder-beet treatment at most intervals, with a significant difference ($P < 0.001$) in digesta pH between the two diet treatments. In contrast to the winter pasture treatment, the fodder-beet treatment was observed to have very few recorded pH values below 5.8, largely maintaining pH in the range above 6.0. The winter pasture diet treatment had a higher mean VFA concentration, and a significantly higher ($P < 0.001$) VFA concentration at the 8 pm-10 am sampling period. Rumen ammonia was significantly ($P < 0.001$) lower in the fodder-beet treatment across the diurnal period, and rumen urea concentration significantly ($P < 0.01$) higher.

While rumen environmental conditions and the CP content of the fodder beet treatment were not optimum for microbial protein production, the efficiency of microbial protein production was higher for the fodder beet treatment than the winter pasture and there was no evidence of any reduced function. The increased urea and reduced ammonia concentration in the rumen may be indicators of a specific strategy of adaptation. The implications of high efficiency of N to microbial protein transformation in certain diets means further investigation of this area of N metabolism is warranted.

Table 1. The difference in average daily intake, CP %, microbial nitrogen production (MNP) and efficiency microbial nitrogen production between the diet treatments * ($P < 0.05$) ** ($P < 0.001$)

	Winter Pasture	Fodder Beet
Average Intake (kg DM/steer/day)	4.5	6.6*
Dietary Crude Protein %	16.3	14.1
Microbial Nitrogen Production (g N)	56.4	104.7**
Efficiency MNP (g N/kg DMI)	12.5	15.5*

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Pasture quality and animal performance in a pasture-fed finishing system

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The challenge for producers of pasture-fed cattle is to find the best genetics to suit their production system. In this study, steers of three distinct Angus genotypes (Lines A, B and C) with average liveweight (LWT) 370kg, 399kg and 400kg were sourced 6 January, 16 February and 10 March 2017 respectively and managed as one cohort, on rotationally grazed phalaris clover pasture swards on a commercial property at Table Top, NSW. Steers were finished to meet pasture-fed weight, fat and Meat Standards Australia (MSA) market requirements.

Pastures were sampled in May and September 2017 and analysed for metabolisable energy (ME, MJ/kg DM) and crude protein (CP, %DM). Liveweights of cattle were obtained within two hours of yarding. Average daily gain (ADG) was expressed in relation to average ME, CP and ME/CP in May and September. At finish, cattle were consigned in two consignments 21 days apart, 11 October and 1 November 2017. Data were analysed using an unbalanced analysis of variance (Genstat 18th edition).

Across the finishing phase pasture provided, on average, 11.8 MJ/kg DM and 26.5% CP. All lines grew at 1.2kg/d with average days to finish of 279, 238 and 216 for Lines A, B and C respectively for consignment 1 and 300, 259 and 237 days for consignment 2. Line C provided the lowest proportion of finished stock for the first consignment (Table 1). In May and September, Line B showed greater weight gain in relation to ME and CP than Lines A and C.

As the beef industry seeks to be carbon neutral by 2030 (Norton, 2017) producers finishing lines of cattle into pasture-fed markets should attempt to understand the production characteristics of different genetic lines of cattle as they relate to pasture characteristics of the farm system.

The current work shows that different lines of Angus cattle have different growth characteristics in relation to pasture energy, protein and the amount of energy relative to protein. Through grow out, those lines that provided the greatest proportion of animals into the first consignment generally showed higher weight gain response to pasture energy and protein levels. Further work should identify the basis for these different growth characteristics in order to predict future animal performance.

Table 1. Average entry weight at start, days to finish and proportion of animals in consignments

Line	Average entry weight (kg)	n	Days to finish consignment 1	Consignment 1	Days to finish consignment 2	Consignment 2
A	370	40	279	47.5%	300	52.5%
B	399	37	238	51.4%	259	48.6%
C	400	15	216	40.0%	237	60.0%

Table 2. Pasture energy and protein levels, average daily gain and gain in relation to pasture energy and protein

Month	Pasture			Cattle				
	ME MJ/kg DM	CP %DM	ME/CP	Line	ADG (kg/d)	ADG / ME	ADG / CP	ADG / ME_CP
May	12.1	22.3	0.54	A	1.36[a]	0.12[b]	0.062[a]	2.56[ab]
				B	1.64[b]	0.13[a]	0.073[c]	2.98[a]
				C	1.34[a]	0.11[b]	0.060[b]	2.48[b]
September	11.8	20.9	0.56	A	1.52[a]	0.13[ab]	0.072[b]	2.70[a]
				B	1.60[b]	0.14[a]	0.077[c]	2.83[a]
				C	1.33[a]	0.11[b]	0.063[a]	2.36[b]

[a,b,c]Significantly different within column and month.

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We gratefully acknowledge the support of NSW Department of Primary Industries in providing feed analysis.

Comparative body composition between Merino and maternal sheep breeds

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Optimum management guidelines for Merino ewes have been developed using whole farm economic modelling underpinned by equations for feed intake and energy use requirements from Australian Ruminant Feeding Standards (Young *et al.* 2011). Similar guidelines are being developed for non-Merinos ewes, which currently produce almost half of the current Australian lamb supply (MLA 2017). Recent work has demonstrated that these feed intake and energy use equations, may not accurately predict liveweight change in non-merino ewes. This could be due to differences in body composition between breeds affecting energy required for maintenance. Maternal sheep breeds (higher reproductive performance) tend towards higher proportions of fat in non-carcass depots (Butler-Hogg 1984). We predicted that maternal type ewes would be fatter than Merino ewes and will store more fat in the internal depots than Merino ewes and undertook an experiment to test this hypothesis.

Computerised axial tomography (CT) was used to determine differences in body composition between Merino and maternal Greeline ewes fed in confinement on either a maintenance or an *ad libitum* diet. Each breed by diet block contained 10 ewes. Helical scans at a slice thickness of 0.75mm were obtained rostral-caudally and then converted into images using a soft tissue algorithm and reconstruction kernel. Analysis was based on seven scan slides per ewe, a technique using anatomical waypoints as an accurate representation of whole body composition. Slides were demarcated for carcass and internal tissues (depot site), converted to pixels and categorized based on density. Pixels classified as fat or soft tissue (muscle and organ structures) were converted to cm^2 for each slide. Data was analysed using the mixed procedure in SAS with diet, breed, slide and depot site as fixed effects. First order interactions were included and removed if not significant ($P > 0.05$).

Maternal ewes had significantly more fat than Merino ewes ($P < 0.05$) and carried fat evenly between the carcass and internal depots, whereas Merino ewes preferentially partitioned fat towards internal depots over carcass depots ($P < 0.05$; Fig. 1*a*). The breeds were not different for area of soft tissue, however both breeds stored significantly more soft tissue within the carcass ($P < 0.05$). In addition, depot site interacted with breed so that the Maternal ewes had a significantly larger difference for storage between the carcass and internal depots ($P < 0.05$; Fig. 1*b*).

Our hypothesis that Maternal type ewes would carry more fat than Merino ewes was supported, however fat tissue was not preferentially partitioned towards internal depots as predicted. This study has implications for the development of management guidelines for non-Merino ewes. Condition scoring is a subjective measure of the fat and muscle tissue at the C site. Given that maternal type ewes have higher proportions of both fat and soft tissue deposited in the carcass, measurements such as condition scoring may not be consistent indicators of energy stores across breeds. Furthermore, given that the breed types are different for the proportions of fat carried internally and in the carcass, objective sub-cutaneous measures of fat are likely to be more accurate depictions of whole body fatness for maternal type ewes than they are for Merino ewes.

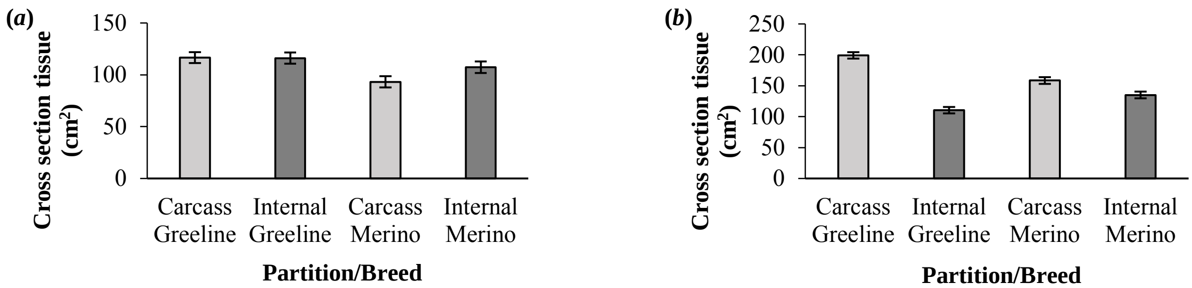

Fig. 1. Breed and Partition interactions for (*a*) fat tissue and (*b*) soft tissue depositions for Merino and Greeline ewes, and the distribution of tissue between carcass and internal tissue.

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Effect of maternal 25-hydroxyvitaminD3 and calcium supplementation on bone turnover in suckling lambs

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Bone mineralisation disorders are common in lambs where the rapid rate of bone development results in metabolic mineral imbalance (Benzie *et al.* 1960). Vitamin D deficiency may cause rickets, and the plasma concentration of vitamin D in lambs is closely related to vitamin D concentration of the ewe during pregnancy (Dittmer & Thompson, 2011). Feeding the metabolite 25-hydroxyvitaminD3 (25(OH)D3, commercialised as HyD®; DSM Nutritional Products) plus calcium (Ca) to wethers increased fractional excretion and reduced retention of Ca compared to vitamin D plus Ca, suggesting increased Ca turnover in the 25(OH)D3 supplemented sheep (Bhanugopan et al., *pers comm*.). The aim of this experiment was to determine if maternal supplementation of 25(OH)D3 to ewes during pregnancy and lactation influences bone turnover rates in their lambs.

In 2017 naturally joined Merino ewes (n = 120) were used in an experiment near Wagga Wagga in NSW. There were two periods of supplementation: ‘pre-loading’ (3–21 June) where pregnant ewes grazed one of six plots of a dry legume and grass pasture, and the lambing paddock (21 June – 19 September) where ewes grazed one of 12 plots sown to dual-purpose wheat. At any time ewes were provided access to an oral loose-lick of either a control supplement (including magnesium, salt and trace minerals) or a supplement that also included 25(OH)D3 (allocation 0.9 mg/head.day) and limestone (allocation 9 g/head.day). The 20 ewes that grazed together in each plot during the pre-loading period were randomly allocated to one of two plots in the lambing paddock, with one of these plots receiving the same supplement as during pre-loading, and the other plot receiving the other supplement. There were therefore four treatment combinations of supplementation period and supplement type: a) control supplement during pre-loading and lambing b) control during pre-loading and 25(OH)D3 during lambing; c) 25(OH)D3 during pre-loading and control during lambing; or d) 25(OH)D3 during pre-loading and lambing. Each treatment was replicated three times. Ewes and lambs remained in the lambing paddock until weaning and continued to receive their allocated supplement. Blood samples were taken from 40 twin-born lambs at marking (15 August; 26 ± 23 days old) and weaning (19 September; 61 ± 23 days old). Plasma osteocalcin (bone formation marker) and crosslaps-CTX-I (bone resorption marker) were analysed using kits (MicroVue™ Osteocalcin EIA kit, Quidel, Immuno Pty Ltd, Australia, IDS Serum Crosslaps ® ELISA (CTX-I), Abacus ALS, Australia). Data were analysed using linear mixed models with fixed effects for treatment and date and their interactions and a random effect of lamb within plot.

Osteocalcin and crosslaps-CTX-I measured in blood samples of lambs did not differ significantly (P > 0.05) between treatments at lamb marking or weaning (Table 1) suggesting maternal supplementation in late lactation did not affect lamb bone turnover. Osteocalcin did not differ significantly between marking and weaning (59.49 v. 58.31 ng/l), however lamb birth date was a significant term for osteocalcin levels (P = 0.002). Crosslaps-CTX-I was significantly higher at weaning compared to marking (0.283 v. 0.257 ng/l; P < 0.001), indicating lower resorption from bone and suggested increased bone mineralisation at weaning, however there was no treatment effect.

Table 1. Osteocalcin (Osteo) and crosslaps-CTX-I (Xlaps) (ng/ml) in plasma of twin-born lambs at marking (M) and weaning (W) when ewes were fed different supplement regimens during pre-loading and/or lambing. Standard error of the difference (sed) and P-values are for treatment x time interaction

	Treatment (‘pre-loading’-‘lambing’)					
	Control-Control	Control-25(OH)D3	25(OH)D3-Control	25(OH)D3-25(OH)D3	s.e.d.	*P*-value
Osteo (M)	61.39	59.65	58.75	57.99	1.76	>0.05
Osteo (W)	60.29	56.29	56.87	60.84		
Xlaps (M)	0.2452	0.2482	0.2566	0.2662	0.0130	>0.05
Xlaps (W)	0.2866	0.2800	0.2870	0.2760		

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Biomass production of typical forages in central Tibet

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Previous Australian Centre for International Agricultural Research (ACIAR) projects established that inadequate nutrition (energy and protein deficits) is the primary cause of poor livestock production in Tibet. Feed availability increases during the growing season (April-September), and generally reaches a peak in mid-to-late summer (August), before declining throughout autumn. Very little feed is available during winter and early spring. Consequently increasing forage quality and year-round availability for livestock is a top priority.

Seven annual forages were evaluated based on yield performance in Qunipa experiment station, located in an area typical of the cropping and agro-pastoral zones of central Tibet. Irrigated cropping is traditional practise in this zone; predominantly spring barley and winter wheat, with lesser areas sown to rapeseed and other crops. Annual precipitation is in the range 400-450 mm, with approximately 90% falling from June to September inclusive (Paltridge et al. 2009). Treatments were allocated to plots using a randomised block design, with four replicates per treatment. Each plot was approximately 3m x 3m, and represented a separate irrigation bay. Irrigation water was applied by hand spraying after sowing and subsequently by flood irrigation at regular intervals. A basal fertiliser application of composted animal manure was applied prior to sowing. Data was statistically analysed using ANOVA.

The results confirm the potential of cereal forage crops in this zone. Linna performed best, yielding 6577 kg DM/ha, which was significantly higher ($P < 0.05$) than any other treatment and 42% higher than the best next treatment, which was also an oat. Future research will include assessment of nutritive value to determine livestock production potential, and further evaluation of these species and varieties.

Table 1. Yield of different forage species grown in Tibet

Common name	Scientific name	Yield (kg DM/ha)
Oat cv Linna	*Avena sativa L.*	6577 ± 391.4 [a]
Oat cv White	*Avena sativa L.*	4622 ± 254.5 [b]
Common vetch cv Lanjian no.2	*Vicia sativa*	4117 ± 62.7 [c]
Oat cv Magnum	*Avena sativa L.*	4002 ± 94.9 [c]
Oat cv Qinghai444	*Avena sativa L.*	3594 ± 92.1 [d]
Chicory cv Sparta	*Cichorium intybus*	3568 ± 44.1 [d]
Sweet sorghum	*Sorghum bicolor*	1737 ± 78.3 [e]

Note: different letters indicate significant differences between different treatments ($P < 0.05$).

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The precision of the pepsin cellulase assay in predicting the *in vivo* digestibility of silage and hay

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The most important indicator of forage quality is metabolisable energy (ME) content which is routinely calculated either from *in vivo* or *in vitro* digestibility. For farmers who rely on this data to formulate rations and feed stock, laboratory errors that impact on precision can be costly can prove very costly. Experience in the United Kingdom (UK) and Europe has shown that digestibility estimates obtained for silage and hay vary with the laboratory, method used to determine digestibility and/or calibration equation when using Near Infrared Reflectance (NIR: Adamson and Givens, 1989). While a significant proportion of UK data has been developed using legume and ryegrass based silages and hays, the forage base used on Australian dairy farms for silage and hay production is considerably more diverse, with the majority of Australian feed testing laboratories relying on the pepsin cellulase (PC) assay, or NIR calibrations derived from this assay, for predicting silage and hay digestibility. The robustness of this assay for predicting the digestibility of a diverse range of silages and hays was examined in this study.

Dry matter digestibility (DMD) was measured in sheep at close to maintenance level of feeding for a diverse range of silages (n=24) and hays (n=16) at the Wagga Wagga Agricultural Institute and Hamilton Research Institute respectively. PC digestibility was determined on replicates of all *in vivo* samples using a modified technique of Aufrere and Demarquilly (1989). Samples were digested in acidified pepsin at 40°C for 24 hours, then heated to 80°C for 45 minutes and subsequently digested in a buffered cellulase solution at 40°C for 24 hours following the addition of 0.8 ml 1M $NaCO_3$.

Predicted mean PC DMD estimates for each hay and silage were obtained using the Restricted Maximum Likelihood Estimation (REML) directive and compared against actual *in vivo* DMD using the generalised linear regression within Genstat® ver 6, with separate regressions for hay and silage.

The PC technique more accurately predicted *in vivo* DMD for hays than silages.

Hay: *In vivo* DMD = 222.3 + 0.623 x PC DMD, r^2=0.75; s.e. =33.3

Silage: *In vivo* DMD = 240.8 + 0.607 x PC DMD, r^2=0.54; s.e. =33.6

Barber *et al*. (1990) reported similar results (r^2=0.55) for OMD of 122 grass silages determined by PC compared with *in vivo*.

Results of this study indicate that while the PC method can be accurately used to predict the *in vivo* digestibility of hays, care should be taken when testing silage quality.

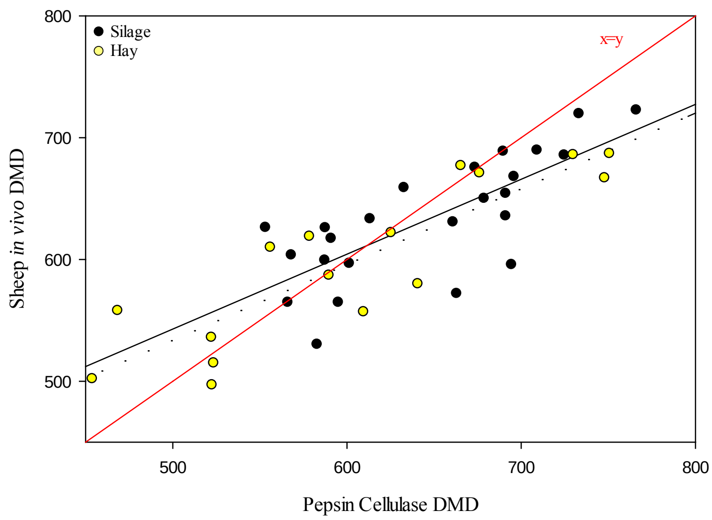

Fig. 1. Relationship between *in vivo* and pepsin cellulase DMD's (g/kg DM) for silages and hays.

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The work of the late A.G. Kaiser is gratefully acknowledged.

Digestibility differences between sheep and cattle fed silage based diets

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Metabolisable Energy (ME) content is the most important measure of forage quality for ruminants and can be calculated from apparent whole tract *in vivo* digestibility. However, ME is more commonly calculated from digestibility values determined *in vitro*, with the values adjusted back to *in vivo* by including standard feeds of known *in vivo* digestibility in the assay. Consequently, ME estimates rely on reliable estimates of *in vivo* digestibility for their prediction. Most of the *in vivo* standard feeds used to derive ME estimates for cattle feeds have been obtained from sheep, due to lower experimental costs and ease of handling; the assumption being that digestibility values are essentially similar for both species (Woods *et al*. 1999; Yan *et al*. 2002).

Twelve silages were fed to sheep and cattle in two experiments in consecutive two years (n=24) to test the validity of using sheep-derived silage digestibility estimates for cattle. Animals differed between years, and within years digestibility was determined consecutively in two cohorts of animals; with four silages fed in each of three consecutive periods. The silages covered a wide variety of forage types currently ensiled around Australia, including temperate and subtropical forages, and differed in level of maturity and weed contamination at harvest. Intake was restricted to 16.5 g/kg live weight and those silages with low nitrogen contents were supplemented with urea to meet minimum dietary crude protein requirements. *In vivo* comparisons were made for digestibility of organic matter in the dry matter (DOMD).

DOMD results from both experiments were combined and analysed using the Restricted Maximum Likelihood Estimation (REML) directive in Genstat® version 18. Species was the fixed effect; experiment and cohort, period and individual animal within experiment were the random effects. Separate estimates of digestibility were estimated for each cohort of each species for a regression analysis.

DOMD ranged from 0.505 to 0.762 and 0.539 to 0.702 for cattle and sheep respectively. There was no clear trend for cattle and sheep to digest silages differently, though significant species differences were observed for three silages in: subterranean clover silage, 0.631 vs 0.589; annual ryegrass/oats, 0.761 vs 0.702, and maize silage, 0.645 vs 0.691 for cattle and sheep respectively. $DOMD_{sheep}$ explained 78.4% of the variation in $DOMD_{cattle}$ (Fig. 1).

It was concluded that sheep-derived values for silage digestibility should, in most instances, be applicable to cattle when compared at restricted level of feeding. However caution should be exercised in extrapolating the data to *ad libitum* feeding scenarios, since differences may become apparent as has been shown in studies conducted by Sudekum *et al*. (1995) with wheat silages.

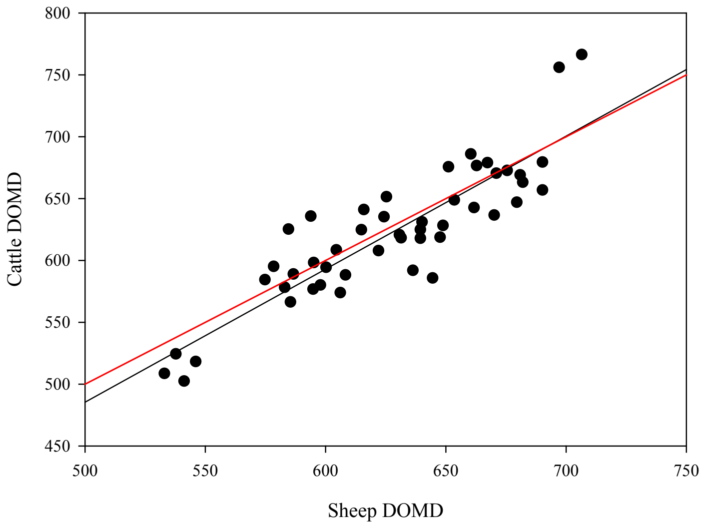

Fig. 1. Relationship between the digestible organic matter (DOMD) of silages in cattle and sheep (g/kg DM).

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Phosphorus supplementation of Brahman heifers in phosphorus deficient country in the NT

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Large areas of northern Australia are acutely Phosphorus (P) deficient yet Dixon *et al.* (2011) state that 'it appears that only a small proportion of cattle grazing P deficient pastures are supplemented or otherwise managed to alleviate P deficiency'. The low adoption of P supplementation suggests that many cattle producers are not convinced of its economic benefits and a contributing factor is likely to be that there are no published studies showing significant increases in pregnancy percentages from feeding mineral (dry lick) P supplements in northern Australia (Winks 1990; Dixon and Coates 2012). This study was conducted to determine the benefits of P supplementation of young Brahman females grazing P deficient country in the Northern Territory (NT).

Following weaning in June 2014, after stratifying for weight, 179 Brahman heifers were randomly allocated to either a +P (n=91) or –P (n=88) treatment (average weight: +P = 171.7 kg, –P = 171.2 kg). The treatments grazed separately in neighbouring paddocks at Victoria River Research Station that were determined to be acutely P deficient (average Colwell P soil test results: 2.5 and 3.1 mg P/kg) and they swapped paddocks in May each year. The treatments were managed in exactly the same way except that their mineral loose lick supplement either contained P (+P) or did not (–P). Weight (curfewed), BCS, hip height and P8 fat depth were recorded twice a year (usually in May and September/October). Heifers were mated for the first time (as 2 year olds) between 5/1/16 and 6/4/16. Pregnancy diagnosis was conducted on 24/5/16 and 14/9/16 using manual palpation and ultrasound to confirm non-pregnancy. Heifers calved in late 2016/early 2017 and were mated for the second time between 3/1/17 and 22/5/17. Calves were weighed and weaned on 23/5/17 and pregnancy diagnosis of heifers was conducted on 23/5/17 and 5/9/17.

There was no difference in growth during the dry seasons (May to October) of 2014 and 2015 but +P grew significantly more over the wet seasons of 2014/15 (+ 33.2 kg, $P < 0.001$) and 2015/16 (+33.3 kg, $P < 0.001$) so that the average weight of the +P treatment was 65.3 kg (54.1–76.6, 95% CI) heavier (+P = 391.8 kg, –P = 326.5 kg, $P < 0.0001$) after the first mating on 24/5/16. There was a 9.8% (4.4-23.9, 95% CI) higher maiden heifer pregnancy percentage for +P, which was not statistically significant (+P = 70.0%, –P = 60.8%, P=0.18). The pregnancy rate of +P was lower than expected considering their weight and so ovarian ultrasound scanning was conducted on 21/6/16 as part of investigations to determine the cause of this. It was found that a higher percentage of non-pregnant heifers were cycling (a corpus luteum present) in +P (+P = 55.6%, –P = 9.1%, $P < 0.01$), indicating that other factors (e.g. bulls, disease etc.) may have been responsible for lower than expected pregnancy rates in +P.

Foetal and calf loss between pregnancy diagnosis and weaning was similar in both treatments (+P = 20.6%, –P = 20.4%, $P = 0.98$). The average weight of lactating heifers was 119.6 kg (104.3–134.9, 95% CI) heavier in +P (+P = 381.8 kg, –P = 262.2 kg, $P < 0.01$), and the pregnancy rate in first lactation heifers was 24.9 (10.4-39.3, 95% CI) percentage points higher in +P (+P = 30.0%, –P = 5.1%, $P < 0.01$).

Seven –P and one +P heifer died between the start of the trial and weaning of the first calves at about 3.5 years of age. This difference in cumulative mortality rate (+P = 1.1%, –P = 8.0%) was statistically significant ($P < 0.05$). In addition, at the time of weaning of their first calves 18 –P heifers were removed from the study as they were considered to be at risk of mortality due to low body condition score. Including these heifers in the analysis gave a mortality/morbidity rate of 28.4% for –P heifers.

The average weaning weight of calves was 33.7 kg (21.0–46.4, 95% CI) higher from the +P treatment (+P = 172.3 kg, –P = 138.6 kg, $P < 0.01$). The total weight of calves weaned from the treatments was 3,072 kg higher in +P which when valued at the current price ($3.50/kg) was worth $10,751. The cost of supplement consumed was calculated to be $1,744.05 higher in the +P treatment.

P supplementation of Brahman heifers was observed to give substantial improvements in growth and reproductive performance in this study. Comparing the treatments, a return on investment of >600% was calculated when the extra cost of supplement provided to the +P treatment was compared to the value of the extra calves produced. When compared to implementing the –P treatment in the dry season only, the return on investment was 268% although a more comprehensive economic evaluation taking into account heifer mortality, re-conceptions, labour and the weight of heifers sold is required. The lack of documented positive responses to P supplementation of breeders in northern Australia (Winks 1990; Dixon and Coates 2012) and information on its cost effectiveness are likely to be major reasons for the low adoption to date. The large benefits from P supplementation found in this study may provide further incentive for increased adoption of P supplementation in P deficient areas.

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Supplementing grassfed steers with canola meal to determine live animal performance and carcase quality

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There is an increasing demand for Australian grassfed beef, however maintaining a consistent year round supply of product is a major concern for the grassfed beef industry. Due to seasonal variation in pasture quality, grassfed producers require supplements which are readily available, cost-effective, nutritionally adequate and are accredited under a grassfed beef program to maintain consistent animal growth rates. Canola meal is a by-product of the oil refining process which is readily available throughout southern NSW and is an approved Pasturefed Cattle Assurance System (PCAS) supplement (PCAS 2016). Supplementing with canola meal has also been reported by (He *et al*. 2013; Nair *et al.* 2015) as either a finishing or growing supplement. Therefore, the objectives of the current study was to investigate if supplementing canola meal compared to a grain based pellet in the finishing ration of beef steers whilst grazing on a low quality pasture would 1) alter growth rates and 2) maintain consistent carcase quality.

Forty Angus and Angus cross steers (471 ± 5kg) were randomly allocated between two treatment groups treatment 1, grain based pellets (n = 20, 4 pens) and treatment 2, expeller pressed canola meal (n = 20, 4 pens) in the Charles Sturt University feeding pens. The feeding period was for 60 days, with supplements initially fed 2.5 kg/head/day of the grain based pellet and 2.0 kg/head/day of canola meal. From day 28 the amount of canola meal fed was increased to 2.5 kg/head/day to balance energy content of the two treatment diets. Lucerne hay was fed *ad libitum* twice daily. Live weight and body condition score (BCS) of the steers were recorded every 14 days. Meat Standards Australia (MSA) data was measured. The mean carcase attributes, carcase weight and ADG were analysed using the MIXED model procedure in SAS statistical program. Change in BCS over time was analysed by repeated-measures analysis using the MIXED Model procedure and day 0 pre-treatment value, was the co-variate, calculated from the average of day –7 (induction weight) and day 0.

Average daily gain and BCS did not differ significantly between the two treatment groups (Table 1). Mean carcase weight of steers was significantly higher when the steers were fed the grain based pellet compared to canola meal (Table 1), potentially due to being fed a higher total energy ration for the first 28 days. All MSA carcase quality attributes did not differ ($p > 0.05$) when steers received canola meal or the grain based pellet.

This study has demonstrated that canola meal can potentially be used as a supplement to finish beef cattle whilst maintaining a PCAS status as there was no significant difference in growth rates or carcase quality.

Table 1. Average daily gain (ADG), BCS and carcase weight of steers fed for 60 days with lucerne hay (*ad libitum)* and either a grain based pellets or canola meal

	Diet[A]		
	Pellets	Canola Meal	*P*-value
ADG (kg/day)	1.46 (± 0.07)	1.34 (± 0.07)	0.233
BCS	3.38 (± 0.04)	3.29 (± 0.04)	0.117
Carcass weight (kg)	285.38 (± 4.36)	275.70 (± 4.36)	0.015

[A]Values are least-squares means ± standard errors of least-squares means after controlling for liveweight at Day 0 as a co-variate.

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The stage of development of *in vitro*-derived cattle embryos does not affect their survival or hatching rate following recovery from cryopreservation by vitrification

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In pursuit of the practice of assisted bovine reproduction over many years we have often observed anecdotally that some *in vitro*-derived cattle embryos develop faster than others within the same cohort. Recently, Asgari *et al.* (2012) and Carrocera *et al.* (2016) have indicated that the survival of bovine embryos following cryopreservation is influenced by their developmental rate. In contrast, Abdalla *et al.* (2010), demonstrated that expanded blastocysts collected on day 7 and day 8 did not affect the survival of embryos after vitrification. This raises the question, therefore, as to whether the stage or age of an embryo's development affects its survival post cryopreservation. Increased understanding of this physiological process may inform best practice in selection of *in vitro*-derived embryos for cryopreservation and for fresh embryo transfer, thereby enhancing the efficacy of *in vitro* fertilization technologies in cattle.

The purpose of the current study was to assess the effect of the developmental stage of *in vitro*-derived expanded bovine blastocysts on their survival and hatching rates following vitrification. Embryos were generated *in vitro* from oocytes aspirated from abattoir-derived ovaries and frozen bull sperm. A total of 112 expanded blastocysts were collected (56 each on days 6 and 7 post-insemination) and each was cryopreserved by vitrification using the standard cryotop method. After 5-10 months of storage in liquid nitrogen, embryos were warmed and cultured *in vitro* for 24 h in order to evaluate their re-expansion rates and for 48 h in order to examine their hatching rates. Our findings show that there were high survival rates of embryos, measured after 24 h, and no difference in hatching rates, measured after 48 h, regardless of the day they had been collected and vitrified (Table 1).

In conclusion, neither the survival nor the hatching rate of bovine expanded embryos was affected by the rate of embryonic development. Hence, expanded *in vitro*-derived blastocysts can be vitrified on either day 6 or day 7 with full expectation of good outcomes upon recovery from cryopreservation.

Table 1. The effects of stage of embryo development on tolerance to cryopreservation

Stage	Vitrified/warmed expanded blastocyst *n* (replicates)	24 h re-expansion rate *n* (%)	48 h hatching rate *n* (%)
Day 6	56 (4)	56 (100)	52 (92.9)
Day 7	56 (4)	56 (100)	49 (87.5)

Fisher exact test of independence was used to compare the age of embryos using the GraphPad Prism 5 software program, version 5.0c (GraphPad Software Inc., San Diego, USA).
There were no significant differences observed between d 6 and d 7 for either of the two variables ($P > 0.05$)

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The accuracy with which the age of bovine foetus can be estimated with trans-rectal sonography during a commercial scanning operation

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The ability to estimate the age of a bovine foetus with a high degree of accuracy is important in commercial and seedstock beef production. Relationships between the age of a foetus and Bi-Parietal Diameter (BPD, 'head diameter') in Angus cattle are available (Kramer *et al*. 2016). However, the accuracy with which the age of the foetus can be determined with a visual estimate of head diameter during a commercial operation, is not known. Our aim was to answer this question.

On 2 December 2015, 127 Angus heifers, 75 of which had been AIed, (Artificially Inseminated) after exhibiting a natural heat were scanned by operator 1. The exercise was repeated on 5 December 2016, by operator 2, with 88 heifers (54 of which had been AIed after exhibiting a natural heat). The dates of AI had been previously recorded. Examinations were conducted by means of trans-rectal sonography using SSD Aloka 500 machine with a UST-588U 5.0MHz linear array transducer and the operators aged every foetus.

The age of every foetus was estimated from a scale on the screen of the machine from which the BPD was estimated by visual reference of the BPD to the scale. Neither the date of AI, the identity of the AIed heifers nor the age of the foetus were available to the operators or data recorders until all scanning was completed. In due course the heifers were calved down and inspected daily, and birth dates were recorded for 70 heifers in 2016 and for 52 heifers in 2017. A small number of heifers failed to calve for natural reasons.

The difference between the actual and the estimated age of each foetus averaged 5.5 days (operator 1), 3.2 days (operator 2) and 4.4 days (combined). The percentage of age estimates that were within four days and seven days respectively of the actual age were 53% and 65% (operator1), 78% and 98% (operator 2) and 63% and 80% (combined). These results are consistent with the regression equations and R^2 values of, y = 1.263x – 17.16, R^2 0.78 (operator 1), y = 1.018x – 6.37, R^2 0.95 (operator 2) and y = 1.042x – 4.99 R^2 0.90 (combined). Regression analyses and R^2 values were obtained using the data analysis tools in Microsoft Excel.

The results show that bovine foetus can be aged very accurately, under commercial operating conditions, by experienced operators. This has important practical implications regarding fertility, a major profit driver in beef cattle production;

1. The number of days it takes for heifers, first calf heifers and cows to become pregnant after the introduction of a bull can be determined with accuracy. Commercial beef producers consider these females to be 'highly fertile'.
2. The accuracy of identifying conceptions to AI, Embryo Transfer (ET) or a backup bull and with natural joining, to put cows and heifers into groups for calving management, can be improved.
3. Highly accurate descriptions of the pregnancy status in sale animals can be provided.
4. Improved fertility EBV's may be possible. Days to calving which is used for calculating one of the fertility EBV's, conflates days to conception and gestation length. It is suspected that these traits do not have common causes and so should be selected for separately.
5. Ageing of bovine foetus can be achieved at a rate of throughput of up to 400 cows per 8 hour working day. The procedure has been used by commercial enterprises for several decades and is commercially viable.

However, each of the sonographers involved in this study have over a decade of practical experience. This raises the question as to how easily a high level of expertise can be available throughout the beef industry? In considering this question, it should be recognised that the echogram (image) produced by the head of a bovine foetus is strong and of a regular and essentially uniform shape and as such, lends itself to computerised measurement with Artificial Intelligence.

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Starch and protein supplementation to late gestation twin-bearing Merino ewes may alter colostral immunoglobulin G (IgG) concentration

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Colostrum for the newborn lamb is integral for survival. The lamb depends on nutrients within colostrum for energy and immunity transfer. Twin born lambs are often at risk of failure of immunity transfer following birth, with twins often having lower serum immunoglobulin concentrations due to reduced colostrum ingestion (Christley *et al.* 2003). Twin born lamb deaths often reach 30% (Hinch and Brien 2014), much higher than single born lamb deaths, possibly associated with inadequate colostrum production resulting in deaths due to failure of immunity transfer. Twin bearing ewes are under high nutritional demand in late pregnancy with demands for foetal growth and colostrum production being greater than her likely dry matter intake from forage, as rumen volume is limited by the growing foetuses (Owen and Ingleton 1963, Banchero *et al.* 2004). Supplementation for several weeks prior to lambing with starch increased colostral IgG concentration (O'Doherty *et al.* 1997) and bypass protein feeds increased IgG yields (O'Doherty and Crosby 1996). However, long term supplementation is costly and time consuming, so Banchero *et al.* (2009) provided single bearing ewes with protein and starch for 14 days prior to parturition, but supplementation did not affect IgG, which may have been because single bearing ewes are under less nutritional stress, and ewes refused some supplement. Short term bypass protein and starch feeding to twin bearing ewes pre-lambing may increase colostral IgG concentration compared to supplementing starch only.

Forty-two synchronised, artificially inseminated twin bearing mixed age Merino ewes grazing natural pastures, (and unlimited oaten hay when pasture was limiting) were randomly allocated to one of two treatments: (1) Control: 600g/head.day barley or (2) Supplemented: 600g/head.day barley and 120g/head.day canola meal. Three replicates of each treatment and ewes were fed in groups of 7, with all supplement being consumed. Ewes were supplemented for 7 days prior to expected lambing (plus a 13-day introductory period). Supplementation ceased 4 days after the last lamb was born. Ewes were condition scored (CS) at the start and completion of the experiment. A colostrum sample was obtained from the ewes within 6 hours of lambing and tested for lactose, protein and fat, and IgG concentration was quantified using a commercial ovine-specific ELISA assay. Two ewes and their lambs were removed from the dataset prior to analysis as one ewe had triplets (supplemented) and one ewe had an enlarged udder (control). Data were analysed using linear mixed modelling with replicate as the random effect.

The CS of ewes in both treatments increased over the experimental period. CS change by treatment displayed a non-significant trend (P = 0.092) with control ewes gaining 0.1 ± 0.09 and supplemented ewes gaining 0.3 ± 0.09 CS over lambing. The colostrum variables are presented below (Table 1). There were no significant differences between the two treatments; however, supplementation with barley and canola meal led to an 18% numerical but non-significant increase in colostral IgG concentration. Given individual supplement intakes likely varied significantly, resulting in variable responses between ewes, supplementation of late gestation twin bearing Merino grazing ewes with protein and starch may increase colostral IgG concentration, with further investigation required using more ewes and controlled intake to test the effect of supplement on IgG production and yield.

Table 1. Effect of control vs supplemented diet on colostrum quality before 6 hours post lambing

	Control (mean ± SE)	Supplemented (mean ± SE)	P-value
Colostrum Fat (%)	10.59 ± 0.485	10.66 ± 0.499	0.919
Colostrum Protein (%)	11.16 ± 0.437	10.72 ± 0.450	0.487
Colostrum Lactose (%)	4.46 ± 0.103	4.58 ± 0.106	0.445
Colostrum IgG (g/L)	137.39 ± 17.791	162.27 ± 17.791	0.243

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Estimating days to insemination in Angus heifers

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The number of days elapsing between the introduction of a bull to a mob of cows and when a cow is successfully mated is a simple measure of the fertility of a cow under natural mating conditions. We estimate this period in two ways, one using foetal age and the other 'gestation length'. This information can be collected at low cost in the normal management routine of a seedstock herd. Our aim is to estimate the errors associated with each method.

On 2 December 2015, 127 Angus cows (74 of which had been AIed after exhibiting a natural heat) were scanned by sonographer 1. The exercise was repeated on 5 December 2016, by sonographer 2, with 88 cows (54 of which had been AIed after exhibiting a natural heat). The dates of AI had been previously recorded. Examinations were conducted by means of trans-rectal sonography using SSD Aloka 500 machine with a UST-588U 5.0MHz linear array transducer and the sonographers aged every foetus Neither the date of AI, the identity of the AIed cows nor the age of the foetus were available to the sonographers or data recorders until all scanning was completed. Heifers were inspected daily during calving and birth dates recorded for 70 heifers in 2016 and for 53 heifers in 2017. A small number of heifers failed to calve for natural reasons.

The four dates of importance in our calculations are: A. Date of Bull In. This is generally known. In our case it was assumed to be the first day of insemination – August 29 in 2015 and September 2 in 2016; B. Date of Insemination. This is generally **not** known. In our case it is the date of AI; C. Date of Pregnancy Test. This was December 2 in 2015 and December 5 in 2016. Ages of foetus were estimated on this day and recorded as discussed and D. Date of Birth of calf. For example, heifer (NXOJ660) was inseminated on 13/09/2015, 15 days after the start of joining. The age (since insemination) of the foetus was therefore 88 days. She calved on 12/06/2016.

Foetal Age was estimated to be 80 days implying insemination on 05/09/2015 and a period of 7 days from Bull In to Insemination. The error in this estimate of days from Bull In to Date of Insemination is 8 days. An alternative estimate can be made using the Date of Birth. The average period from date of insemination to date of birth ('Gestation Length' as defined by Breedplan) is 279 days for this group of animals. NXOJ660 calved on 12/06/2016, implying Insemination on 07/09/2015 and 9 Days to Insemination. The error in this estimate of the Days to Insemination for NXOJ660 is 6 days. The calculation above was made for all the heifers.

The average (unsigned) error of the estimates of Days to Insemination, based on estimated Foetal Ages, was 5.4 days for the animals tested in 2015, 3.2 for those tested in 2016 and 4.4 for all the animals. The average (unsigned) error of the estimates of Days to Insemination, based on the average 'Gestation Length' of 279 days in 2015 and 276 days in 2016, was 3.4 days for 2015, 3.2 for 2016 and 3.4 for all the animals. The Gestation Length estimate was more accurate than the Foetal Age estimate in 2015 but they were of the same order of accuracy in 2016. We conclude that the errors in the two methods of estimation are sufficiently small and independent to justify collecting both pieces of information and our reasons for this are listed (1 to 4) below. We found that there is little relationship between the errors in the two methods of estimation.

We ran a simple two variable regression equation with Days to Insemination as the dependent variable and the two estimates of Days to Insemination as independent variables. Estimates using this equation were more accurate in 2016, though not in 2015 or the combined data set. The average unsigned error for the estimates of Days to Insemination in 2016 using the regression equation was 1.8 days. The range of the errors of estimates of Days to Insemination from this equation was –6 days to +7 days, (2 weeks), and within +/- 3.5 days for 45 of the 53 inseminations.

1. Fertility is a major profit driver in beef cattle production. The costs of low fertility seem to be masked by adjusting the date of calving to achieve a high proportion of early calves.
2. Date of birth is usually recorded in seedstock enterprises. Pregnancy testing is also usual and could easily be extended to include aging of foetus.
3. Days to Insemination can be estimated using both pieces of information simultaneously. Estimated Breeding Values for Days to Insemination and 'Gestation Length' would allow selection for both these important attributes.
4. The accuracy of foetal aging will only increase over time and it could be to the net benefit of the beef cattle industry to make this happen more (rather than less) rapidly.

Flushing ewes on green feed at joining can increase conception and reproduction rates

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Providing ewes with nutritional supplementation prior to joining, termed as 'flushing', can improve lambing percentage through an increase in ovulation rate. The aim of this project was to demonstrate and validate on commercial farms using grazing management 'typical' to those farms, the research conducted by Robertson *et al.* (2014 and 2015) that showed reproductive advantages from flushing ewes short term and throughout joining on green feed.

Agriculture Victoria established a total of 32 commercial farm demonstration sites in Victoria, New South Wales and South Australia between 2013 and 2017. The project aimed to investigate the effects of short term flushing with green feed (including lucerne) or lupins, and long term flushing with lucerne, on ewe conception (ewes scanned pregnant per 100 ewes joined) and reproductive rates (lambs scanned per 100 ewes joined) compared to ewes grazing typical dry pasture traditionally used during joining at individual demonstration sites.

Over 22,000 ewes (n = 600–900 crossbred, composite or merino ewes per demonstration site) were joined between late December and March over a five year period for an autumn/winter lambing. The ewes were divided randomly between the following treatments; Phase 1 (2013–2014; 22 sites): (1) Control: graze typical dry pasture available throughout joining; (2) Short Flush: graze any green feed source one week prior to joining and one week into joining; (3) Control Plus Lupins: graze typical dry pasture plus supplement with lupins for one week prior to joining and one week into joining; Phase 2 (2015–2017; 10 sites): (1) Control: graze typical dry pasture available throughout joining; (2) Short Flush: graze lucerne one week prior to joining and one week into joining; (3) Long Flush: graze lucerne one week prior to joining until the end of joining or for a minimum of five weeks. Ewes were identified using electronic identification tags, condition scored and weighed at the start of their treatment, weighed 2 weeks later, and in phase 2 at the end of joining. Pasture samples were collected for quality analysis and paddock feed on offer assessed. Pregnancy scanning results were obtained.

The results showed a reproductive rate advantage for the Short Flush on green feed compared to the Control. Twenty of the 22 commercial properties in Phase1 displayed an increased reproductive rate on green feed. Of these 20 sites, 13 had a statistically significant increase ($P < 0.05$) in reproductive rate ranging from 10 to 33 more lambs scanned per 100 ewes joined, compared to the Control. Conception rates were analysed from 2014-2017 and significantly increased ($P < 0.05$) on the Short Flush for five of 23 sites, ranging from 4 to 13 extra pregnancies per 100 ewes joined, compared to the Control. Two of eight sites showed 5 extra pregnancies per 100 ewes for ewes on a Long Flush compared to the Control.

Ewes in the Control Plus Lupins treatment responded with a significant increase ($P < 0.05$) in reproductive rate at five of the eight sites ranging from 8 to 21 more lambs scanned per 100 ewes joined compared to the ewes in the Control. However this response was not as high as the ewes in the Short Flush treatment.

In Phase 2, three of the eight sites with a Control treatment showed a statistically significant ($P < 0.01$) reproductive rate advantage in ewes in the Long Flush treatment ranging from 16 to 47 more lambs scanned per 100 ewes joined compared to the Control. Furthermore three of ten sites recorded a statistically significant ($P < 0.01$) reproductive rate advantage in ewes on the Long Flush over the Short Flush. At all sites the Long Flush ewes pregnancy scanned a similar or at three sites statistically higher ($P < 0.05$) number of foetuses per ewe joined compared to the Control or Short flush ewes.

Reproduction rate in Short and Long Flush ewes was largely influenced by ewes producing more twin foetuses. Overall there were significantly more pregnant ewes at some sites; however this was less of an influence than reproduction rate.

This project showed that flushing ewes by providing a green feed source one week prior to joining and one week into joining can improve lambing percentage through an increase in multiple ovulations and ewes pregnant. The data suggests there is no negative impact on ewe conception or reproduction rate at these sites when grazing on lucerne throughout joining compared to a short flush or grazing on typical dry pasture. As lucerne is almost always a scarce resource at joining time, producers should understand the relative value of using lucerne for other purposes (e.g. finishing lambs or growing out weaners) before allocating it to ewes at joining.

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Changes in serum insulin-like peptide 3 and testosterone concentrations in male sheep during development

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Insulin-like peptide 3 (INSL3) is a major secretory product of Leydig cells in testes (Ivell and Bathgate 2002). Along with testosterone, serum INSL3 concentrations have emerged as an *in vivo* marker of Leydig cell maturity and function (Bay and Andersson 2011). However, circulating INSL3 profile is yet to be investigated in male sheep. The present study was carried out to: (1) modify the existing enzyme immunoassay (EIA) to measure INSL3 in sheep serum (2) investigate the changes in serum INSL3 and testosterone concentrations in male sheep during development at pre-pubertal, pubertal and post-pubertal ages.

Blood samples were taken from normal, male sheep (n = 83) in four age groups (group I, 3–6 months; group II, 6–12 months; group III, 12–24 months; group IV, 24–36 months). Serum INSL3 was measured using a homologous bovine EIA as described previously, with modifications (Kawate *et al.* 2011). Testosterone was also measured in same samples using an EIA (Kawate *et al*. 2011).

The minimum detection limit of the INSL3 assay was 0.08 ng/mL and the detection range was 0.08–80 ng/mL. Serum INSL3 concentrations increased ($P < 0.01$) continuously with age, i.e., from group I to group IV (Fig. 1A). Serum testosterone concentrations were not different ($P > 0.05$) between group I and group II, but increased ($P < 0.05$) from group II to group IV (Figure 1B). These results showed a sustained increase in INSL3 concentrations from group I to group IV, but the pattern of testosterone increase differed during early age. Significant positive correlations (Spearman's r) were observed between INSL3 and testosterone concentrations ($r = 0.63$, $P < 0.0001$), INSL3 concentration and body weight ($r = 0.75$, $P < 0.0001$), testosterone concentration and body weight ($r = 0.75$, $P < 0.0001$); during overall study period, circulating INSL3 and testosterone concentrations showed a similarity in release patterns of the two hormones of Leydig cell origin.

In conclusion, a rapid and highly sensitive EIA was developed to quantify INSL3 in sheep by modifying an existing EIA procedure. Different INSL3 and testosterone dynamics were found during early age of male sheep. Circulating sheep INSL3 concentrations seem to better reflect Leydig cell maturation especially during pre-pubertal and pubertal ages.

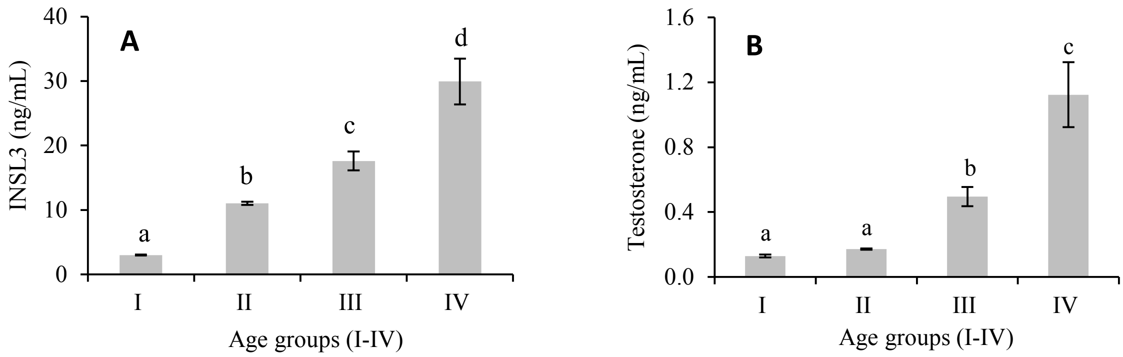

Fig. 1. Mean ± SEM serum insulin-like peptide 3 (A) and testosterone (B) concentrations in male sheep during development at pre- and post-pubertal ages. Data are for group I (3–6 months, $n = 18$), group II (6–12 months, $n = 22$), group III (12–24 months, $n = 21$) and group IV (24–36 months, $n = 22$).[a-d]Within a hormone, means without a common superscript differed ($P < 0.05$).

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Productivity of a beef twinner herd in Western Victoria

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A multi-breed composite selection line for twinning was developed at the US Meat Animal Research Center (USMARC) (Reviewed Cummins *et al*. 2008). This report covers the use of these cattle on a commercial, predominantly sheep plus beef farm in Western Victoria over the period 2013–2017. This herd is calving in autumn, weaning in November with weaners sold in January, with twins and singles managed together. The steers gain about 25 kg after weaning and go into the regional weaner sales and seem to fit within the range of weights seen in other producers' cattle. Calving is managed in a drift system with twice daily inspection to provide assistance at birth and for the first couple of days as required. The operator feels he could handle a herd at least twice as large within the limitations of other farm duties and resources. We have previously presented data on conception rates in this herd (Cummins *et al*. 2015) and note that breeding herd structure can be optimised by pregnancy testing. For this reason we are presenting data here based on the number of cows calving.

The herd reproductive performance is shown in Table 1. Poor results in 2016 may relate to severe drought conditions, from mid pregnancy until the start of mating. The selection at USMARC has produced a line of cattle which produce twin calves, however calf mortality in our herd seems higher than reported at USMARC (Cummins *et al*. 2008) and needs to be improved. In normal beef herds in USA the average calf mortality is 6.5% (APHIS 2010), no current report for our region was seen. Thus we assumed that a normal beef herd in our region might have a calves weaned per cow calving of 0.94 which could be compared with our twinner herd of 1.14, i.e. our herd is 21% higher than the normal expectation.

The average weaning weight of calves born as singles within this herd was 311 kg (SD 45) and for twins it was 267 kg (SD 43) with an overall average of 290kg (SD 49). Twin born weaners weighed 86% of the single born calves. The weaning weight per cow for our herd is $1.14 \times 290 = 331$Kg. If we assume that a conventional herd had the same weaning weight as our singles then the comparable weaning weight per cow is $0.94 \times 311 = 292$ kg giving the twinners an advantage of 13% per cow. Graham *et al*. (1990) showed that cows suckling twins had a 20% higher energy requirement than cows with singles. In our herd with 22% rearing multiples then this twinner herd of 100 cows has the same requirement as 104 normal cows so on an equivalent grazing pressure basis the twinner herd still produces 331 kg while the normal herd produces $1.04 \times 292 = 304$ kg which is still an advantage of 9% to our twinner herd.

The USMARC selection has exposed variation which now needs to be worked on for further improvement.

Table 1. Reproductive performance of twinner cows on a farm in Western Victoria where 25% of the herd are first calf heifers

	2013	2014	2015	2016	2017	Total/Average
No Cows	56	82	77	73	72	360/72
Calves Born/Cow calving	1.36	1.24	1.44	1.47	1.40	1.33
Calves Weaned/cow calving	1.25	1.11	1.14	0.99	1.24	1.14
Calf mortality	8%	11%	21%	33%	12%	14%

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Liveweight profile during the reproductive cycle influences carryover reproductive rate in maternal type ewes

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The profitability of Merino based sheep production systems is optimised at a stocking rate that enables efficient utilisation of grown pasture and supplements and provides adequate nutrition for breeding ewes (Young *et al.* 2011). Ewe nutrition impacts her wool production, reproduction and mortality and the survival, growth and lifetime wool production of her progeny. In 2016 and 2017, 31% of the breeding ewes nationally were non-Merino ewes (pure breed, first and second cross, and composite ewes) and they produced around 48% of the slaughter lambs (MLA April 2017). The changing demographic of the ewe flock has contributed to increased marking rates over the last decade of ~1% per annum, however there is still potential to improve the management and productivity of non-Merinos in the national flock.

At four sites across Australia and in each of two years, flocks of 500-800 non-Merino adult ewes were managed to a range of condition score targets during pregnancy. In the second year the ewes also grazed different levels of food on offer during very late pregnancy and during lactation. After weaning in both years and up until pregnancy scanning in the following year, all ewes were managed as one flock at each site. Liveweight and condition score profiles were monitored during the reproductive cycles. The full details of these experiments including treatment effects on ewe liveweight, condition score, lamb birth and weaning weights and survival are reported in Hocking-Edwards *et al.* (2018), Behrendt *et al.* (submitted) and Thompson *et al.* (submitted).

Carryover reproductive rate (number of foetuses per 100 ewes scanned, expressed as a percentage; RR) was analysed using General Linear Models with a multinomial distribution and logit link function with previous years birth type as a fixed effect and ewe liveweight at joining as a covariate. A second model included liveweight change during pregnancy, liveweight change during lactation and liveweight change between weaning and joining along with birth type and ewe liveweight at joining. Site, year and experimental units within site and year were adjusted for within the model.

Joining liveweight had a significant effect on RR. At 60kg, the RR was 124.6% for ewes that had previously born single lambs and 138.9% for ewes that had previously born multiples. An extra kg of liveweight at joining delivered a 1.3% increase in RR for both previous birth type classes ($P < 0.001$).

Liveweight change during each phase of the previous reproductive cycle and previous birth type were significantly associated with carryover RR. On average, a 1 kg gain of conceptus free liveweight during pregnancy delivered an extra 2.1 lambs per 100 ewes joined ($P < 0.001$). This compared to an extra 1.8 lambs per 100 ewes joined ($P < 0.001$) or 1.2 lambs per 100 ewes joined ($P < 0.001$) when these same gains in liveweight occurred during lactation or in the period between weaning and joining in the following year. The effects of liveweight change during each phase on RR were linear across a wide range of liveweight gain and loss and did not interact. The effects of changes in liveweight on subsequent reproductive rate were also smaller for ewes that had previously carried multiple foetuses.

The impact of adequate nutrition during pregnancy and lactation has well-recognised outcomes for lamb survival and growth to weaning. However, mis-management of liveweight profiles during the previous pregnancy and lactation, regardless of liveweight at joining, can have additional effects on carryover reproduction. Improving our management of liveweight profiles will contribute to increasing the national marking rate and will need to be accounted for in whole farm models to determine the optimum management of ewes in different environments and seasons.

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Factors affecting the embryo yields and quality in ewes indigenous to Bangladesh

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Multiple ovulation embryo transfer (MOET) has the potential to speed up genetic improvement by increasing selection intensity through the female line, enabling them to have more offspring than would be possible naturally. Several factors such as type of synchronizing agent, choice of gonadotrophin and mating system have been associated with embryo yield, quality and success of MOET in sheep (Bari et. al., 2000; 2001). No research on MOET in sheep has been done in Bangladesh. Therefore, this experiment was undertaken to observe the factors affecting the embryo yields and quality within MOET program in indigenous ewes in Bangladesh. All donor and recipient ewes were synchronized by injecting Cloprostenol (175 μg) nine days apart or by inserting intravaginal sponges impregnated with Fluorogesterone acetate (FGA; 45 mg) for 12 days. Donor ewes were superovulated by injecting either Pregnant Mare Serum Gonadotrophin (PMSG) or Porcine Follicular stimulating Hormone (pFSH). Oestrus donor ewes were mated naturally or laparoscopically inseminated. The embryos were recovered by semi-laparoscopic method on Day 5 or 6 following insemination. The mean number of embryos recovered (6.9±0.28) and embryo recovery rate (73.9%) was significantly higher (P<0.05) in ewes given FGA than Cloprostenol. The mean number of embryos recovered (9.0±0.45) and embryo recovery rate (77.9%) with pFSH were higher than with PMSG (P<0.001). The ewes breeding by laparoscopic insemination showed significantly higher (P<0.05) fertilization rate compare to natural mating (Table 1). Though there was no significant difference between the groups on grade1 embryo yields, the highest proportion of degenerated embryos were found in cloprostenol treated ewes. The best synchronization agent for the recovery of acceptable numbers of normal embryos may be FGA. FSH is the choice of gonadotrophin for induction of superovulation in indigenous ewes. However, PMSG may be acceptable due to its low cost and easy availability in Bangladesh.

Table1. Effects of different synchronizing and superovulatory agents and mating systems on responses within MOET in indigenous ewes

	Synchronizing agents		Superovulatory agents		Mating method	
Parameters	Cloprostenol	FGA Sponge	PMSG	pFSH	Natural	Laparoscopic
ER/Donor (Mean± S.E.)	3.4±0.34[b]	6.9±0.28[a]	4.0±0.18[b]	9.0±0.45[a]	5.6±0.24[b]	6.2±1.93[a]
ERR (%)	65.3[b]	73.9[a]	56.1[b]	77.9[a]	74.29[b]	72.09[a]
% FO	96.1[a]	100[a]	96.9[a]	100[a]	87.0[b]	96.8[a]
Grades of Embryos						
Grade 1	93.1 [b]	100[a]	91.4[a]	94.5[a]	92.3 [a]	97.3 [a]
Grade 2	2.2	–	6.5[a]	5.5[a]	6.0	1.7
Grade 3	–	–	–	–	–	–
Grade 4	1.0	–	1.6	–	1.2	1.0
Grade 5 Unfertilized/Degenerated	4.2	–	0.5	–	0.5	–

[a,b]Values with different superscript letters within each row are significantly different (at least *P* < 0.05).
ER, embryos recovered; ERR, embryo recovery rate; FO, fertilised ova

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Management of anestrus and repeat breeding cows and heifers raised in *Char* areas of Bangladesh

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Profitability of dairy cow rearing relies heavily on good reproductive efficiency and milk production. Certain goals should be achieved for efficient reproductive performance. The main limitations of efficient and profitable reproduction are anoestrus and repeat breeding. In Bangladesh 40% of postpartum cows remained undetected in oestrus when they completed one or more ovarian cycles (Shamsuddin *et al*. 2001). As a result, alternative approaches are tried. Hormone treatment with fixed-time artificial insemination (AI) has been developed elsewhere (Peters et al., 1999). The commonly used hormonal protocol in lactating anoestrus cows is ovulation synchronization (Ovusynch). Hormone treatments in repeat breeder cows are generally used to synchronize their oestrus cycles. There has been previous studies investigating hormone treatment in anoestrous and repeat breeder cows in Bangladesh, but ovusynch is rarely used. However, in *char* areas (Low lying flood and erosion-prone areas in or adjacent to major rivers), there is no report on the use of oestrus synchronization followed by fixed-time AI in indigenous cows. Therefore, this study was designed to manage reproductive problems with an aim to improve reproductive performance in *char* areas. A total of 300 households were investigated to explore the reproductive problems based on rectal palpation and history of unobserved oestrus more than 60 days postpartum and delayed puberty at or more than 24 months in heifers. The cyclic cows and heifers were treated with ovusynch protocol, a single injection of GnRH (gonadorelin®, 0.5 mg, 5 mL) intramuscularly. Ten days after GnRH administration, a single injection of dinoprost tromethamine (Lutalyse®*Pfizer* Animal Health; Belgium) was injected intramuscularly (25 mg, 5 mL). The cows were inseminated at 70 and 90 hours after dinoprost injection and a single dose GnRH was given immediately after first AI. A total of 225 (31%) cows and heifers were identified with reproductive problems. Twenty-seven (67.5%) cows and 31 (86%) heifers showed oestrus in response to ovusynch protocol after an average of 68–70 hours. Significantly ($P < 0.05$) higher proportion of heifers showed oestrus than cows. Pregnancy rate (52.5%) in cows was not significantly higher than in heifers (47.2%) confirmed by rectal palpation 60–80 days after service (Table 1). Thirty-nine repeat breeding cows were treated with dinoprost tromethamine (25 mg, 5 mL). A second injection was given at day 10. AI was performed at 70 and 90 hours after the second $PGF2\alpha$ injection. A single injection of 0.1 mg (1 mL) GnRH analogue was given immediately after first service. In repeat breeding cows pregnancy rate (30.8%) was significantly higher following treatment with dinoprost tromethamine than control group (without any treatment) (Table 2). This result showed that indigenous cows and heifers could be treated with oestrus synchronization protocols and fixed-time AI for higher pregnancy rate. Treatment of repeat breeding cows with dinoprost tromethamine and GnRH may improve pregnancy rate.

Table 1. Effect of ovusynch protocol on oestrus response and pregnancy rate in repeat breeder cow

Anoestrus Animal	No. of animal showed to oestrus	% of oestrus response	No. pregnant	Pregnancy rate (%)
Cows (n=40)	27	67.5^a	21	52.5^a
Heifers(n=36)	31	86^c	17	47.2^c

The superscript values within the same column differ significantly ($P < 0.05$).

Table 2. Effect of PGF2α and GnRH on pregnancy rate in repeat breeder cow (RB)

Groups	No. of Repeat Breeder	No. of Pregnant cow	Pregnancy rate (%)
Treated	39	12	30.8^a
Control	16	1	6.0^b

^{a,b}The values differ significantly ($P < 0.05$)

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Productivity of Bali cattle bulls based on scrotum size, bodyweight and feed consumption

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Bali cattle play important roles as the producer of services and products that are useful for the purpose of human life; and are a national asset in the agriculture sector, so their existence needs to be conserved (Anonymous 2011a), and the productivity of the population increased (Anonymous 2011b). The purpose of this research was to quantify the relationship between scrotum size and bodyweight in Bali cattle, and quantify the nutrient composition of common feedstuffs. The research used 30 Bali cattle bulls from three regencies in West Nusa Tenggara Province (Lombok Tengah, Lombok Barat and Lombok Utara Regency), on average three years old, divided into three groups based on scrotum size, i.e. K1 = Smallest; K2 = medium and K3 = largest scrotum size.

The quality of the feed commonly used in the regions was measured by proximate analysis (dry matter, organic matter, crude protein, crude fat and fiber, TDN). Daily feed intake in bulls was recorded.

Common feedstuffs ranged in nutritive value from being a below maintenance feed source (e.g. soybean straw) to a feedstuff that alone may support a moderate level of growth (e.g. Cassava waste) (Table 1). Intake of TDN was higher for bulls in the LoBar region (Table 2). Bali cattle bulls in the LoBar Regency had the biggest scrotum length (SL) = 20.38 ± 2.19 cm and diameter (SD) = 10.33 ± 2.05, as well as body weight (Table 3), which may have been related to their nutritional management. This requires further investigation.

It is concluded that improved nutritional management likely increased bull weight and scrotum size, which should have implications for their fertility.

Table 1. The quality of feeds (%)

Feed	Condition	DM	OM	CP	Fat	CF	TDN
Elephant grass	Fresh	11.9	77.9	8.4	1.6	29.4	56.3
Field grass	Fresh	20.7	83.5	5.2	2.3	30.9	55.9
Rice straw	fresh	41.1	67.0	6.8	1.5	23.4	45.6
Rice straw	dry	61.6	67.0	6.3	0.3	30.4	69.9
Corn straw	Fresh	19.8	82.5	15.7	1.3	22.8	64.1
Corn straw	dry	36.5	79.9	10.5	0.6	29.9	62.7
Cassava waste	fresh	11.5	82.7	20.2	2.6	19.9	65.5
Soybean straw	dry	90.1	83.8	4.2	1.9	45.4	49.7

DM = Dry Matter, OM = Organic Matter, CP = Crude Protein , CF = Crude Fiber, TDN = Total Digestible Nutrients.

Table 2. Nutrient consumption of Bali cattle bulls (kg/head/day)

Locations	Dry Matter	Crude Protein	TDN
Lombok Tengah Regency	3.8–4.4	0.4–0.5	2.1–2.6
Lombok Utara Regency	5.0–6.3	0.5–0.7	2.5–3.5
Lombok Barat Regency	7.4–9.2	0.61–0.67	3.9–4.9

Table 3. The average of scrotum size of Bali cattle bull from each group

Groups Size	Lombok Tengah Regency			Lombok Utara Regency			Lombok Barat Regency		
	SL (cm)	SD (cm)	BW (kg)	SL (cm)	SD (cm)	BW (kg)	SL (cm)	SD (cm)	BW (kg)
K1 (Smallest)	14.93 ± 1.25	6.00 ± 1.34	215.20 ± 5.90	14.67 ± 0.58	6.90 ± 0.00	220.30 ± 8.55	15.60 ± 1.51	7.55 ± 0.00	335 ± 23,87
K2 (Medium)	16.75 ± 0.59	7.67 ± 0.21	233.00 ± 8.22	16.50 ± 0.58	7.58 ± 0.39	242.00 ± 34.09	17.45 ± 0.07	8.40 ± 0.00	385.00 ± 37,61
K3 (Biggest)	20.00 ± 3.28	8.48 ± 0.44	251.00 ± 8.18	19.00 ± 1.00	8.48 ± 0.29	285.00 ± 39.34	20.38 ± 2.19	10.33 ± 2.05	465.00 ± 37,01

Note: Score SL (cm): Biggest = ≥18; Medium = 16–17.9; Smallest = 12–15.9.
SD (cm): Biggest = ≥8; Medium = 7–7.9; Smallest = 4–6.9

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Rectal temperature of Merino ewes differs between two bloodlines

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Severe heat stress occurring around conception is a cause for embryo mortality in sheep (Sawyer 1979). In the context of increasing ambient temperatures and increasing heatwaves likely to occur across Australia, more attention needs to be applied to the impact and mitigation of heat stress on reproduction, particularly the factors affecting body temperature under natural conditions in Australian sheep. This study examined factors such as bloodline, ewe weight and body condition score using a single collection of rectal temperature around the time of artificial insemination (AI).

Ewes representing two bloodlines (Bloodline A; n = 728, Bloodline B; n = 744), purchased from five separate flocks (range n = 90–421), were prepared for AI at the Agricultural Research Centre, Trangie NSW (31.99 S, 147.95 E). In total, 1472 ewes were inseminated over four days, being two consecutive days in a week over two consecutive weeks. Semen from all sires (n = 15) was used on all four dates of AI and in different AI sessions of each day. About 30 minutes before AI (mean 28.5 ± 11.9 min, range 1.3–111.3 min), ewes were sedated via intramuscular injection using Xylazil (Xylazine hydrochloride 100mg/mL, Ilium, diluted in 1000 mL sodium chloride 0.9%, Baxter) at a dose rate of 2.25 mL per head. Rectal temperature and time were recorded before sedation by one operator and again after AI (Post-sedation) by a second operator using digital thermometers (Accuflex5, Model 016-537, Physiologic, AMG Medical, Montreal, QC, Canada). Linear mixed models were used to determine the factors affecting pre-sedation body temperature. The base model included terms for bloodline (n = 2), year of drop (n = 4), ewe body condition score (BCS) and ewe weight. Flock (n = 5), day of AI (n = 4), session (n = 3) and pre-AI nutrition management group (n = 3) were included as random terms. To examine the factors affecting post-AI body temperature, the amount of time that elapsed between sedation and the time post-AI was added to the base model. All two-way interactions were examined and sequentially ordered in the model according to the level of significance. Non-significant terms were sequentially dropped from the model. All statistical analysis was performed using the *lme4* package (Bates *et al.* 2015) within R software (R Core Team 2017).

The main results are provided in Table 1, indicating that ewes from Bloodline A had higher temperatures than Bloodline B and ewes from the 2012 drop were cooler than those ewes of other drops (–0.06°C, $P < 0.05$). Among temperatures recorded after sedation, ewes of different bloodlines continued to differ ($P < 0.001$), 2014 drop ewes were warmest of all ewes (+0.09°C, $P < 0.01$) and heavier conditioned ewes had greater increases in temperature ($P < 0.05$). Average ewe temperature increased linearly after sedation (+0.008°C/min, $P < 0.001$).

These results suggest that differences may exist in rectal temperature between ewes of different bloodlines, but that age or other factors associated with particular drops of ewes also contribute to variation. The implication is that ewes with higher temperatures will be more prone to heat stress events, however, little else is known about these differences in the context of heat stress. Consequential impacts of high rectal temperature on reproduction needs examination. Factors such as ewe age, genetic base and the currently unknown genetic correlations with production traits need to be considered if breeding or selection decisions are to be made on the basis of body temperature. The ability of a single point temperature measure to describe an animal's temperature rank within a flock needs further investigation, because a single point temperature collection in mammals cannot account for the effects of homeostasis, circadian rythymn and acclimation.

Table 1. Effects of bloodline, weight (WT), body condition score (BCS) and time on ewe rectal temperature before and after sedation

	Bloodline A c.f. Bloodline B	Drop	WT	BCS	Time (°C/min)
Pre-sedation	+0.13 ± 0.04°C **	-0.06 ± 0.03°C *	ns	ns	-
Post-sedation	+0.10 ± 0.03°C ***	+0.09 ± 0.03°C **	ns	+0.05 ± 0.02°C *	+0.008 ± 0.0008 ***

*P < 0.05; **P < 0.01; ***P < 0.001. Body condition score and Time are reported as coefficients.

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The collection of the data would not have been possible without the help and support of Dr Sue Mortimer (NSW DPI), David Mula (NSW DPI) and students, Alice Burwell, Dugald Proudford, George and Paddy Burns.

Rectal temperature of Merino ewes and pregnancy outcome following artificial insemination

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Animals with a high set-point temperature are taken to be less resistant to heat stress and may, as a result, have lower reproduction outomes under conditions of high temperature (Hansen 2009). For users of artificial reproduction technologies, it would be useful if pregnancy outcomes (described hence forth as fertility) could be predicted from the ewe's temperature on the day of insemination. This study examined variation in rectal temperature taken from ewes before sedation and artificial insemination, and their fertility.

The site was located at the Agricultural Research Centre, Trangie NSW (–31.99 S, 147.95 E). In total, 1472 ewes were prepared for AI. The ewes represented two bloodlines and were purchased from five separate flocks. Average rectal temperature was 39.4°C, ranging between 38.0 and 40.5°C. Body weight was recorded one month prior to AI. Data analysed was limited to 2 consecutive days of inseminations records (n=718), due to concerns of the accuracy of fetal aging at pregnancy scanning (D 63–71) in identifying ewes pregnant to back up rams. Semen from all sires was used on both dates of AI. About 30 minutes before AI (mean 28.5 ± 11.9 min, range 1.3–111.3 min), ewes were sedated via intramuscular injection using xylazil (Xylazine hydrochloride 100mg/mL, Ilium, diluted in 1000 mL sodium chloride 0.9%, Baxter) at a dose rate of 2.25 mL per head. Rectal temperature and time was recorded before sedation using a digital thermometer (Accuflex5, Model 016-537, Physiologic, AMG Medical, Montreal, QC, Canada). Maximum ambient temperatures were mild for the time of year (27–33°C). Binomial generalised mixed models were used to determine the effect of temperature on fertility (0 or 1). Fixed effects included temperature, bloodline (n=2), ewe body condition score and ewe weight. Random terms included the day of AI (n = 2) and sire (n = 16). All two-way interactions were examined and sequentially ordered in the model according to the level of significance. Non-significant terms were sequentially dropped from the model. Statistical analysis was performed using R (R Core Team, 2017).

Mean fertility of the ewes was 71.3% and despite significant bloodline differences in temperature (data not shown), there was no relationship of temperature with fertility. An interaction between temperature and weight tended to affect fertility (P=0.07), where it appears heavier ewes had lower fertility when they had a higher temperature and lighter ewes had lower fertility when their temperature was lower (Fig. 1).

These results suggest that temperature recorded once, within 30 minutes of AI cannot predict fertility, as observed in cattle (Burrow 2001), especially when the ambient conditions are mild. Prolonged exposure to high ambient temperature elevates body temperature, which can elevate embryo mortality, yet this interaction may be tempered or exacerbated by liveweight.

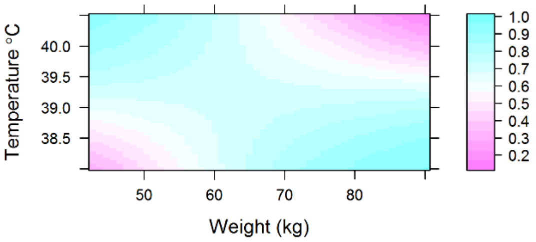

Fig. 1. A surface plot for ewe pregnancy (0-1) with temperature (°C) and body weight (kg).

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The collection of the data would not have been possible without the help and support of David Mula (NSW DPI), Alice Burwell, Dugald Proudford, George and Paddy Burns.

Ewe culling and retention strategies to increase reproductive rates in Merino sheep. 2. Economic analysis

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Six ewe culling strategies were evaluated across 3 resource flock datasets representing multiple bloodlines by Hatcher *et al.* (2018). In each flock a combined strategy improved all reproduction traits and breeding efficiency (BE – number of lambs weaned per ewe joined per year). The 6 strategies culled ‘passengers’ - ewes that did not conceive or raise many lambs - and retained ‘performers’ - ewes with the best lifetime reproductive performance. This study calculated change in flock profitability, including the impacts on the flock age structure and the influence of age and birth type-rear type (BTRT) on wool production and quality.

A gross margin (GM) per dry sheep equivalent (DSE) was calculated using the flock income and costs based on a flock reconciliation that accounts for changes in the age structure of the flock when the passengers are culled and more maidens must be retained. It was assumed that scanning was already conducted for nutritional management. The gross margin was adjusted for the change in grazing pressure by varying the DSE/ewe based on BTRT. Clean fleece weight and fibre diameter of the ewes in the flock was estimated, making allowance for the number of ewes of each age group, the variation in BTRT and the proportion of ewes that were born as twins. It is expected that fixed costs won’t change and therefore the change in GM will reflect change in profitability.

The flock GM was increased by culling passengers and retaining performers (Table 1). The increase was greatest in the CSIRO flock ($1.88/DSE and 347% return on the expenditure associated with assessing and identifying the ewes (ROE)) and least in the NSW flock ($0.27/DSE and 45% ROE). The increase in gross margin closely matched the increase in average weaning percentage with little impact of the cost of assessing and identifying the ewes. In the CSIRO data, improvement in reproduction was only observed with the combined strategies. Contrary, in the NSW dataset, culling the twice-drys was as beneficial as the combined strategies. The SARDI dataset showed a response to the individual practices but a bigger response with all combined. This gross margin analysis only valued the benefit for a flock once a steady state has been reached and ignores the transition period when the flock size is reduced due to culling, but prior to any gains in reproductive performance.

This empirical analysis expands the range of experimental resource flocks beyond those previously used (Lee *et al.* 2014) and confirms their conclusions. In future work a more detailed analysis capable of evaluating a range of flock initial conditions could generate culling scenarios relevant to a broader range of industry flocks and include a full analysis of the impact on other productivity traits such as CFW, FD and mortality.

Table 1. Breeding efficiency and the gross margin per DSE for the ‘No Culling’ strategy for the 3 datasets. For the other strategies it is the difference from ‘No Culling’ and the return on selection expenditure (ROE)

		CSIRO			NSW			SARDI		
	Strategy	BE %	GM $/DSE	ROE %	BE %	GM $/DSE	ROE %	BE %	GM $/DSE	ROE %
Absolute value	No Culling	70.6	18.76	-	71.7	33.59	-	88.1	58.27	-
Change in value	Twice Dry	0.3	*	*	1.6	0.36	292	1.2	0.27	1785
	Twice L&L	0.1	*	*	0.2	0.05	15	0.1	0.00	0
	Random 50	–1.2	*	*	–0.7	–0.04	0	–0.4	–0.09	0
	Lifetime 50	0.1	*	*	0.2	0.04	8	1.4	0.30	90
	All & Random	8.2	*	*	0.7	*	*	0.8	0.13	36
	All & Life50	9.7	1.88	347	1.3	0.27	45	3.9	0.82	239

*Insufficient replacement ewes produced to replace the older ewes that are culled or dying.

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Progesterone supplementation improves early embryonic development in sheep

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Embryonic mortality is a major factor impacting on reproductive efficiency of sheep flocks, and losses within the period between conception and birth are estimated to be as high as 20% (Parr 1992). Progesterone is known to play a major role in the establishment of a uterine environment suitable for embryo implantation. Kleemann, *et al*. 2001, showed that progesterone supplementation can enhance embryo survival. However, there are few studies that have examined the effects of progesterone supplementation on early embryo development and subsequent productivity. This study examined embryonic development in ewes supplemented with progesterone in the period before implantation.

The data were collected from ewes located at Turretfield Research Centre, between 1993 and 1997. Cast-for-age South Australian Merino ewes (132) were used and were maintained in good body condition throughout. They were randomly divided into two replicate groups and then, within replicates, were randomly allocated to a progesterone supplemented treatment (P; 300mg progesterone delivered by controlled internal drug release inserts, CIDR), or an un-supplemented control treatment (C). The ewes were oestrous-synchronized using progesterone CIDRs and subsequently, P treatment ewes were supplemented using a vaginal CIDR placed 24h after the expected median time of ovulation (i.e. 48h after pessary withdrawal) for 3 days. All ewes were artificially inseminated (intrauterine) approximately 51h after initial pessary removal. Embryos were collected immediately after slaughter from ewes at 10, 12, 17 and 20 days after the expected median time of ovulation. Blastocysts, elongated blastocysts and conceptuses were collected by flushing each uterine lumen with phosphate buffered saline (PBS) containing 2% (v/v) heat inactivated sheep serum (HISS) and measurements taken as shown in Table 1.

The present experiment shows significant effect ($P < 0.05$) of progesterone treatment on early embryo development. The impact of progesterone supplementation on embryo development measures were apparent as early as day 12 and 14 and it seems that early effects of progesterone are present well beyond the supplementation time. This suggests that the effect is not just on the developing placenta but also directly on the embryo; a pattern which was also reported by Kleemann *et al*. (2001). Whether these developmental changes have subsequent advantages in terms of birthweight and survival have yet to be tested but have been proposed for cattle (Lonergan *et al*. 2016).

Table 1. Progesterone effects on embryo development pre-implantation

	Day 12		Day 14		Day 17		Day 20	
Treatment	C	P	C	P	C	P	C	P
n	13	23	9	6	14	9	14	19
Embryonic length (mm)	0.36±0.04[a]	0.75±0.06[b]	1.19±0.23[a]	2.43±0.49[b]	6.54±0.4[a]	8.09±0.8[b]	15.55±0.46[a]	17.60±0.44[b]
Embryonic width (mm)	0.29±0.03[a]	0.48±0.04[b]	0.73±0.14[a]	0.90±0.04[a]	0.73±0.04[a]	0.98±0.08[b]	_	_
Embryonic dry weight (mg)	–	–	0.07±0.02[a]	0.17±0.02[b]	0.56±0.05[a]	1.14±0.23[b]	16.11±1.70[a]	23.78±1.3[b]

Within days, treatment means with different superscripts differ significantly ($P < 0.05$).

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Performance of the Walk Over Weighing station in a mob of pregnant beef cattle

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Walk over Weighing (WoW) stations are a useful tool providing producers with real time live weight (LW) data for individual animals and across the herd (González *et al.,* 2014). Paired with rotational grazing management, WoW stations can be used to identify LW changes through a rotational grazing system. Implementation of WoW technology may improve pasture management and facilitate selection for improved herd and genetic improvement, fertility, and growth rate.

This research project aimed to test the feasibility of the WoW station in a rotational grazing system. A mob of July-calving Angus Shorthorn cross cows (n=67) located in the Liverpool Plains of NSW, were monitored using a WoW station from 15 April to 15 September 2015. The WoW station was setup in a central watering yard, surrounded by 4 paddocks which could be opened and closed as in a rotational grazing system. Pasture type was a C4 tropical mix in all rotations except rotation 4, which was fodder oats. Dry matter per hectare was assessed by cutting 10 quadrats per paddock at ground level at random intervals following an 'M' pattern through the paddock. Dry matter assessment was performed before and after each rotation.

Both LW and live weight change (LWC) were affected by date (Fig. 1; $P < 0.001$), however it was difficult to statistically describe temporal trends and differences amongst individual dates because of the large number of repeated measures and each rotation length being different. A total of 15,735 data points were collected over the trial period, with the mean number of recordings per animals per day being 1.26. A correlation analysis showed that LWC was dependent on dry matter per hectare (DM/ha) for all rotations ($P < 0.05$), however r^2 values were 0.49, 0.12, 0.72, 0.31 for rotations 1 to 4 respectively. The lower r^2 value in the second rotation may be due to cattle breaking through a fence midway through the rotation, enabling access to other pasture.

The dataset showed the potential for a WoW station to monitor fluctuations in live weight over an extended period of time. Calving occurred during the third rotation, corresponding with a large decrease in LW, although pasture availability was also initially lower in rotation 3 compared to other rotations. The ability of the WoW station to capture LW data with minimal labour, shows its potential for use in cattle production systems where animals may be left in the paddock for many months without husbandry interventions. The application of remote data collection could have significant impacts on the way remote cattle enterprises operate.

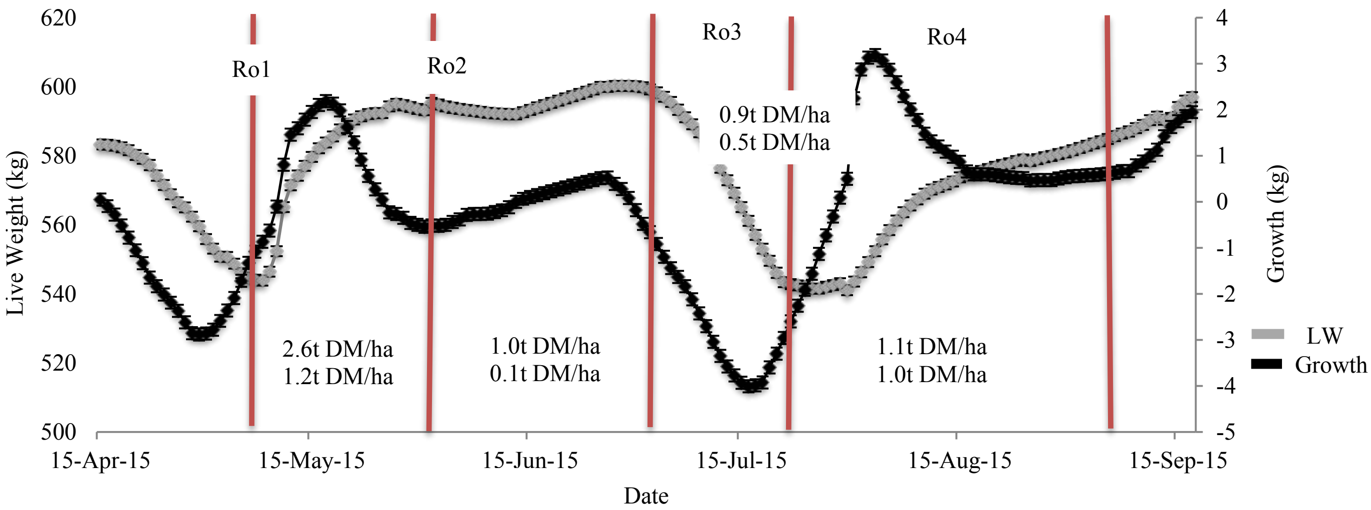

Fig. 1. Changes in live weight (LW) and growth rate (as rolling average of live weight change) of 67 Angus Shorthorn cross lactating cows in a rotational grazing system. Liverpool Plains, NSW. Vertical lines show rotation change, while the DM/ha at the beginning and end of each rotation is displayed in their respective rotation periods. Ro = rotation period.

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Development of automated sheep condition scoring

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Body condition score (CS) of ewes has a close relationship with reproductive and lactational performance, as well as the growth and survival of their lambs to weaning (reviewed by Kenyon *et al*. 2014) and is an indicator of animal welfare, thus making it a practical, on-farm decision making tool. CS has advantages over other measures of production such as liveweight because it is independent of skeletal size, physiological state, gut fill and fleece characteristics. CS in sheep is measured by palpitation of the transverse process of the lumbar vertebrae to assess the shape and cover of the tissue (muscle and fat) over the ribs and spine (Jefferies 1961). Despite its advantages, it can be time and labour intensive, and is subjective in nature. The development of automated, objective condition scoring - such as that currently used commercially in the dairy industry (http://www.delavalcorporate.com/our-products-and-services/farm-support/delaval-body-condition-scoring-bcs/) – will overcome these limitations, and can be used in conjunction with risk analyses to facilitate management decisions.

This project investigated the automation of condition scoring of sheep using imaging techniques. A Microsoft Kinect V2 depth camera was used to collect images which were then analysed using machine learning techniques to predict condition score.

Phase 1 of the trial consisted of the collection of images from 37 freshly-shorn Border-Leicester x Merino (BLM) ewes from several camera configurations, including lateral, dorsal and posterior views, to determine the optimal camera location. From these images, it was ascertained that a region of interest (ROI; used to predict CS) was best fitted to images collected from the dorsal view.

Phase 2 of data collection consisted of capturing images from 238 freshly-shorn (within a week of shearing) mixed age and breed ewes from four commercial properties, using the dorsal camera placement. Arising from inconsistent lighting during image collection, images obtained in Phase 2 could not successfully be fitted with a ROI using the process applied in Phase 1 modelling. Thus, a new method based on obtaining vectors at different points on a grid over a 'point-cloud' representing the sheep was used to define the y-coordinate of the anchor point of the ROI (Fig. 1). Importantly, this technique allowed analysis of images even when only a partial image could be obtained due to poor lighting.

Using the 'point cloud' method for identification of ROI, both regression and classification models were trialled. The regression error was too high (MSE = 0.688) with the Phase 1 dataset, therefore the model was simplified to a classification task using the ranges: CS<2.5; 2.5<CS<3.5; CS > 3.5. To overcome challenges associated with sheep size variability, and variation in shearing surfaces, a low granularity image was used in the analysis, which generated F1 scores to describe the accuracy of predictions taking into account both precision and recall. The Phase 1 dataset produced a F1 score of 0.84, and a F1 score of 0.57 for the Phase 2 dataset, with considerably lower performance associated with the classification of condition scores <2.5 (Table 1). This can largely be accounted for by the small data-set of this group (n=27 ewes).

In order to improve the accuracy of prediction of CS, more data need to be captured, with particular emphasis on sheep with CS <2.5. Further, potential improvements in extraction of features through development of ROI identification may improve the accuracy of the predictions. This could be done with the use of object detection software and/or latent structured prediction models.

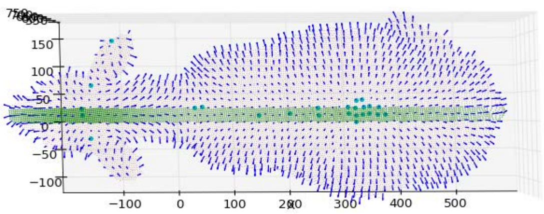

Fig. 1. Region of interest defined using a 'point cloud'.

Table 1. Condition score predictions from phase 2 dataset

	Precision	Recall	F1-score
CS ≤ 2.5	0.22	0.15	0.18
2.5 < CS ≤ 3.5	0.64	0.75	0.69
CS > 3.5	0.51	0.38	0.44
Mean	0.56	0.58	0.57

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Poultry producer network: linkages address challenges and enhance innovation

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Small-scale free-range egg production has increased in Australia in recent years in response to demand for products that are not conventionally produced, with 70% of free range farms in NSW being paddock based. Typical of emerging industries, this sector is highly fragmented and characterised by new farmers that are poorly connected, have limited access to industry information and services and are often established on low knowledge base. At an on-farm level this translates to poor access to appropriate inputs, services and technologies, limited opportunities for capacity building and limited ability to identify and address risks and poor practice.

To address these challenges a producer network was established based on an innovation systems approach. Central to this project were; (i) securing funding for the establishment and extension practitioner facilitation of the network, (ii) provision for different modes and thresholds for participation, (iii) involvement of ancillary specialist service providers, (iv) validation of farmer innovation, critiqued against existing research and regulation, (v) circulation and promotion of farmer learnings and innovation, and (vi) project partners providing incentives for on-ground works. The group consisted mainly of small-scale free-range egg producers that were located in the same region and had similar production systems and sizes, which promoted interaction and enhanced learning. Also included were participants from associated sectors of the egg industry, which provided diversity and complementary capabilities, introducing new knowledge, capacity and opportunities for innovation. Formal network activities included meetings, workshops and an online communication and resource platform, and informal exchanges between producers, service providers, researchers, dealers and agencies.

Participants reported network interactions (formal and informal) moved parties from no or weak linkages to moderated to strong collaborative linkages, providing many benefits including the environment for innovation. This included (i) vertical linkages between suppliers and producers to improve knowledge flows to generate and convert ideas to achieve innovations, resulting in more appropriate inputs and services better adapted to the needs and scale of the production system, (ii) horizontal linkages between producers to increase information share, farm-to farm learning and diffusion of learnings and adaptations resulting in an increased rate of adoption, problem solving and capacity building. The collaboration resulted in various forms of innovation including new ways of performing tasks and the adaptation of existing resources across various areas of the production system including food safety, productivity, biosecurity, marketing and welfare. As an example, Table 1 details the welfare improvements achieved through collaboration between the small scale free range egg producer network and other parties in the value chain.

This project demonstrates that facilitated group networks can address some of the inherent challenges of emerging industries and enhance the capacity for innovation through improved value chain linkages.

Table 1. Welfare improvements achieved through collaboration between small scale free range egg producer network and other parties in the value chain

Linkage	Collaborative action and innovation	Welfare improvement
Supplier/Producer	Alignment of rearing systems with the environment into which birds are placed, including floor rearing and access to the outdoors	Reduced stress in transition to farm placement
Supplier/Producer	Identification and supply of a bird genotype better suited to outdoor production systems	Reduced mortality
Supplier/Producer	Feedback to manufacturers on housing structures and equipment needs resulted in new products and technologies	Improved environment and reduction of heat stress
Service provider/producer	Veterinary understanding of and involvement in the system to support disease prevention and investigation	Improved flock health
Producer/Producer	Developing and sharing novel methods to supply cool drinking water to birds	Reduced heat stress
Producer/end user	Supply of spent hens to meat processors in accordance with newly developed specifications for use in the food chain	Birds humanely slaughtered

Temperature–Humidity index affects lying behaviour in dairy cows

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Although management strategies are available to reduce the effects of heat stress on dairy cows, heat stress continues to impact both the production and welfare of dairy cows. Recent research in genomics identified genetic markers for heat adaptation (Nguyen et al., 2017) and subsequent research has identified physiological and metabolic parameters related to heat adaptation (Garner et al, 2016). However cows will adapt their behaviour in response to a heat event as a first response, and these changes may have consequences for health, fertility and milk production. An understanding of fundamental behavioural changes linked to cows genetically selected for heat adaptation is important to avoid unintended adverse consequences on ease of management, productivity and welfare. The aim of this study was to compare behavioural responses of cows that are genetically selected to be tolerant or susceptible to heat stress.

Twenty cows genetically identified as heat tolerant (genomic estimated breeding value (GEBV) 0.0137 +-0.00830) and 20 cows identified as heat susceptible (GEBV -0.0127+-0.00832) were managed as one herd with *ad libitum* pasture availability and a supplement intake of 6kg DM/cow/day, and were milked in a rapid exit milking system. Cows were fitted with motion sensors and intra-vaginal temperature loggers for 3 weeks during mid-lactation in January 2017. Daily milk production and hourly air temperature and humidity were recorded. Responses in milk production and vaginal temperature were analysed in cows either tolerant or susceptible to heat stress in response to changes in Temperature-Humidity Index (THI, for equation see Bryant *et al*. 2007) using the REML directive in GenStat® 18. Polynomial regression analyses were performed to investigate the relationship between THI and behavioural variates (walking and lying) while Analysis of Variance was used to examine differences in daily patterns of behaviour and body temperature.

During the study weather conditions were relatively mild, with a range in maximum THI of 56.9 to 82.4 and minimum THI of 44.8 to 62.0. The response to changes in THI in milk production, body temperature and behaviour was not affected by heat stress susceptibility. However, overall there was a significant correlation ($P < 0.01$) of maximum body temperature to maximum THI, especially when THI increased above 70, while no correlation between THI and milk production (on the same day or delayed up to 4 days) was observed. When the five hottest and coldest days were compared (excluding days with significant rain), cows did reduce the total time lying on hot days (7.49 vs 9.55 h, $P < 0.01$) which was particularly evident between 10:00 and 15:00 ($P < 0.05$), presumably to facilitate cooling. Activity did not differ between hot and cold days. Body temperature peaked late afternoon when cows were brought in for milking, at which time cows had to actively walk to the dairy and where they may have been kept at relatively high stocking density on concrete flooring before milking. Despite mist cooling being used on the hottest days, no obvious reduction in body temperature was observed until the cows had returned to pasture and THI had started to decline. Delaying milking to the early evening on hot days may reduce the effect of heat stress and warrants further research.

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Body temperature responses of *Bos taurus* and *Bos indicus* lot fed steers during summer

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Variations in body temperature (**BT**) can be used as an effective tool for assessing the thermal responses of cattle, particularly when they are exposed to hot environmental conditions (Gaughan *et al*. 2014). A 100 day study was conducted from mid-December 2015 to mid-March 2016 to investigate BT changes of lot-fed *B. taurus* and *B. indicus* steers. Six pens (150 steers/pen) of mixed genotypes with an initial body weight of 466.30 ± 10.2 kg were used at a commercial feedlot in the Southern Downs region, Qld, Australia. Steers did not have access to shade during the study period. Body temperatures were monitored via data loggers (iButton, 1922T, Maxim Integrated, California, USA) which were implanted into 33 steers of mixed genotypes: (*B. indicus*, n = 17; *B. taurus*, n = 18) on day 0 of the study (induction into the feedlot). Data loggers were sutured *in situ* between the internal and external abdominal oblique at a depth of approximately 20 mm by a qualified veterinarian. The implanted steers were allocated to pens, where there were 3 pens which had five implanted steers and 3 pens which had six. Body temperatures were obtained at 1 h intervals over 66 days.

Body temperature data were analysed using a repeated measures model (PROC MIXED; SAS Institute, Cary, NC) using residual maximum likelihood (REML) estimation. The model included the random effects of genotype (*B. taurus* or *B. indicus*) and animal ID, with the period of the day (period 1; 0601 to 1000 h, period 2; 1001 to 1400 h, period 3; 1401 to 1800 h, period 4; 1801 to 2200 h, period 5; 2201 to 0200 h, period 6; 0201 to 0600 h) being a fixed effect. The rate of change in heat gain/loss was determined by assessing hourly changes in BT of both genotypes.

Mean BT was higher ($P < 0.001$) for the *B. taurus* steers compared with the *B. indicus* steers at 38.9 ± 0.02ºC and 38.7 ± 0.02ºC respectively. Although BT between genotypes was numerically close there were differences in the rate of change in BT. The BT of the *B. taurus* steers followed consistent diurnal patterns of increase and decrease throughout the day. Mean BT increased by 0.69ºC in the *B. taurus* steers between 0700 h to 1400 h (Fig. 1). This represents a mean increase of 0.09ºC/h, over 7 h. The greatest rate of heat gain occurred between 0800 h and 1100 h (0.50ºC; 0.13ºC/h). The steers lost body heat between 1500 h and 0600 h at the rate of 0.04ºC/h. This highlights that the rate of cooling is much slower (44%: $P < 0.001$) than the rate of heat gain. This has implications for assessing the impact of heat load on *B. taurus* cattle. In contrast change in BT of the *B. indicus* steers were not as consistent. There were small increases in BT at 0500 h and 0600 h, followed by a small decrease at 0700 h. Mean BT then increased from 0800 h to 1200 h (0.25ºC; 0.05ºC/h). The rate of change was slower ($P < 0.001$) than the *B. taurus* steers. From 1300 h to 2000 h there was a net heat gain of 0.15ºC. From 2100 h to 0400 h there was a net heat loss of 0.37ºC (0.05ºC/h). There was little change in the BT of *B. indicus* steers.

The pattern of heat gain/loss for the steers was not a uniform change through the day or at night, with the rate of change in BT being influenced not just by breed type but also by the intensity of heat load to which cattle are exposed. The biological implications of this are yet to be defined and further investigations are warranted.

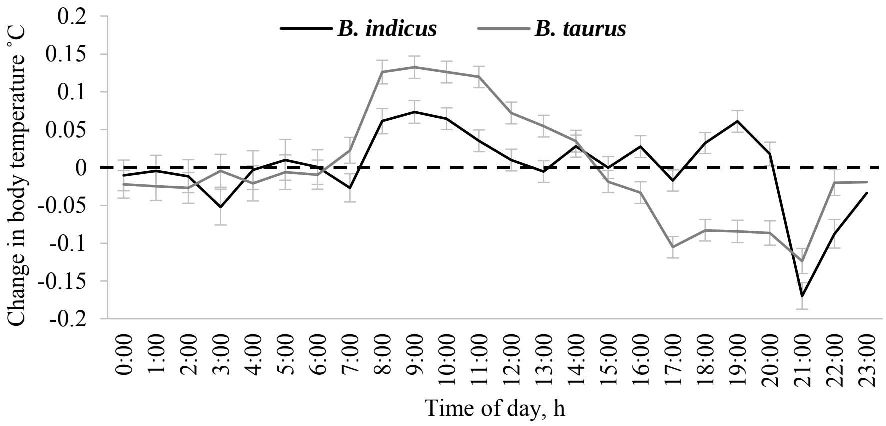

Fig. 1. Mean hourly change in body temperature (CBT; ºC) of *B. taurus* and *B. indicus* steers over a 66 day study during summer. If the CBT is above the dashed line the animal is above its mean BT (38.9 ± 0.02ºC and 38.7 ± 0.02ºC respectively for *B. taurus* and *B. indicus* steers).

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The relationship between infrared thermography measured on farm and the potential indicators of stress in beef cattle

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Infrared Thermography (IRT) measures the amount of radiation emitted from an object and converts this information into a thermal image (Ludwig *et al.* 2014). Recently, IRT has shown potential for non-invasive monitoring of health and welfare in non-human animals without any contact with the subject at all, unlike other measures that are time-consuming and invasive such as, blood cortisol or rectal temperature (Schaefer *et al.* 2015). With strong links to poor animal welfare and poor carcass quality (Ellies-Oury *et al.* 2016), the information received from IRT may help to identify these 'at-risk' animals earlier on in the supply chain and reduce the losses associated with poor quality meat, specifically dark, firm and dry meat (DFD).

Infrared thermography from an experiment designed to measure the effect of stress in beef cattle (n = 384) from seven different farms was used to determine the relationship between IRT, temperament and meat pH. On farm, infrared cameras collected radiometric data of the eye whilst cattle were restrained in the head bail of the crush. Simultaneously each animal was given a crush score in accordance with the International Beef Recording Scheme. At each of the farms, flight speed was measured by recording the time it took each animal to pass through two infrared beams as it exited the crush and dividing this time by the distance between the two beams. All on-farm measurements occurred between 2 and 5 weeks prior to slaughter. Meat pH was measured post-slaughter by abattoir personnel and any ultimate pH levels above 5.7 was classified as DFD. The 90th quantile of the rolling maximum retinal IRT across at least 10 seconds of footage for each animal was used in the analysis after which the IRT data for each farm was standardised by using the group median. Pearson correlation coefficients were calculated to determine the linear relationship between variable. An analysis of variance was also used to determine the effect of crush score on IRT.

Cattle with a crush score of 1 had significantly lower IRT compared to the other crush scores (Table 1; P < 0.0001). Cattle with higher IRT exited the crush at faster speeds (r = 0.11, p<0.0001), suggesting that IRT identified a stress response in more temperamental animals. There was also a significant positive correlation between IRT and DFD (r = 0.12, P < 0.0001) indicating that a higher IRT 2–5 weeks prior to slaughter, may be associated with high pH at slaughters.

These preliminary results indicate that, IRT has the potential to provide additional information about animals to help producers make better informed management decisions to decrease losses associated with poor meat quality.

Table 1. Standardised least squares means of beef cattle measured on farm using the 90th quantile IRT and different crush scores

Crush Score	Least squares mean (°C)	SE	df	lower.CL	upper.CL	group
1	-0.49	0.10	4285	-0.68	-0.30	a
2	0.07	0.03	4285	0.01	0.13	b
3	-0.1	0.03	4285	-0.15	-0.05	c
4	-0.01	0.03	4285	-0.07	0.06	bc

*Data was standardised across farms and the least squares means represents the deviation from the median.

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Physiological responses of three beef cattle breeds exposed to a continuous high heat load

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Physiological responses of cattle to acute heat load have been well described, however, previous studies have not examined the effects of continuous high heat load where there is no diurnal respite. This study examined the effects of these latter conditions on three breeds of cattle.

Nine steers (3 Angus, 3 Brahman and 3 Brangus) were used in a 30 day (3 replications of 10 days each) environmental chamber study. The steers were exposed to 3 days of thermoneutral conditions (TN1), 4 days of hot conditions (HOT) followed by 3 days of thermoneutral (TN2). For TN1 and TN2 dry-bulb temperature (T_{DB}) and wet-bulb temperature (T_{WB}) were maintained between 20°C and 25°C. T_{DB} and T_{WB} reached 28°C on the first day of HOT and then increased daily to a maximum of 35°C on the last day of HOT.

Dry matter intake (DMI) was measured on a daily basis. Individual rectal temperatures (RT) were obtained every 5 minutes and respiration rates (RR) were obtained hourly as breaths per minute (bpm). RR and RT response to heat load were analysed using a mixed model procedure in SAS. Baseline RR and RT were calculated for each steer by averaging the RR and RT values for days 2 and 3 of TN1. Individual baseline values were then used to convert HOT period RR and RT into relative values, RRR and RRT.

There were breed × day ($P < 0.05$) effects for DMI during HOT with Angus having the lowest DMI ($P < 0.05$) compared to the Brahman and Brangus. Angus had a mean DMI during TN1 of 6.13 ± 1.2kg, Brahman 7.16 ± 2.2 kg and Brangus 7.4 ± 3.26 kg. On day 6 (3rd day of continuous heat) DMI of the Angus had decreased ($P < 0.05$) to 2.6 ± 0.63 kg, whereas the DMI of the Brahman and Brangus were 7.33 ± 1.3 kg and 6.9 ± 2.13 kg respectively.

Mean RT and RRT for the Angus differed (P < 0.05) from Brahman and Brangus. The RRT and RRR (Figs 1and 2) observed across the 3 replications show breed × day affects ($P < 0.05$). There were no RT differences ($P > 0.05$) for breed × day during TNC and on day 2 all breeds had a mean RRT of 38.9 ± 0.2ºC. On day 6 the mean RT peaked for Angus at 40.8 ± 0.2ºC. At the same time RT were 39.4 ± 0.2 ºC for Braham and 39.8 ± 0.2ºC for Brangus. The RT of the Brahman and Brangus continued to increase until the cessation of HOT with peak RTs of 39.5 and 40.0 ± 0.2ºC respectively. This suggests that the maximum threshold RT for the *Bos indicus* breeds were not reached (Fig. 1). In the current study there were no differences ($P > 0.05$) between Brahman and Brangus for RT during TN1, HOT and TN2.

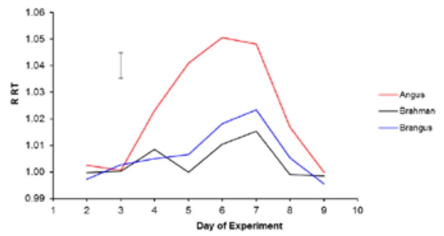

Fig. 1. Mean relative rectal temperatures (RRT) (°C) for each breed. Error bar corresponds to 2 standard errors.

During TN1, mean RR for Brahman (22.9 ± 7.8 bpm) and Brangus (30.5 ± 7.8 bpm) were lower ($P < 0.05$) than that of the Angus (76.8 ± 7.8 bpm). RR of the Angus peaked on day 6 (average T_{DB} = 33.4ºC, T_{WB} = 31.4ºC, relative humidity (RH) = 87% and temperature humidity index (THI) = 89)) at 134.4 bpm whereas the RR of Brahman and Brangus were still increasing at the cessation of HOT with RR's of 62.2 ± 7.8 bpm and 99.2 ± 7.8 bpm, respectively. There was a breed × day effect ($P < 0.001$) for RR. Over the first 2 days of HOT the rate of increase in the RRR were similar for all breeds. The decrease in RR of the Angus on day 6 may indicate that the Angus had shifted from rapid open-mouth panting to deep open-mouth panting (Fig. 2). The timing of this change in RR was similar to the apparent acclimation point observed for RT.

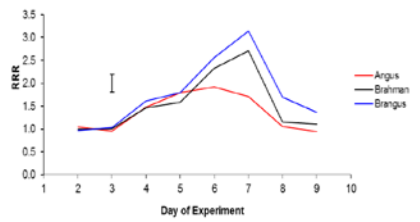

Fig. 2. Mean relative respiration rates (RRR) (bpm) for each breed. Error bar corresponds to 2 standard errors.

The results of the current study reaffirms that *Bos indicus* are more heat tolerant than *Bos taurus* breeds, and that the cross of these two genotypes respond in a similar manner to *Bos indicus*. It also appears that coat colour is not an important contributing factor to the heat tolerance of cattle housed indoors.

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Investigating the use of infrared thermography for the detection of skin inflammation in sheep with varying fleece lengths

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Infrared thermography (IRT) has potential for remote monitoring of extensively raised sheep. IRT has been shown to detect changes in interdigital temperature associated with foot lesions (Talukder 2015) and it is therefore reasonable to propose that it may be capable of detecting other sources of inflammation. Due to the insulating properties of wool, it is likely that a fleece length greater than 2mm may significantly impact on the ability of IRT to reliably identify areas of inflammation of the skin from a thermal image. It was hypothesised that IRT measurements on sheep with vaccination-related inflammation and at varying wool lengths may indicate whether this method can be used to detect other causes of skin inflammation, particularly with regards to inflammation associated with fly strike.

An experiment was conducted using IRT to detect skin inflammation in sheep. The experiment was conducted under and with approval from AgResearch Animal Ethics Committee, AE number 13780. The experiment analysed IRT images of 30 sheep taken three times daily for three days following an intradermal injection of the commonly used vaccine formulation, Covexin10®. Four patches measuring 10cm x 10cm for two control and two injection sites were shorn into the fleece of each animal, with each animal randomly allocated two different wool lengths giving a total of 60 tests at three different wool lengths (20 tests per length): short (1–2 mm), medium (5–10 mm), and long (15–20 mm). Having control areas of each length on the animal, each animal was able to serve as its own control. An initial subcutaneous vaccination was administered at 1 mL/sheep to prime the immune response, then a dose of 0.1 mL was administered intradermally into the injection region of each of the test patches on each sheep at day 0 and day 7. IRT images were analysed to extract maximum temperatures for each of the injection and control sites. These measurements were taken to detect a localised inflammatory response.

IRT maximum temperatures at control and injection sites were analysed day by day within each sheep. A one-sided paired t-test comparison of the difference between means was performed to compare maximum temperatures for injection sites and control sites within individual animals and measurement days for each of the three wool lengths. At short wool length, significant increases in temperature ($P < 0.05$) were found between control and injection sites for individual animals on five out of the six measurement days; with mean temperature for all sheep across all days at the control site being 30.4ºC ± 2.16ºC, and at the injection site 30.7ºC ± 2.08ºC (n.s.). At medium wool length, significant differences ($P < 0.01$) were found between injection and control sites for individual animals on three of the six days; with mean temperature for all sheep across all measurement days at the control site being 25.5ºC ± 2.68ºC and at the injection site, 25.6ºC ± 2.77ºC (n.s.). At long wool length, significant differences ($P < 0.01$) were found between injection and control sites for individual animals on two of the six days; with mean temperature for all sheep across all measurement days at the control site being 21.6ºC ± 2.96ºC, and at the injection site, 21.8ºC ± 2.90ºC (n.s.). Variation in IRT-derived temperature was lower in short wool compared to medium and long wool.

These findings suggest that IRT may be capable of detecting skin inflammation in sheep at short wool lengths, with reduced reliability of detection as wool grows longer and shows increased variability in temperatures. The IRT technique appears unlikely to have applicability in detection of localised inflammation of the skin in wool sheep. Further investigation may be warranted into the potential for IRT use in detection of skin inflammation in remote monitoring systems in animals without a thick fleece, for example, hair sheep.

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Producer engagement in a lamb supply chain – a value chain approach

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The Australian Lamb Company (ALC) is an export meat processor located in Western Victoria. Lambs procured for ALC are purchased from a range of different areas within Southern Australia, either directly from producers, using a livestock agent supply model, or from saleyards. More than 1000 producers supply ALC with lamb each year, presenting a large network of suppliers.

A novel project was started in 2017 with the aim of engaging ALC's livestock agents and producers, and was funded using a Meat and Livestock Donor Company (MDC) model, with additional support from The Department of Economic Development, Jobs, Transport and Resources. This project was pursued due to ALC having an interest in building relationships with their supply chain partners, enhancing producer feedback, supporting the interpretation of carcase feedback and supporting the implementation of practice change on farm to ensure lambs supplied are meeting market requirements, while using a value chain approach.

O'Keefe (1998) discusses the challenges of establishing supply chain management in Australian agribusiness and the need to cooperate, develop trust and commit to a shared vision when establishing supply chain partnerships to be an effective competitor. A previous project that focused on a beef supply chain added value to producer feedback using an online tool (Livestock Data Link), and found the use of this tool provided incentives within their supply chain (Webb *et al.* 2016). A related project within the same beef supply chain used a facilitated engagement process to improve producers' ability to meet target market specifications and strengthen the processor-producer relationship (Crawford *et al.* 2016). There have been no published studies in lamb supply chains, to the author's knowledge.

To engage producers, livestock agents were contacted in an informal manner to determine their interest in the project, between the months of September and December 2017. A range of engagement methods was planned, including group meetings, one-on-one meetings and large forums. Leat and Revoredo-Ghia (2008) found that building collaborative relationships and trust is an enabler for knowledge sharing and has a positive influence on learning and supply chain performance. With this concept in mind, a group of ten producers located in a specific geographical region was formed with the intention of meeting four times per year. Engagement with a further two groups was planned.

Unfortunately, due to the difficulty in forming groups of producers, the project was not able to proceed. However, ALC were able to form one group of producers and deliver one meeting. Learnings from this project suggest that the time of year a lamb supply chain approaches their livestock agents and producers is critical to the success of building relationships and groups. Furthermore, a formal approach to engage livestock agents on a larger scale should be used in future to ensure greater interest is generated. Learnings from the group formed indicate that when livestock agents are engaged, their involvement can be extremely rewarding. For example, many of the producers within the group had not previously attended industry events. This indicates that a wider demographic of producers can be engaged with the potential to create change in an extremely meaningful way due to the strong relationship some producers have with their livestock agent.

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Methods for anomaly detection applied to non-specific data sets to improve AI hazard detection without user specific interactions

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Recent spikes in the number of data collection systems available for a wide variety of farm environment parameters has improved the early detection and prevention of system failures. However, in a high number of cases the capability fails the end user based on a technicality in the systems configuration. To overcome this, an analysis was performed on the suitability of using artificial intelligence (AI) algorithms to perform anomaly detection for the purpose of generating alerts and alarms without specific interaction from the user. This allows the input of any dataset over a period of time to be analysed for anomaly detection and reported if appropriate, irrespective of the actual environment variable being measured or end-user interaction.

The first component used was a z-scoring system with an upper and lower limit of +/-2. Each system is assessed based on the following criteria

- Detection speed from the time the event first occurred
- The number of false positives produced over the analysis period
- Recovery speed once the system had returned to its normal operating parameters

Although the z-score method appeared to activated early in the analysis, in actual fact it had detected a pre-cursor error in the system which was not immediately obvious. The analysed dataset was recorded water tank levels for which the period of 'normal operation' remained under automation control to maintain a water level between 1800 mm and 2100 mm. The first fault condition was a failure of the pump to start allowing the water level to continue to fall below the 1800 mm threshold. The system failure was then further compounded by the fact that a burst pipe let water out of the system at an alarming rate.

Prior to the recovery of the water level the z-scoring system indicates an earlier than expected recovery to normal operating parameters, falling back within normal limits prior to the water level reaching the managed levels of 1800 mm – 2100 mm. This false positive is an artefact of the z-scoring mechanism when a significant majority of the data (up to that point in time) is no longer within the 'normal operating range'. Therefore, we concluded that the z-scoring system, although initially accurate, can only be relied upon to generate a notification once per 60 samples.

The second method analysed was the Local Outlier Factor (LOF) method. This method determines the likelihood of a single point being an outlier based on its distance to its nearest neighbour. This method can be effective not only in detecting end user system failures (tanks, pumps, pipes etc.), but also technology failures based on parameters such as a loss of battery power or network communications, e.g. mobile coverage.

Since the analysed dataset was only two-dimensional against time, it was assumed that the nearest neighbour is simply the next or previous point in the sequence. Using the same dataset as before, this method shows no discernible change at the point of either system failures, however unlike the first method a sharp spike indicated a prolonged period without reporting. This spike indicated a network failure to report the sensor input for over 24 hours, a substantial increase from the average 4 hours observed throughout the rest of the dataset.

The absence of data did not present as an outlier using the z-scoring method and likewise the system failure was not evident using the LOF method. A combination of methods will prove the most effective automatic detection system. While some methods are more effective at analysing sensor data and user system failures, others are better at detecting network and equipment failures. It must also be noted that although these methods are capable of anomaly detection they have a limited capability to categorise the anomaly itself. Detection and notification in many cases can occur without user interaction, however at the point of detection it is still up to the user to determine the exact problem, cause and solution to the identified issue.

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The effect of grazing intensity of lucerne (*Medicago sativa*) pasture on defoliation dynamics and pasture intake in dairy cows

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The effects of lucerne (*Medicago sativa*) pasture allocation on grazing intensity, pasture intake, pasture intake rate, diet quality, and animal production were investigated in a sub-tropical Partial Mixed Ration (PMR) dairy system. The study took place at the Gatton Research Dairy, South-East Queensland, with a 28-day adaptation period followed by an eight-day treatment period during November and December 2016. The experiment was a completely randomised design with twenty-four multiparous Holstein-Friesian dairy cows randomly assigned to one of four treatments (three cows per group, by two replicates). Treatments were decreasing levels of pasture allocation, averaging 30.6, 20.5, 15.1 and 10.9 kg dry matter (DM)/cow.day with a targeted DM utilisation of 33, 49, 66 and 92% respectively, to achieve 10 kg DM/cow.day of pasture intake. All groups were offered 11 kg DM/cow.day as PMR to achieve a daily intake of 21 kg DM/cow.day for all treatment groups. Pasture intake, intake rate and pasture utilisation were measured using the pasture disappearance method (Benvenutti *et al.* 2016). Tensile strength of tillers was measured using a tension meter. Grazing time was measured using GoPro cameras with a photo taken every 10 seconds. Diet quality was calculated from feed analysis conducted at Dairy One forage laboratory (Ithaca, USA).

There was no difference in PMR intake between treatment groups, however residual pasture height, pasture intake, and milk yield declined by 10%, 2 kg DM/cow.day and 0.6 L/cow.day respectively, for every 10 kg DM/cow.day decrease in pasture allocation. Cows grazed the top grazing stratum (TGS) across 80% of the pasture area before regrazing an area of the paddock, regardless of allocation level. Pasture intake (kg DM/ha) of the TGS was at least 2.9 times higher than subsequent strata, regardless of allocation level. Therefore, the decline in pasture intake under lower allocations is explained by the transition from grazing the top stratum to grazing subsequent strata. Stem proportion, tiller density, and tensile strength of tillers were used to calculate grazing resistance, which increased by 15.2 kg/100cm^2 for every 10% decline in residual pasture height (Table 1), and likely caused an ingestive constraint on pasture intake (Poppi *et al.* 1987). Grazing time tended to decrease with decreasing residual pasture height, therefore total pasture intake declined as a function of both lower intake rate and a shorter grazing period. Metabolisable energy (ME) intake and milk yield also declined with declining dry matter intake and diet quality, due to lower pasture allocations (Table 1).

When the horizontal utilisation of the TGS approached 100%, the proportion of un-grazed, un-contaminated pasture (PUP) approached 0% of the area. At this point, intake, intake rate and milk production declined, similar to results found by Benvenutti *et al.* (2016). Therefore, grazing management strategies for lucerne pasture in subtropical PMR dairy systems should allocate pasture to primary herds to achieve an utilisation approaching 0% PUP, where intake and production are maximised. Secondary grazing herds or mechanical methods should be utilised to remove residual pasture to the ideal height for pasture regrowth.

Table 1. Average daily defoliation dynamics, pasture structure, pasture intake, diet quality and milk yield per cow, in response to decreasing daily pasture allocations

Pasture Allocation (kgDM)	Residual Pasture Height (%)	Horizontal Utilisation (%)	Pasture Intake (kgDM)	*Grazing Time (min/day)	**Pasture Intake Rate (kgDM/hr)	ME Intake (MJ/cow)	Grazing Resistance (kg/100cm^2)	**Milk yield (L/cow)
30.6^a	69.7^a	94.2	10.9^a	220	3.0	226^a	43.9^a	25.8
20.5^b	61.1^{ab}	99.0	8.8^{ab}	194	2.7	202^b	53.8^{ab}	25.4
15.1^c	58.2^{ab}	99.6	7.1^{bc}	161	2.6	178^c	59.4^{abc}	25.0
10.9^d	50.7^b	100.0	6.1^c	154	2.4	169^c	72.8^c	24.7

Means with common superscripts within columns are not significantly different at $P < 0.05$.
*Grazing time tended to increase with increasing allocation, however was not significant ($P = 0.064$).
**Results had a significant linear relationship with pasture allocation ($P < 0.05$).

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Eating quality of lamb is not affected by grazing Neptune messina (*Melilotus siculus*)

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Waterlogged and saline areas in the high rainfall zone generally are dominated by species such as tall wheat grass (*Thinopyrum ponticum*) or puccinellia (*Puccinellia ciliata*) (Bonython *et al.* 2011). Providing these areas with a companion legume will help to increase the overall productivity of the land through (i) provision of a high quality forage, and (ii) contribution of symbiotically fixed soil nitrogen for the nutrition of other pasture species (Fenton *et al*. 2003). Unfortunately, many widely sown legume varieties do not tolerate the combined effects of salinity and waterlogging. *Melilotus siculus* (messina) is commonly found in saline, marshy areas of the Mediterranean basin, and was identified as a promising pasture legume suitable for both waterlogged and highly saline soils (Rogers *et al*. 2011). Prior to the commercial release of Neptune messina as a new pasture cultivar, a 'duty of care' grazing trial was undertaken to ensure it had no deleterious effect on meat eating quality.

A factorial design was used with six replicates of two grazing treatments (Neptune (SA40002) messina (*Melilotus siculus* ((Turra) Vitman ex B.D. Jacks))) or control (Monti subterranean clover (*Trifolium subterraneum* ssp. *yanninicum*)). Seventy-two Border Leicester x Merino lambs (3 male and 3 female per rep) were stratified by liveweight and then grazed the plots (0.18ha) for 52 days. Male lambs were then processed in a commercial facility without electrical stimulation. Fresh colour (*L*, a*, b**) of the *M. longissimus thoracis et lumborum* (LL) was measured 48hr post mortem. Samples of LL were aged for 12 days and then frozen before measurement of shear force (SF; Hopkins and Thompson 2001) and sensory analysis of aroma, flavour, tenderness, juiciness and overall liking. Sensory samples were grilled (Pethick *et al*. 2005) and then tasted by 72 volunteers over two days. Samples were rated using a 9-point category scale, from 1 dislike extremely to 9 like extremely.

Fresh colour and SF were not significantly different between meat samples from lambs grazing the two pastures (Table 1), and were within levels considered acceptable by at least 50% of consumers (SF < 49N (Hopkins *et al*., 2006); L* >34 and a*>9.5 (Khliji *et al*. 2010)). There were no significant differences in consumer scores between meat from lambs grazed on the two pastures (Table 1), however the aroma and flavour of the control treatment tended to be preferred (P<0.1). Overall, meat eating quality from both treatment groups was acceptable, and it is concluded that grazing Neptune messina had no deleterious effect on meat appearance or eating quality.

Table 1. Fresh colour, shear force (LSM±SEM) and sensory attributes (mean±SD) of meat samples from lambs grazing Neptune messina or Monti subterranean clover (control)

	Neptune messina	Control
Lightness (L*)	35.8 ± 0.75	35.9 ± 0.75
Redness (a*)	16.7 ± 0.56	16.4 ± 0.56
Yellowness (b*)	6.9 ± 0.36	6.5 ± 0.36
Shear force (N)	34.4 ± 2.47	31.3± 2.47
Tenderness	6.4 ± 1.64	6.4 ± 1.75
Juiciness	6.0 ± 1.55	6.0 ± 1.74
Flavour	6.7 ± 1.29	6.9 ± 1.35
Aroma	6.5 ± 1.42	6.8 ± 1.33
Overall liking	6.5 ± 1.42	6.6 ± 1.51

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Metabolisable energy content of perennial ryegrass cultivars grown at two sites in Victoria, Australia

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Perennial ryegrass (*Lolium perenne* L.) is the predominant forage species used in the Australian dairy industry. However, evidence suggests that the full potential of this species is not being realised, as both dry matter (DM) production and utilisation are below what is considered achievable (Harmer *et al*. 2016). A three-year experiment was conducted at two sites in Victoria, Australia, to determine how much genetic gain has been achieved from perennial ryegrass breeding from the 1970s to the present day. This paper reports the metabolisable energy content from year 2 for the perennial ryegrass cultivars that were evaluated.

Thirty six perennial ryegrass/endophyte combinations (i.e. 36 'treatments') were sown in May 2014 on a commercial dairy farm in Mooroopna North in northern Victoria, and at DemoDairy, Terang in south-west Victoria, and continued for three grazing seasons, finishing in May 2017. Over this time, there were 39 grazing events at the northern Victorian site and 17 at the south-west Victorian site. The perennial ryegrass cultivars covered a range of ploidy types, seasonal maturity as well as date of cultivar release. Pasture measurements undertaken included rising plate meter pasture heights, herbage accumulation, pasture nutritive characteristics, botanical composition, proportion of plants with endophyte, and plant number. Pre-grazing pasture samples were cut at every grazing at the south-west site and at every second grazing at the northern site. Samples were selected for a high (>90%) ryegrass content, cut to approximate grazing height, and analysed for *in vitro* dry matter digestibility (DMD), neutral detergent fibre (NDF), acid detergent fibre (ADF), and crude protein (CP) using Near Infrared Spectroscopy (NIR). Metabolisable energy (ME) was calculated from DMD using: ME = 0.17 x DMD – 2.0 (SCA 1990). (Six cultivars were excluded from this analysis due to time since release (>40 years), early season maturity or that they were not yet released commercially).

There were significant differences in ME content between ploidy x maturity types at each grazing date at both sites, with treatment differences likely to have been associated with heading dates, rust incidence and the amount of dead material present (Table 1). The data from both sites indicated that there were benefits in ME from the tetraploid cultivars, with higher ME, compared with the diploid cultivars. These differences in ME content need to be assessed in conjunction with other cultivar characteristics such as dry matter accumulation and longevity when deciding what perennial ryegrass cultivar to sow.

Table 1. Estimated metabolisable energy content (MJ/kg DM) in perennial ryegrass cultivars as affected by ploidy and maturity. The data is from the second year (2015) of the experiment. The number of cultivars in each category is indicated in the parenthesis

	Northern Victoria					South-west Victoria				
	16 Mar	4 May	27 Jul	6 Oct	17 Nov	6 Feb	15 May	14 Jul	1 Sept	7 Oct
Diploid – mid (14)	9.7	11.2	11.6	11.5	11.1	11.0	11.2	11.9	12.0	11.6
Diploid – late (10)	9.8	11.0	11.7	11.6	11.2	11.2	11.1	11.9	12.0	11.7
Tetraploid – late (6)	10.2	11.5	12.0	11.7	11.3	11.2	11.7	12.4	12.4	12.1
P value	0.001	0.007	0.003	0.001	0.083	0.004	0.001	0.001	0.001	0.001
l.s.d. (P=0.05)	0.24	0.31	0.22	0.11	0.19	0.14	0.25	0.14	0.14	0.16

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The influence of plant structure on pasture utilisation by dairy cows grazing Lucerne (*Medicago sativa*)

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Improving pasture utilisation while maintaining high pasture intake and cow productivity is a key strategy to maximize economic returns in pasture based dairy systems. This study investigated the effect of pasture allocation on pasture intake and utilisation in a sub-tropical Partial Mixed Ration (PMR) dairy system. The companion paper by Ison et al (2018) presented the results on pasture intake which was maximised when at least 5% of the pasture area remained un-grazed. The aim of this paper was to look at the relationship between plant structure and pasture utilisation for different pre-grazing pasture heights (PGPH) when the proportion of un-grazed pasture was at least 5% of the allocated pasture area. The study took place at the Gatton Research Dairy, South-East Queensland, with a 28-day adaptation period followed by an eight-day treatment period during November and December 2016. Multiparous Holstein-Friesian dairy cows were offered 11 kg dry matter (DM)/cow.day as PMR, and four levels of pasture allocation daily (averaging 30.6, 20.5, 15.1 and 10.9 kg DM/cow.day), while PGPH varied from 40 to 60 cm. Regression analysis was used to establish the relationship between the vertical distribution of plant structure (leaf and stem proportion and stem tensile resistance) measured from the top down of the pasture at different utilisation depths (pasture utilisation depth) and PGPH.

Plant structure was significantly affected by both PGPH and pasture utilisation depth (R^2>=0.93, $P < 0.001$). The leaf proportion decreased and stem proportion and tensile resistance increased with both increasing PGPH and from top to bottom of the Lucerne pastures (Figure 1). Plant structure did not seem be the sole driver of pasture utilisation across the different PGPHs. When the proportion of un-grazed pasture was 5% of the paddock area grazing depth (as % of PGPH), which is the top down depth of the pasture that the cows grazed, increased as PGPH decreased irrespective of pasture allocation (39, 34 and 28 % for PGPH averages of 40.0, 51.8 and 59.6 cm respectively). However, absolute grazing depth (cm) was relatively constant across PGPH (15.5, 17.9 and 16.9 cm respectively). It seems that the cows did not maintain the same level of pasture utilisation (%) when PGPH increased as it would have resulted in a significant decline in leaf proportion in the diet as well as an increase in tensile resistance of the grazed stems (Fig. 1). This response is consistent with previous studies where stems were found to act as a vertical barrier to defoliation (Benvenutti et al 2008). On the other hand a constant leaf proportion in the diet did not seem to drive pasture utilisation depth as it would have resulted in a greater decline in pasture utilisation % when PGPH increased with potential negative consequences on pasture intake. We conclude that, while the stems seemed to play a role limiting pasture utilisation depth to no more than 39%, the cows slightly reduced the leaf proportion in the diet and grazed tougher sections of the stems in order to maintain a relatively constant grazing depth of approximately 17 cm and achieve high levels of pasture intake as the PGPH increased.

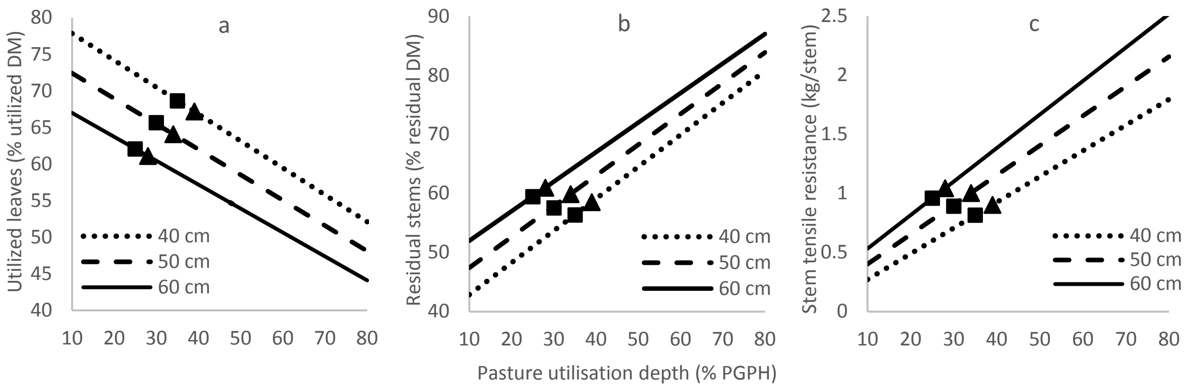

Fig. 1. The relationship between plant structure and pasture utilisation depth (% PGPH: pre-grazing pasture height) of Lucerne pastures of different PGPHs (40, 50 and 60 cm). Symbols indicate plant structure at the grazing depth when 5 (▲) and 10 % (■) of the pasture area remained un-grazed and pasture intake was maximum.

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Quantifying greenhouse gas emissions from the Australian red meat sector

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The red meat sector is important to Australia. It is also a major source of greenhouse gas (GHG) emissions. Under the Paris Agreement, the Australian Government has committed to reduce national GHG emissions by 26-28% of 2005 levels by 2030. Reducing emissions from livestock, particularly the red meat sector, will be key to achieving this goal. In this paper we quantify baseline (2005) and current (2015) GHG emissions from the Australian red meat sector. Quantifying baseline emissions is the first step in developing pathways for the red meat sector to reduce GHG emissions.

Emissions associated with the red meat sector include emissions from livestock (enteric fermentation of methane, manure), meat processing, energy use, agricultural soils (pastures, cropping to produce livestock feed), savanna burning, land use and land use change. Baseline emissions were calculated from emissions reported in the Australian UNFCCC National GHG Inventory (Commonwealth of Australia, 2017), with additional data sourced from the Australian Meat Processor Corporation and life cycle assessment studies. Emissions from the inventory were allocated to the red meat sector based on animal numbers, feed intake, meat production and resource use. We excluded dairy cattle, and emissions from sheep were corrected for meat-wool co-production. Live export animals were not included once they left Australia. Full details are available in the project final report (Mayberry *et al* 2018).

GHG emissions from the red meat sector in 2005 were 124.1 Mt CO_2e – equivalent to 21% of total national emissions (Table 1). These values are higher than those previously reported because we include emissions from land use and land use change. In both 2005 and 2015, the major sources of emissions were conversion of forest land to grassland and enteric fermentation. A reduction in deforestation between 2005 and 2015 was the key driver of the large reduction in total emissions from the red meat sector during this period. Most emissions from enteric fermentation were associated with beef cattle on pasture (78%). Afforestation and revegetation were the major sink for GHG emissions.

Strategies to further reduce GHG emissions from the red meat sector by 2030 will need to target the main sources of emissions. This will include reduced deforestation and reduced enteric methane fermentation from grazing livestock.

Table 1. Greenhouse gas emissions (Mt CO_2e) from the Australian red meat sector

Category	2005	2015
Permanent conversion of forest to grassland or crop land (deforestation)	75.3	30.1
Enteric fermentation	40.1	38.9
Management of grasslands, sown pastures and crops for livestock feed	13.9	5.7
Manure	3.8	3.7
Meat processing	1.4	1.4
Energy use on farm and in feedlots	1.4	1.4
Afforestation, revegetation and management of forest land	–11.8	–12.5
Total	124.1	68.6

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Grazing lambs on dual-purpose crops increases the sale weight of yearling lambs in a Tablelands production system

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A four-year study at CSIRO's Ginninderra Experimental Station near Hall, ACT compared three livestock systems: pasture only (Control), pasture with dual-purpose (DP) crops with priority-grazing of crops given to ewes (ECG) or with priority-grazing of crops given to weaners (WCG). 'Priority-grazing' referred to the cohort (ewes or weaners) being given priority to graze crops over the other cohort, although the other cohort was given access to crops where forage production from crops was in excess of requirements. The site was set up as nine farmlets (3 replicates per system), each divided into paddocks of 0.23 ha. Initially (2013), the control farmlets had 4 x 0.23 ha paddocks (the same number of pasture paddocks as the cropping treatment), but they were increased to 6 x 0.23 ha paddocks for 2014-2016 (same total number of paddocks as the ECG and WCG treatments) due to very high supplementation requirements in the Control in 2013 (Table 1). In every year, one paddock in each of the WCG and ECG farmlets was sown to DP canola and one to DP wheat, with crops grazed in sequence during late autumn and winter. Crop grazing periods were managed to minimise the impact on grain yield. The six Merino ewes in each farmlet were joined for lambing in July/August. Lambs were weaned in October/early November; six weaners were retained in each system for sale as yearlings. These retained weaners were sold in late July or early August after the crop grazing period, although Control weaners were retained until mid-August in 2015 and early September in 2016 due to high pasture availability. Weaner and ewe data were analysed using linear mixed models with fixed model farmlet and random model treatment x year.

Retained weaners from the WCG treatment were significantly heavier at sale compared to control lambs in three years, and significantly heavier than ECG weaners in two years (Table 1). Over the four years of the experiment, the retained WCG weaners were heavier (44.3 kg) than those in the Control (39.2 kg) or ECG (39.1 kg) treatments at sale (P < 0.001). Weaners from the ECG treatment were heavier at sale than the Control weaners in 2013, which had growth rates restricted during winter due to low pasture growth, but were lighter than Control weaners in 2015, where pasture availability in the Control treatment was higher. The only year where sale weights of weaners did not differ between treatments was 2014, when the season was marked by an early break and good pasture growth conditions throughout. The 4-year average live weight of weaners sold per hectare was higher in the WCG treatment (238 kg) compared to the ECG and Control (both 205 kg). The 16% greater weaner live weight sold per hectare in the WCG treatment compared to the Control treatment was due in equal part to a higher number of weaners sold per hectare (including both excess and retained animals) and a higher average sale weight. The greater live weight of weaners sold per hectare in the WCG treatment over the ECG treatment was entirely due to a higher average weight of yearlings at sale. This was associated with higher live weight gains on the dual-purpose crops. The interaction of treatment and year was significant for the amount of supplementary grain fed to animals (ewes and weaners) in each farmlet (Table 1). Mean clean fleece weight per ewe across the 4 year experiment was significantly heavier (P = 0.003) in the ECG (3.9 kg) and WCG (3.8 kg) treatments compared to the Control (3.5 kg).

Table 1. Lamb sale weights and amount of grain fed (dry) per farmlet for each treatment 2013-2016. LSD values reported at P<0.05; P-values are for treatment x year interaction. Different subscripts indicate significant difference within row (lower case) or column (upper case).

Parameter	Year	Control	ECG	WCG	LSD	*P*-value
Mean sale weight of yearlings (kg/head)	2013	31.5^{aA}	38.4^{bA}	40.8^{bA}	3.1	<0.001
	2014	51.2^{B}	48.9^{B}	50.9^{B}		
	2015	39.2^{aC}	36.1^{bA}	43.7^{cA}		
	2016	34.6^{aA}	32.9^{aC}	41.4^{bA}		
Total sale weight of lambs (kg/farmlet ha)*	2013	222^{aA}	180^{bA}	191^{abA}	37	0.005
	2014	227^{A}	221^{B}	240^{B}		
	2015	203^{aAB}	240^{bB}	233^{abB}		
	2016	169^{aB}	181^{aA}	246^{bB}		
Grain fed (kg/farmlet ha)	2013	794^{aA}	283^{bA}	233^{cA}	5	<0.001
	2014	67^{aB}	49^{bB}	49^{bB}		
	2015	3^{aC}	75^{bC}	77^{bC}		
	2016	56^{aD}	135^{bD}	88^{cD}		

*Includes weights of excess weaners sold post-weaning and retained weaners sold at approximately 12 months of age.

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Opportunities for improving gross margins for mixed sheep/cropping farms

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The integration of sheep and crop enterprises on mixed farms involves compromises. Current high meat and wool prices are increasing producer interest in improving sheep production without reducing crop returns. However, the integration practices or changes to management which would have the largest impact on whole-farm profits are not obvious due to the biological complexity of flow-on effects on production from one enterprise to the other. This is particularly the case where cropping practices alter the feedbase for sheep. The use of whole-farm simulation models can assist in identifying overall production and financial outcomes.

To identify large financial opportunities from changed management on integrated sheep/cropping farms, two mixed farming regions in NSW were chosen. Representatives of the two producer groups and regional advisors were invited to suggest management changes which were locally relevant, or which they wanted to test. The decision support tool AusFarm (version 1.4.14) (Moore *et al.* 2007) was used to model one farm within each region – Temora and Condobolin – between 1970 and 2015. The base farm simulated at each location was constructed to represent average regional practice. The base farm at Temora used a purchased Merino ewe, joined in January to produce crossbred lambs, with a stocking rate of 3.5 ewes/pasture ha, and 60% of the farm cropped. The base farm at Condobolin was a self-replacing Merino flock, stocked at 1.4 breeding ewes (2.1 sheep)/ha, joined in December, and 40% of the farm cropped. Average prices for the period 2012-2016 were used to calculate annual gross margins for the entire simulated period. Gross margins from altered management were compared with that of the base farm at each location.

Changes to sheep management such as changing the sale date of lambs, increasing stocking rate and joining date resulted in large increases in farm gross margins (Table 1). Increasing the proportion of farm cropped did not result in larger gains than some alternative sheep management, while the benefit of grazing winter cereal crops was limited due to trade-offs in crop yield loss for livestock gains. A large reduction in pasture growth caused a large reduction in farm gross margin, highlighting the need to maintain pasture production for grazing enterprises on mixed farms. The benefit of a particular practice sometimes differed between locations; increasing lamb survival was less valuable where breeding ewes comprised more of the flock. The results indicate that large opportunities exist to improve farm financial performance by optimising sheep management.

Table 1. Deviations from the base mean total farm, sheep and crop gross margins ($/ha) using a range of alternative management at Temora and Condobolin (1970–2015)

		Change in management						
Location		20% more crop area	No grazing winter cereals	50% reduction pasture growth	5% increase lamb survival	Increase 1 ewe/ha	Change lamb sale date	Later join date and increase ewe/ha
Temora	farm	32	–1	–91	15	22	39	40
	sheep	–13	22	–160	35	66	97	94
	crop	–13	17	–32	–1	–15	–10	–7
Condobolin	farm	28	3	–43	9	83		74
	sheep	–4	–5	–70	14	144		121
	crop	12	16	–2	1	–8		3

Reference

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Impact of selected demographics on consumer's weight preference for lamb roasts

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One of the strategies adopted by the Australian lamb industry to achieve carcases required for leaner, more consumer acceptable cuts was a focus on genetic improvement. This has seen a continuing rise in the average carcase weight of Australian lamb, with no signs that this trend is going abate. This has presented a challenge to the industry, as prepared in a conventional way, lamb cuts from such heavy carcases are too heavy for many modern domestic 1-2 person households. Consequently, there has been a re-emergence of cuts at the retail level developed in the 'Trim' lamb campaign of the mid 90's (Hopkins *et al.* 1995). While this has been a good strategy for the hind leg cuts, the challenge has been greater for the forequarter which has led to a program to develop new forequarter cuts (Fowler *et al.* 2017). To aid this process a survey was undertaken to establish consumer attitudes towards lamb shoulder roasts with a focus on the weight of the cut.

Respondents were first notified of the broad survey topic, the anonymity of data and its ultimate use, when first approached to participate in the survey. Demographic questions were then posed, and those relevant to this paper were: the age of the respondent, how many people lived in their household and how often they went food shopping (daily, few times a week, once a week, fortnightly or monthly). Furthermore respondents were required to indicate their ideal sized roast to feed their household (0.5, 1.0, 1.5, 2.0, 2.5, 2.5kg+, do not consume roasts, don't know). General linear models were used to examine the relationship between the various factors. All analyses were performed using the R statistical package (R Core Team 2017).

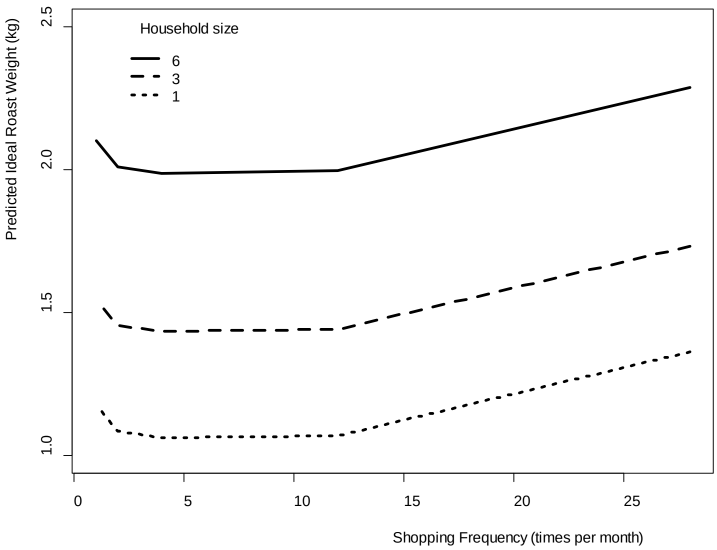

Fig. 1. The relationship between ideal roast weight (kg) the number of people in the household (1-6), and shopping frequency (times per month).

A total of 868 respondents participated in this study and they represented a range of demographics, with more respondents being female and the majority of respondents being in the 30-49 age group. As the number in a household increased the 'ideal weight' of a roast increased ($P < 0.001$: Fig. 1), and there was an impact on the 'ideal weight' of the frequency of shopping ($P < 0.001$: Fig. 1) such that respondents who shopped daily preferred the heaviest roasts. The 30-64 year-old respondents preferred the heaviest roasts ($P < 0.001$), with the 18–29 and 65+ year age groups preferring the lighter roasts. The lower weight considered ideal for these age groups would suggest a preference for smaller cuts. Furthermore, households with less people also have a preference for lighter roasts with an ideal of ~1.0 kg. These findings support the development of new smaller forequarter lamb roasts in line with the increase in 1–2 person households.

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Thresholds for technical replicates when measuring pH

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Establishing quality control procedures is important for laboratories, especially if accredited by the International Organization for Standardization. Under pinning this is the ability to make statistically based decisions about the need for repeating measurements. In the past we have developed such standards for traits like shear force (Hopkins *et al.* 2012) and particle size (Hopkins *et al.* 2014) of meat, along with the number of technical replicates which are required for producing robust means for traits such as shear force (see Holman *et al.* 2015). Other routine measures such as pH and intramuscular fat have been widely measured, but thresholds for deciding on the need to repeat measures have not been published. Based on a database the appropriate threshold was determined for pH which could be applied to a range of red meat samples.

Data from 4773 samples were used in this analysis. These data came from 35 experiments, based on beef, lamb and alpaca from 9 different cuts. Samples within experiments were tested after a range of different ageing periods (ranging from 0–14 days) and were all tested in the laboratory using the method adapted from Dransfield *et al.* (1992). For this procedure two measures are taken and then a third if the difference between the first two measures is considered too large. The analysis aimed to derive what the absolute difference (AD) should be before a third measure is required. The distribution of the AD was highly skewed, with most (91.1%) differences less than 0.03 AD (<0.021 SD). Where no third pH measurement was taken, 95.6% of duplicate pH measures were within 0.02. Where a third measurement was taken, most measurements differed between 0.03 and 0.1. In view of this, it was decided to truncate the AD at 0.03, denoted ADT (AD truncated). Therefore, ADT took four values: 0, 0.01, 0.02, and >0.02. ADT was then modelled in a mixed model with fixed effects of mean pH, muscle and species and all associated interactions, and random effects of experiment, and its interactions with muscle, species and mean pH. Since ADT takes four discrete values an ordinal analysis was also undertaken with the same fixed and random effects to confirm the results. This models the probability that the ADT takes values 0, 0.01, 0.02 and >0.02. All analyses were performed using the R statistical package (R Core Team 2017).

Where a 3rd pH measurement was taken, most pH3 (89.7%) were within 0.02 of either pH1 or pH2 measurement, suggesting that either pH1 or pH2 was an errant value. Where the pH3 min difference was >0.03 it was more likely to be when the difference between pH1 and pH2 was also large. There were significant effects of mean pH and muscle and a significant interaction ($P < 0.05$). There were no significant effects of species or interactions involving species. Of the random terms, there were also significant effects of experiment and experiment by muscle, but no significant interactions involving mean pH or species. Wald tests for the ordinal analysis were very similar to those of the linear analysis. The variance components were also very similar.

An average relationship between mean pH and ADT was considered adequate. There was a very significant relationship between mean pH and ADT, however the increase in ADT with mean pH was not appreciable over the range of pH in this data. Therefore, one can just look at the overall distribution of AD in which 8.9% (100-91.1%) of observations had an AD above 0.02, and 4.4% (100–95.6%) had an AD above 0.03. It is proposed that an AD above 0.02 be considered as the threshold above which a third measurement is taken.

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Thresholds for technical replicates when measuring intramuscular fat

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Establishing quality control procedures is important for laboratories, especially if accredited by the International Organization for Standardization. Under pinning this is the ability to make statistically based decisions about the need for repeating measurements. In the past we have developed such standards for meat traits like shear force (Hopkins *et al.* 2012) and particle size (Hopkins *et al.* 2014) along with the number of technical replicates which are required for producing robust means for traits such as shear force (see Holman *et al.* 2015). Other routine measures such as pH and intramuscular fat (IMF) have been widely measured, but thresholds for deciding on the need to repeat measures have not been published. Based on a database the appropriate threshold was determined for IMF which could be applied to a range of red meat samples.

Data from 122 observations from 10 experiments and 8 cuts were used in this analysis. Loin was the only cut where all three species (beef, alpaca, lamb) were measured, for the other cuts only lamb was measured. Samples within experiments were tested for IMF after freeze drying and grinding using the adapted Soxhlet method (Smith *et al.* 2017), where duplicate 2.5 g freeze-dried samples were extracted with 85.0 mL hexane for 80 min within a Soxtec machine and the residual oven dried for 30 min at 105 °C and weighed. The difference in tin weight before and after extraction constituted the IMF, which was then expressed as a percentage of fresh (wet) sample weight.

IMF data varied from 0.02 to 29.8%. In view of this large range (over two orders of magnitude), modelling the coefficient of variation (CV) was appropriate (initial models with standard deviation showed significant effects of mean not apparent in the final CV models). A log transformation of CV was applied to remove variance heterogeneity. Log (CV) was modelled in a linear mixed model with fixed cut by species by mean IMF effects and random effects for experiment, experiment by species (Loin only) and experiment and species by mean IMF interactions. All analyses were performed using the R statistical package (R Core Team 2017).

There were no significant differences in the mean response between cuts or species. However, interactions between muscle and mean IMF, and muscle and mean IMF and species (for the loin only), were almost significant at the 5% level. These effects were minor, and a model based on a simple CV is adequate (Fig. 1). Given that there was no significant relationship between CV and muscle or species, we considered the distribution of CV across the whole dataset to determine a threshold for taking a third measurement.

The estimated 90% and 95% quantiles of CV values are 11.5% and 17.9% respectively. It is suggested that a CV above 10% (rounding down from 11.5% for the 90% percentile) be adopted as a threshold for taking a third measurement.

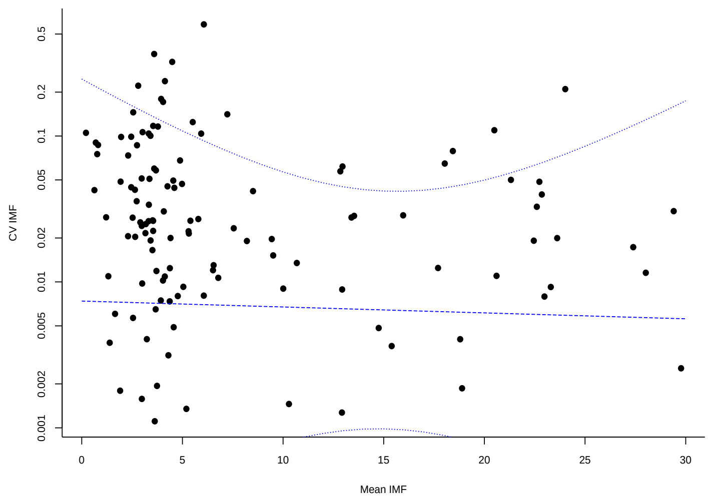

Fig. 1. Relationship between mean IMF and the CV of IMF (with 95% confidence interval).

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Comparing the Nix Color Sensor Pro™ and HunterLab MiniScan™ colorimetric instruments when evaluating aged beef colour stability over 3 days retail display

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Consumers will often base their perception of beef freshness on its colour and doing so, preferentially purchase beef that presents a bright red appearance. Meat scientists and industry are aware of this behaviour and have focused much effort on optimising beef colour appeal and endurance (stability) throughout retail display. Colorimetric instruments have been applied to objectively measure colour and can provide this information as CIE colour coordinates (L*, a*, b*) which can be used to calculate the total colour change over a selected period (ΔE). The HunterLab MiniScan™ (HUNTERLAB) is a common colorimetric instrument with a history of use to quantify beef colour (Tapp *et al.* 2011). The Nix Color Sensor Pro™ (NIX) has, at present, less of a background in meat colour measurement but has garnered interest because of its relative cheapness, connectivity and user-friendly interface (Holman *et al.* 2017). However, before comparing the results from these two colorimetric instruments, it is important to first compare their capacity to detect colour variation. Here we aimed to fulfil this paucity; using aged beef and measuring colour stability over 3 days retail display.

M. *longissimus lumborum* (LL; n = 8) were randomly selected from the boning room of a collaborating abattoir at 24 h post-mortem. These were divided into 6 equal portions (n = 42; portion within LL was recorded); vacuum packaged; and assigned to 1 of 3 ageing periods (0, 3 and 5 weeks) so that 2 portions from each loin were represented in each treatment combination. Once aged (1-2 °C), each sample was sectioned into slices (thickness: 3-4 cm); placed onto a black Styrofoam tray (dimensions: 13.5 cm^2) so the muscle fibres on the exposed surface were orientated perpendicular to the PVC over-wrap (food film thickness: 15.0 µm). These were allowed to bloom for 30-40 min at 1–2°C before the first colour measurement was recorded (0 d) – a further 3 measurements (1, 2 and 3 d) were taken across the subsequent 3 days at 1 day intervals (total: 4) between which samples were held under continuous florescent lighting (58 W NEC Tubes delivering 789 lx) and at 3–4°C. At each colour measurement interval both the HUNTERLAB (aperture: 25 mm; Model 45/0, HunterLab Associates Laboratory Inc., Hong Kong, PRC) and NIX (aperture: 15 mm; Nix Sensor Ltd., Ontario, CAN) were set at D65/10°, and the average CIE values from 4 (HunterLab 2012) and 7 (Holman *et al.* 2017) technical replicate measures respectively were averaged. Results from 0 d and 3 d were then transformed to ΔE as per AMSA (2012). This was then analysed using a linear mixed model with instrument as a fixed effect, and ageing period, LL, portion and their interactions as random effects.

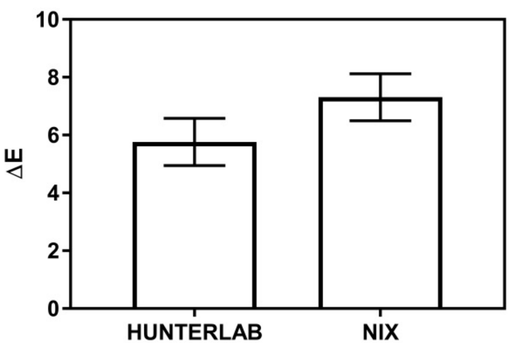

Fig. 1. Predicted mean (± standard error) total colour change (ΔE) of beef held for 3 d retail display as measured using two different colorimetric instruments: HunterLab MiniScan™ (HUNTERLAB) and Nix Color Sensor Pro™ (NIX).

Figure 1 shows NIX ΔE to be higher ($P < 0.01$) than for the HUNTERLAB which suggests that the NIX captured or detected more variation in beef colour compared to the HUNTERLAB across the 3 days of retail display. Potential explanations for this observation could include; the fewer technical replicates taken for the HUNTERLAB; the smaller NIX aperture preventing 'edge-loss' and allowing connective tissue and fatty deposits to be better avoided; or instrumental calibration and reproducibility differences. Based on this outcome, there is a need to compare further these instruments in terms of their capacity to measure specific CIE coordinates that underpin consumer acceptance of beef colour.

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Holding temperature and time effects on the colour stability (CIE colorimetrics) of aged beef

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Consumers are willing to pay a premium for beef that is guaranteed as tender; and ageing, wherein beef is held under cold storage for a period following slaughter to tenderise, is a practical means for industry to capitalise on this opportunity. Consumer purchasing behaviour is also influenced by beef's colour and therefore it is of commercial interest to preserve acceptable colouration during display (stability) to optimise its retail-potential. Past research has identified temperature as an important factor driving the efficacy of ageing (Coombs *et al.* 2017) – but additional understanding of temperature-time implications on beef colour stability is necessary before its application within the Australian industry can be determined. This project aimed to address this requisite and explore ageing temperature and time effects on beef colorimetrics across 3 d of retail display.

Twenty beef (LL; M. *longissimus lumborum*) were randomly selected; divided into 8 equal portions (n = 160), which were individually vacuum packaged; and assigned so that 12 portions representing 6 different LL were allocated to each of 4 ageing periods (Age; 6, 8, 10 and 12 d) × 3 holding temperatures (Temp; A, B and C). Each Temp was applied within a single unit (TCU; CF-80DZ WAECO™, Dometic Ltd., AUS) and monitored using ambient temperature loggers (Table 1). All remaining portions were held for 14 d at control temperatures that represented industry practice (n = 8 per TCU). At the completion of their assigned treatment combination, the internal temperature of each portion was recorded. Each portion was then sampled, overwrapped and placed under retail conditions – displayed at 3-4°C beneath continuous fluorescent lighting (Holman *et al*. 2018). Colorimetrics (CIE: L*, a* and b*) were recorded in duplicate, at 4 intervals over 3 d (Display), and using the same spectrophotometer (Model 45/0-L, MiniScan™, HunterLab Associates Laboratory Inc., Hong Kong, PRC) with a 25 mm aperture and D65/10° settings. Data were then analysed using a linear mixed model with Temp, Age, Display and their interactions fitted as fixed effects; LL, portion and their interactions fitted as random effects.

Table 1. Temperature control unit (TCU) mean ± standard deviation ambient temperatures and internal sample temperatures

TCU	Ambient Temp. (°C)	Internal Temp. (°C)
A	3.2 ± 2.3	3.6 ± 0.5
B	4.5 ± 1.2	4.5 ± 0.6
C	6.4 ± 1.5	6.8 ± 0.6
Control1	1.0 ± 2.0	0.6 ± 0.3
Control2	1.6 ± 1.8	1.4 ± 0.5

Temp, Age and Display 3-way interactions were only shown to affect a* (P = 0.002). Independently, Temp and Age had significant 2-way interactions with Display on L* and b* (Fig. 1). From these outcomes, it was evident that colour stability implications must be considered when ageing temperature-time parameters are manipulated (e.g. for tenderisation purposes) but compared to the threshold for consumer acceptance of beef colour we recognise these effects may be of little practical significance – within the constraints of this study.

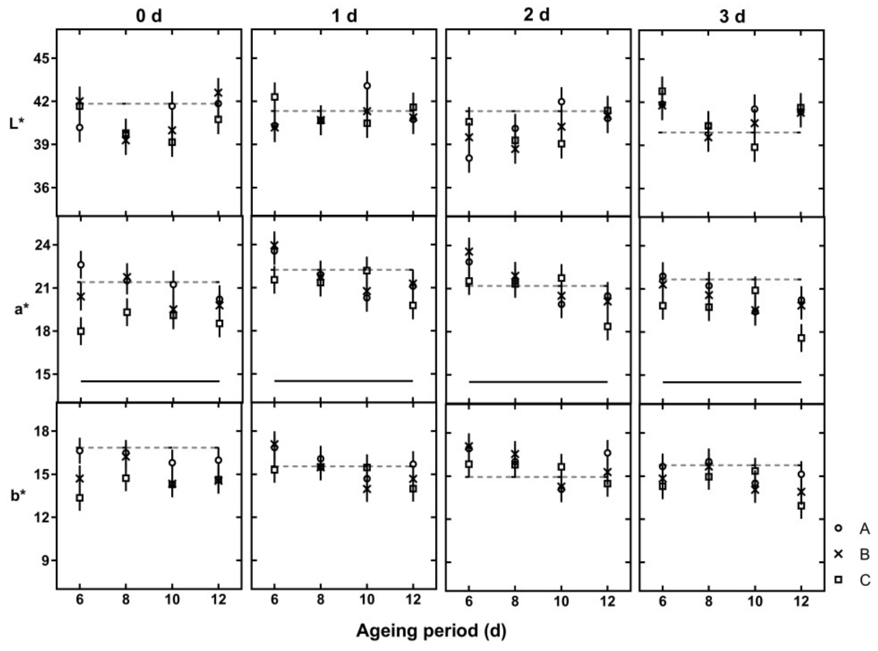

Fig. 1. Predicted mean L*, a* and b* colorimetrics (± standard error) of displayed (0-3 d) beef loins aged at different temperature and time combinations. Controls were averaged and shown as dashed-grey lines. Holman et al. (2017) a* consumer acceptance threshold was included as a solid-black line in the corresponding plots.

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Implications of step chilling on meat color investigated using proteome analysis of sarcoplasmic fractions of beef *longissimus lumborum* muscle

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pH-temperature control of pre-rigor muscle is often used to improve beef tenderness, based on the concept of an optimal pH-temperature window. For hot boned meat one way to target the window is to apply steps in the chilling process. Therefore, a step chilling (SC) procedure was applied on excised bovine *longissimus lumborum* muscle, starting at 0–4°C for 5 h, then holding the temperature at 12-18 °C for 6h, followed by 0-4°C again until 24h post-mortem. The sarcoplasmic proteins were extracted from the step chilling beef samples, as well as control samples, held under routine chilling (RC, 0–4°C, till 24 h post-mortem) at 24 h, 7 d and 14 d post-mortem to investigate the effect on the sarcoplasmic proteome as a result of SC. For the color traits, the MIXED procedure (SAS, 9.0) was used with chilling methods, storage time and their interaction fitted as fixed effects, and animal (n = 6) as a random effect. Tests of differences were applied using the PDIFF statement and significant difference was set at $P < 0.05$. Proteins with a minimum fold change of 1.5 ($P < 0.05$) were detected by comparing the averaged spot intensities of triplicate gels of the same samples ($n = 3$) with three comparison groups (SC vs. CC at 1, 7, 14d, respectively).

It was shown that muscles subjected to SC had a temperature at around 15°C for 5 to 10 h post-mortem, and exhibited a slow temperature, but rapid pH decline. Beef steaks treated with SC had better lightness (L^* values), redness (a^* values) and chroma than those of RC samples at 1 and 7 d chilled storage, while there was no significant difference for a^* values and chroma at 14 d (Table 1). The SC samples also exhibited a lower relative content of surface metmyoglobin, higher metmyoglobin reduction ability and NADH content (Table 1), compared with RC beef steaks during storage, indicating the SC treated beef showed a better color stability. A total of 28 differential protein spots were identified by two-dimensional gel electrophoresis and mass spectrometry. Bioinformatics analysis indicated most of them were involved in glycolysis and energy metabolism (phosphoglycerate mutase, malate dehydrogenase, pyruvate dehydrogenase, and adenosine kinase), and stress response (peroxiredoxin, heat shock 70 kD protein, glutathione S-transferase, alpha-aminoadipic semialdehyde dehydrogenase) and etc. The present study provided valuable information for understanding the molecular mechanisms responsible for the color improvement which results from step chilling, as well as for screening markers associated with beef color.

Table 1. Effect of chilling methods on the color and color related traits of beef steaks from *longissimus lumborum* muscle during storage time

Trait	Chilling method	Storage time (days) 1	7	14	SE
L^*	SC	40.7^{bx}	42.9^{ax}	42.6^{ax}	1.61
	CC	38.8^{by}	41.0^{ay}	40.5^{ay}	
a^*	SC	21.8^{bx}	23.9^{ax}	19.1^{cx}	0.53
	CC	19.9^{by}	21.9^{ay}	17.9^{cx}	
Choma	SC	26.2^{bx}	28.4^{ax}	23.5^{cx}	0.52
	CC	23.7^{by}	25.4^{ay}	23.6^{bx}	
MetMb*	SC	0.58^{cx}	0.73^{bx}	0.87^{ax}	0.01
	CC	0.63^{cy}	0.77^{by}	0.93^{ay}	
MRA (%)	SC	80.6^{ax}	90.2^{ax}	84.2^{ax}	3.34
	CC	58.7^{by}	78.4^{ay}	64.8^{by}	
NADH	SC	59.3^{ax}	50.3^{bx}	42.4^{cx}	3.02
(mmol/g)	CC	52.0^{ay}	41.3^{by}	35.4^{cy}	

*Relative content of MetMb was calculated based on the transformed equation: [2 -(K/S572)/(K/S525)] (Li *et al*. 2012).
a–c, Means within the same treatment differ along storage times; x-y: Means differ between chilling methods ($P < 0.05$).

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Effect of animal and abattoir factors on incidence of dark-cutting in Australian feedlot beef cattle

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Dark-cutting (DC) in beef carcasses is a complex multifactorial condition influenced by pre- and post-slaughter factors including animal nutrition and temperament, duration of transport, abattoir management, and seasonality (Knee *et al*. 2004). In Australia, a carcass is classified as DC when the meat ultimate pH (pHu) of the *m. longisumus thorasis* at the quartering site is greater than 5.70 or when the meat colour is greater than AUS-MEAT colour 3 (AUS-MEAT 2005). The 2015–17 Australian beef eating quality audit reported high pHu as the main reason for non-compliance. The reported incidence of DC was 7–12 % in grass-fed and 1.5–2.5 % in grain-fed cattle, with an increased incidence in late summer and early autumn. It is recognized that the higher incidence of DC carcasses from grass-fed compared to grain-fed cattle is associated with seasonality of pasture availability and energy content (Knee *et al*. 2004), however, the exact causes of dark cutting in feedlot animals have not yet been identified.

A data set which was previously analysed for rate of pH fall (Warner *et al.* 2014) was used to investigate the factors influencing dark-coloured meat and elevated pHu in carcasses from grain-fed Australian cattle. Data was collected over 4-5 days from 1090 beef carcasses from 6 processing plants in Queensland, New South Wales, Victoria and Western Australia between March and May 2006. Data recorded and included in the model were; hot carcass weight (HCW), pHu, and meat colour (using AUS-MEAT standard colour chips; 1a = palest to 6 = darkest) measured at grading, loin temperature at pH 6 (Temp@pH6; calculated by interpolation from pH and temperature measurements in the *longissimus*), eye muscle area (EMA), and days on grain or concentrate feeding (DOF; 60 to 350 days). Data were analysed using GenStat software (GenStat 18, VSN International Ltd, Hemel Hempstead, UK) using a logit transform, binomial distributions and General Linear Mixed Models to analyse the carcass and animal parameters that determine dark meat colour and high pHu incidences, and Restricted Maximum Likelihood to analyze the effects of carcass and animal parameters on pHu. Fixed effects were HCW, EMA, DOF, and Temp@pH6. Random effects were plant/date/chiller/lot (ie. lot was nested within chiller which was nested within date which was nested within plant).

For these grain-fed cattle, the incidence of pHu > 5.70 ranged from 0 % in Western Australia to 24.6 % in Queensland, the incidence of dark- coloured meat (meat colour score > 3) ranged from 0 % in Western Australia to 24.5 % in New South Wales. The incidence of carcasses failing in both characteristics varied from 0 % in Western Australia to 12.3 % in New South Wales, and carcasses from Queensland and Victorian abattoirs ranged from 0.7 to 2.6 %. This indicates that dark-coloured meat in grain-fed cattle is not always accompanied by high pHu, in agreement with Mahmood *et al.* (2017) who attributed this variation to differences in glycolytic potential and mitochondrial activity between typical DC (high pHu-dark colour) and atypical DC (normal pHu-dark colour) meat. Carcasses from animals with larger EMA and carcasses with higher Temp@pH6, all had lower incidences of high pHu ($P < 0.05$). An increase in EMA from 40 to 100 cm^2 is predicted to result in a decrease in pHu of 0.5 units. Carcasses from animals with longer DOF, higher HCW, and higher Temp@pH6 all had lower incidence of dark meat colour ($P < 0.05$). Carcasses with bigger EMA are generally the result of long term high energy intake and thus high pre-slaughter glycogen reserves, large HCW and lower DC incidence, in agreement with McGilchrist *et al.* (2012). An increase in Temp@pH6 from 27 to 41°C is predicted to decrease the pHu by 0.07 units and produce paler meat which is consistent with the lower pHu seen in PSE (pale soft and exudative) meat observed in pigs.

Many studies focus on pre-slaughter stress and nutrition influencing the presence of dark-coloured and high pHu meat. But this study suggests that for grain-fed cattle, beside pre-slaughter energy intake and HCW, post-slaughter metabolic activity (eg. glycolytic potential) and mitochondrial activity need to also be assessed when investigating causative factors for DC in grain-fed beef carcasses.

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Comparative assessment of eating qualities of biltong (beef, chevon and mutton) cured with *ocimum gratissimum* paste

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The value of meat and its products to the purchaser are mostly dependent on eating quality and keeping quality as well as nutritional values (Warner *et al.* 2010). However, untreated fresh meat normally has a short shelf life resulting in spoilage; hence different processing methods are required to process into shelf stable meat products (biltong). *Ocimum gratissimum,* a leafy medicinal plant with high phytochemical activity (Mlitan *et al*. 2014) was used as a curing agent in processing to extend shelf life. *Ocimum gratissimum,* is high in flavours, chemotherapeutics and antimicrobial properties (Wills *et al*. 1998), hence it can be used as a curing agent. A study was undertaken aimed at investigating the impact of this plant on organoleptic traits of biltong, a ready-to-eat dried meat product which can be based on different meat types.

Meat types (beef, chevon and mutton) were cured with *Ocimum gratissimum* paste (Ogp). The paste was obtained by blending leaves (1.360 kg). The meat types were cut into 8 - 10 x 2 x 1.5 cm strips along the grain. Strips of the meat types were allocated to six treatments (controls and treatments) and each treatment was replicated twenty times and labelled as T^1, T^3, T^5 for controls (no Ogp) and T^2, T^4, T^6 for beef, chevon and mutton, respectively. Treatments (T^2, T^4, T^6) were cured with (Ogp) paste for a period of 10 hours. After curing, both uncured and cured meat strips were dipped into a mixture of hot water (100^{o}C) and vinegar for two hours to prevent mould growth and all were mildly seasoned. The strips were then sundried for a whole day under insect free conditions and transferred to shade for two weeks (75% relative humidity). Biltong samples were served to 40 panelists (semi-trained and trained members) of both sexes, with ages ranging between 25–35 years old. Panelists used a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely) to grade how much they liked or disliked each sample and microbiological analysis was undertaken. Data collected from this study were analysed using analysis of variance where model terms include (Dependent variable, population mean, fixed effect of treatment and random residual error) were analyzed using (SAS 2002) while means were separated using the Duncan Multiple Range Test from the same software.

The taste panellists rated beef biltong (T^2) as the highest scores ($P < 0.05$) for colour (3.93 ± 0.78), texture (3.78 ± 0.14), juiciness (4.81±0.26), flavour (6.85 ± 0.57) and overall acceptability (7.37±0.32) and this was closely followed by the flavour (6.07 ± 0.88) and acceptability (7.03 ± 0.58) of chevon biltong (T^3 and T^4). This is in accordance with the results of Anjaneyulu *et al.* (2007), who reported that most consumer's judge meat and meat products based first on colour and then flavour, while mutton biltong (T^5 – 5.11 ± 0.60 and T^6 – 2.14 ± 0.59) flavour and texture respectively, recorded the least preference in parameters considered and this corroborates the report of Okubanjo (1990) that most citizens of developing countries like Nigeria prefer less tender meat/meat products probably for longer chewability.

Table 1. Sensory evaluation of biltong meat types cured with *Ocimum gratissimum* paste

Parameters/meat types (%)	Colour	Texture	Juiciness	Flavour	Saltiness	Overall Acceptability
Beef T^1	$3.76±0.12^b$	$3.38±0.84^{ab}$	$4.01±0.26^a$	$6.45±0.57^a$	$3.62±0.27^b$	$5.97±0.31^b$
Beef T^2	$4.16±0.12^a$	$3.78±0.14^a$	$4.81±0.26^a$	$6.85±0.57^a$	$4.02±0.40^a$	$7.37±0.32^a$
Chevon T^3	$3.93±0.78^b$	$3.36±0.62^{ab}$	$4.04±0.99^a$	$6.07±0.88^a$	$3.71±0.46^b$	$5.07±0.56^b$
Chevon T^4	$3.90±0.81^b$	$3.30±0.66^{ab}$	$3.93±0.80^b$	$6.00±0.71^a$	$3.70±0.49^b$	$7.03±0.58^a$
Mutton T^5	$2.78±0.12^c$	$2.89±0.77^b$	$2.96±0.99^c$	$5.11±0.60^b$	$3.44±0.25^b$	$4.81±0.59^c$
Mutton T^6	$2.86±0.11^c$	$2.14±0.59^b$	$3.00±0.20^b$	$5.14±0.58^b$	$3.46±0.23^b$	$4.06±0.56^c$

$^{a–d}$, Means on the same row with different superscripts are significantly different ($P < 0.05$).

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Effects of transient hypo- and hyperthyroidism on the compensatory growth of broilers and Fe retention in their meat

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Red meat is an important source of iron (Fe) in human nutrition, but the fat in meat is a limiting factor especially for obese persons with heart disease. In animals the majority of Fe is stored in red blood cell and muscles. Animals have a limited capacity to excrete iron (Kreutzer and Kirchgessner, 1991), so that retention is largely controlled by absorption. Iron is absorbed according to need and is therefore affected by factors such as the iron status of the body and age. As such storage of iron in meat occurs with aging (Underwood and Suttle, 2000). Some studies have proposed that thyroid hormones have an inhibitory effect on body cell proliferation and also simultaneously, a stimulatory effect on cell differentiation (Holsberger and Cooke 2005). Differentiation development occurs with aging, specially, in muscles by hypertrophy and iron storage. The aim of this study to enrich chicken meat with Fe, by transient hypo or hyper thyroidism after feed restriction. A total number of 600 one-day broiler chicks were allocated to 6 experimental groups with 4 replicates per treatment (n=25) in completely randomized design. Experimental groups included: 1) control group(C), 2) control group + Fe supplementation in grower phase diet (C+Fe), 3) feed restriction group: 24 feed restriction from 9 to 18 days of age (FR), 4) FR + Fe supplementation in the grower phase diet (FR+Fe), 5) FR+Fe in conjunction with induced hyperthyroidism in the grower phase (HyperT) by levothyroxin (T4) administration and 6) FR+Fe in conjunction with induced hypothyroidism in the grower phase (HypoT) by Methimazole (MMI) administration. Based on statistical analysis with Duncan's multiple range test, the lowest feed consumption was observed in the FR group while birds in the control group consumed more feed than other experimental groups ($P < 0.05$). There were no significant differences in body weight and average daily gain among experimental groups ($P > 0.05$). Lower feed intake during the restriction period in FR groups led to lower body weight in them (data are not shown); therefore There is a compensatory gain after feed restriction removal that is expected by higher muscle growth. Assessment of iron concentration in chicken meat showed a higher Fe concentration in the HypoT group compared to the others (P<0.05). The European Poultry Efficiency Factor (Hristakieva et al, 2014) in the end of study was higher in the FR group than other experimental groups, especially, the control group ($P < 0.05$). Results of this study indicated that transient hypothyroidism in conjugation with Fe supplementation in the grower phase after feed restriction lead to a higher Fe content in broiler chicken meat. However further studies are needed about the produced meat in human nutrition.

Table 1. Effects of transient hypo- and hyperthyroid activity induced by Methymazole (MMI) and levothyroxine (T4), respectively, on commercial traits and Iron (Fe) retention in broiler chickens

	Body weight (gr)	Feed Intake (gr/day/bird)	Average Daily gain (gr/day/bird)	Feed conversion rate	European Poultry Efficiency Factor	Meat Fe content (gr Fe/Kg meat)
C	2939	116.0 [a]	57.09	2.04 [a]	235.83 [c]	0.0086 [b]
C+Fe	2951	110.7 [b]	57.11	1.94 [a]	248.84 [bc]	0.0089 [b]
FR	3046	97.7 [e]	59.46	1.65 [c]	342.39 [a]	0.0078 [b]
FR+Fe	3021	106.6 [cb]	59.87	1.81 [b]	289.79 [b]	0.0085 [b]
FR+T4+Fe	2963	106.3 [cd]	58.38	1.82 [b]	294.25 [b]	0.0059 [b]
FR+MMI+Fe	2863	102.7 [d]	56.95	1.80 [b]	297.57 [ab]	0.0124 [a]
SEM	43.05	1.12	1.31	0.039	14.92	0.0024
P-value	0.244	<0.0001	0.46	0.0003	0.0036	0.037

A different letter within columns indicates a significant difference ($P = 0.05$).

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Prediction of intramuscular fat of lamb loin using a hand-held near-infrared device

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Intramuscular fat (IMF) is a trait which is important to Australian lamb processors as it contributes to the nutritive characteristics and eating quality of retail lamb cuts. While health concerns during the 1970's and 1980's led to consumers seeking leaner meat products, fat content also determines juiciness and flavour which are important eating quality traits. Near Infrared (NIR) spectroscopy has been extensively used as a method for measuring the fat content of foods as the long chain fatty acids give rise to distinct peaks in the spectra. However, much research on the use of NIR to predict IMF has been completed on samples which have been freeze dried and homogenised prior to analysis. Therefore, the aim of the current study was to determine the potential for two hand held NIR devices to measure the IMF of lamb carcases in at-line and on-line situations.

The *m. longissimus lumborum* (LL; loin) of 175 randomly selected carcases were measured at a commercial lamb processing plant. The loins were measured at 25 min post mortem (PM) and 24 h in-situ through a slit in the subcutaneous fat on the caudal portion of the LL below the *m. gluteus medius* (rump) using a TerraSpec® 4 NIR system (ASD Inc.). Spectra were collected in transmission mode with an integration time of 10s in 5 positions and were recorded in wavelengths between 350 nm to 2500 nm. IMF analysis was completed using the Soxhlet method (AOAC 1992). Partial least squares regressions were conducted using Matlab software (The Mathworks Inc. 2013).

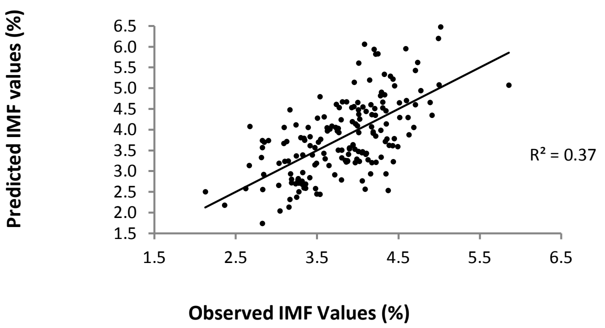

Fig. 1. Prediction of loin IMF using spectra measured at 24 h post mortem.

Using spectra collected at 25min PM, there was some ability to predict IMF (R^2 = 0.26), however there was a slightly greater ability to predict IMF using spectra collected at 24 h PM (R^2 = 0.37; Fig. 1). These results are similar to findings in pork where R^2 values of 0.35 and 0.29 have been reported (Balage *et al.* 2015) although the range of IMF percentages in pork was identified as a limiting factor.

As the lamb loins measured had a range of IMF values from 1.42–7.58% with a mean of 3.8% (s.d 1.08), 95% of the samples in the current study had an IMF content of between 1.86–5.74%. Therefore it is plausible that this small range of IMF values limited the accuracy of the calibration models as the accuracy of regression models, including partial least squares regression, is dependent on the range of the data set (Davies and Fearn 2006). Thus, the models presented here may be further improved by increasing the range of IMF values of carcases measured to create calibration models to include a larger number of carcases with low and high IMF contents.

Overall, the results from this study indicate that there may be potential to predict IMF values of lamb carcases using hand held NIR devices. However further development is still required before industry can benefit from the method which includes the development of calibration models with a larger range of IMF values.

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Characteristics of two southern Australia pasture-fed beef supply chains

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One of the goals in modern beef supply chains is for producers to target specialist market segments such as farm assured pasture-fed product that meets processor and Meat Standards Australia (MSA) specifications. A number of processors operating in this market segment draw their livestock from a range of Australian states, and face challenges to their supply chain management due to variability in livestock producer management practices, type of stock and climatic conditions.

Carcase data were obtained from a farm assured pasture-fed supply chain in each of Victoria (Vic; n = 134,114) and Tasmania (Tas; n = 49,942) between 1 May 2015 and 31 May 2017. Both supply chains were targeting supply of carcases of 280-320 kg hot carcase weight (HCWT) and 5–22 mm P8 fat depth and meeting MSA requirements. The MSA data, collected by MSA graders, were analysed using an unbalanced analysis of variance (Genstat 18th Edition) to explore differences ($P \leq 0.05$) in carcase attributes between the two supply chains. Average monthly attributes are shown in Table 1.

The Vic supply chain sourced stock that provided carcases that were more than 39 kg HCWT heavier across the year resulting in average weights in January, October, September and November being higher than the 320 kg maximum specification. The least difference occurred in June and July. The Vic supply chain provided carcases with P8 fat depths that were generally consistent with the Tas supply chain, with the greatest differences in fat depths occurring in August, September, December and January. In contrast the Tas supply chain provided carcases with rib fat depths greater than the Vic supply chain from March to July. The Tas supply chain had a consistently higher pH through the year with overall average pH being 5.55 and 5.60 for the Vic and Tas supply chains respectively. The Tas supply chain carcases also had greater average eye muscle area (EMA) across the year, likely as a result of processing and grading differences where the Tas supply chain processes a Spencer Roll, influencing eye muscle shape (M. Inglis, *pers. comm.*).

The study revealed significant differences in carcase attributes over two years for cattle supplied through two distinct supply chains that were targeting the same market specifications. The differences described may be a result of using different pasture-based finishing systems and management for source livestock. They could also reflect differences in stock genetics that impact on maturity at finish, or differences in processing for end product that could influence carcase attributes such as EMA.

Finishing systems for pasture-fed beef are significantly impacted by seasonal conditions and producers' feed-base and livestock management skills. To maintain efficiency and optimise value in supply chains, producers and processors need to identify constraints in the supply chain that may impact on the opportunity to create product(s) with the highest retail value. Tan (2002) noted that an integrated supply chain requires commitment by all members of the chain and the exchange of relevant information. Where livestock are supplied to meet specific customer needs, this information exchange supports the integrated performance of procurement and logistics strategies.

Table 1. Average monthly carcase attributes from Victoria (Vic) and Tasmania (Tas) supply chains

Attribute	Chain	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
HCWT	Vic	321^{a}	320^{a}	315^{a}	312^{a}	307^{a}	296^{a}	305^{a}	316^{a}	322^{a}	321^{a}	324^{a}	324^{a}	317^{a}
(kg)	Tas	280^{b}	290^{b}	284^{b}	284^{b}	277^{b}	275^{b}	275^{b}	266^{b}	273^{b}	279^{b}	279^{b}	286^{b}	279^{b}
P8	Vic	11.4^{a}	10.6	10.2^{a}	10.5	10.8	10.1	10.8^{a}	10.8^{a}	11.2^{a}	11.4	11.3^{a}	11.5^{a}	10.9^{a}
(mm)	Tas	10.4^{b}	10.9	10.9^{b}	10.5	10.5	10.4	10.4^{b}	9.7^{b}	9.9^{b}	11.1	10.6^{b}	10.5^{b}	10.5^{b}
Rib fat	Vic	7.9^{a}	7.8	7.8^{a}	7.6^{a}	7.6^{a}	7.0^{a}	6.9^{a}	7.6	7.9^{a}	8.3	8.2	8.3^{a}	7.8^{a}
(mm)	Tas	7.5^{b}	7.7	8.2^{b}	8.1^{b}	8.3^{b}	8.1^{b}	8.1^{b}	7.9	7.1^{b}	8.2	8.3	8.0^{b}	8.0^{b}
EMA	Vic	68.4^{a}	67.8^{a}	67.2^{a}	68.4^{a}	69.5^{a}	71.6^{a}	72.1^{a}	70.9^{a}	71.0^{a}	70.8^{a}	69.9^{a}	69.1^{a}	69.4^{a}
(cm^2)	Tas	73.8^{b}	74.0^{b}	74.9^{b}	74.9^{b}	75.1^{b}	74.5^{b}	74.6^{b}	75.1^{b}	74.4^{b}	74.8^{b}	74.6^{b}	74.3^{b}	74.6^{b}
pH	Vic	5.54^{a}	5.53^{a}	5.54^{a}	5.54^{a}	5.57^{a}	5.55^{a}	5.55^{a}	5.55^{a}	5.55^{a}	5.54^{a}	5.55^{a}	5.53^{a}	5.55^{a}
	Tas	5.59^{b}	5.62^{b}	5.61^{b}	5.61^{b}	5.61^{b}	5.60^{b}	5.60^{b}	5.60^{b}	5.59^{b}	5.60^{b}	5.59^{b}	5.59^{b}	5.60^{b}
MSA	Vic	60.9^{a}	60.7	60.7	60.5^{a}	60.8^{a}	60.4	60.2^{a}	60.5^{a}	60.8^{a}	61.0^{a}	61.0^{a}	61.2^{a}	60.8^{a}
Index	Tas	60.4^{b}	60.6	60.8	60.8^{b}	60.3^{b}	60.4	60.0^{b}	59.9^{b}	60.1^{b}	59.4^{b}	60.1^{b}	60.6^{b}	60.3^{b}

[a,b]Means followed by a different superscript within a column are different at the $P \leq 0.05$ level.

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We gratefully acknowledge JBS Southern Australia for providing access to carcase data.

The role of pre-slaughter hide washing in the hygienic supply of beef

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Minimising enteropathogen contamination is crucial to the safe production of beef. To achieve this, many curative and preventative strategies are implemented throughout the beef supply chain, including pre-slaughter hide washing in abattoir lairage. The effectiveness of this procedure in preventing the spread of pathogens to the carcass and packaged primals is unclear, though literature suggests it worsens contamination (Bell 1997; Mies *et al.* 2004). In addition, there is little published on the effect of washing on meat quality and animal welfare aspects of production.

Pre-slaughter hide washing involves cleaning the live animal with water to improve visible and microbiological cleanliness. The exact method by which this is conducted varies and may include: misting from below (Preston *et al.* 2016), power-hosing (Bryne *et al.* 2000; Preston *et al.* 2016), belly washing (Preston *et al.* 2016), commercial cattle washing systems applying water from above and beneath the animal (Mies *et al.* 2004), or a combination of these. The ideal time point for pre-slaughter washing to occur is unclear, and it may take place anywhere as early as two days (Petersen 1983) or as late as 15 minutes prior to slaughter (Kannan *et al.* 2007). Pre-slaughter cleanliness is regulated by Australian and International standards, including the Australian Standard for Hygienic Production and Transportation of Meat and Meat Products for Human Consumption (AS 4696-2002), and the CODEX Alimentarius Code of Hygienic Practice for Meat (CAC/RCP 58-2005).

The improvement in visible cleanliness of the hide provided by pre-slaughter washing has not been formally quantified in the literature, with results simply stating that animal cleanliness improved (Bell 1997; Bryne *et al.* 2000). The effect on visible carcass contamination has been reported in lambs and suggests carcasses from washed animals have less macro contaminants compared to those from unwashed animals (Biss and Hathaway 1996). The improvement in microbiological cleanliness provided by pre-slaughter washing has been evaluated on both the hide and carcass. Of the various methodologies tested, the most effective have little to no effect on hide contamination (Bell 1997; Bryne *et al.* 2000), and some actually increase contamination (Mies *et al.* 2004). The relationship between pre-slaughter washing and subsequent microbiological contamination of the carcass also lacks rigor. Studies have reported that carcasses from washed animals had greater contamination (Bell 1997), or no significant difference in contamination from unwashed animals (Bryne *et al.* 2000). The available literature suggests that improvements in visible cleanliness do not always correspond to improvements in microbiological cleanliness, and that whilst pre-slaughter washing may produce an animal that is acceptable in terms of visible cleanliness, the effect on subsequent carcass contamination is, at best, negligible.

The effect of washing the live animal on behavior and welfare has received little attention. In one study of goats, the increase in blood indicators of washed animals was not significantly different to unwashed (Kannan *et al.* 2007). However, whilst being washed 'the animals tended to move during the initial seconds in an effort to avoid the water spray' (Kannan *et al*. 2007), suggesting the treatment was a stressor. Preston *et al.* (2016) reported similar observations and a strong positive correlation between cattle mounting and the number of washes with a high-pressure hose. The number of washes was also related to ultimate pH and the incidence of dark cutting (Preston *et al.* 2016), similar to the relationship observed by Petersen (1983) in lamb carcasses. These studies suggest pre-slaughter washing is a stressor affecting behavior and welfare, though further investigation is required.

Pre-slaughter washing is ineffective at consistently controlling contamination, and has potentially negative effects on animal welfare, behavior, and resultant meat quality. There is much scope for further work in this area to ensure washing methodologies are fit for purpose and not detrimental to the quality and consistency of beef produced.

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Development of a national standard language to describe seed contamination of lamb carcasses at slaughter

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Grass seed contamination of carcasses is a problem affecting all sectors of the lamb supply chain. In 2012, Meat & Livestock Australia (MLA) commissioned a national survey of Australian sheep and lamb processors which revealed grass seed contamination to be the number one problem facing many businesses (Collins 2013). The desire of key industry sectors to collaborate and develop a national focus and communication strategy to address the issue of seed contamination, led to the development of a National Grass Seed Action Plan (2013–2015), involving the whole of the lamb supply chain.

Producer awareness and education were recognised as an essential strategy for addressing the problem. The lack of a standard language to describe seed contamination of lamb carcasses was identified as an impediment to improved producer understanding of the impact of seed on the processing sector.

Consequently, Australian lamb processors are collectively working towards the adoption of a new language to describe seed contamination in lamb carcasses at slaughter, which all processors will use when delivering feedback to producers. The introduction of this national standard will reduce confusion for lamb producers and their agents, ensuring that any feedback about seed contamination is consistent across processing plants.

The new language, developed in consultation with processors, is based on the location of the seed in the carcase and the potential impact that it may have on the final value of that carcase. A large number of seeds on the flanks, while annoying and requiring trimming of the carcase, does not have as large an economic impact on the value of the final product, as compared to a small number of seeds lodged within a high value cut such as the loin.

The use of this language and the reporting of seed contamination in a line of lambs is triggered if seed is detected in carcasses on the slaughter chain, and the slaughter floor supervisor determines it necessary to either:

- send carcasses to the retain rail for further trimming; or
- the chain speed requires slowing to enable extra trimming; or
- extra trimmers are required on the chain.

If any of these scenarios are required in order to contend with the amount of seed, then the level of contamination is recorded as follows:

1. Any seed in ***Section 1*** of the carcase means it is described as having ***heavy*** seed contamination.
2. If there is no seed in Section 1 but there is seed in ***Section 2***, then the carcase is described as having ***medium*** seed contamination.
3. If there is only seed in ***Section 3***, then the carcase is described as having ***light*** seed contamination.

The presence of infected seeds means the carcase is graded as heavily contaminated, regardless of the location of the seed.

The carcase inspector then estimates the percentage of the lot with heavy, medium and light seed.

A number of the major lamb processing facilities in Australia have now moved to adopt this language and once embraced by all processors, it will provide clearer market signals to producers and their agents, thus leading to a better understanding of the impact of seed contamination in the lamb supply chain and facilitating the adoption of practices to mitigate this issue.

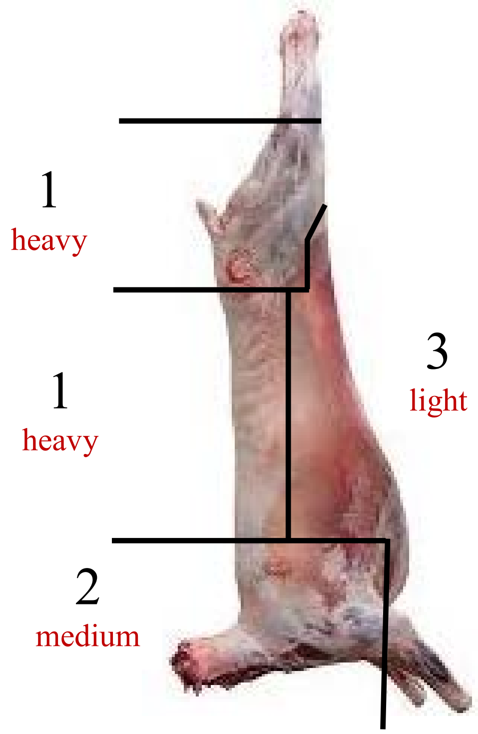

Fig. 1. Sections of the lamb carcase used to define seed contamination.

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Measuring drip loss techniques and the impact on alpaca (*Vicugna pacos*) meat quality

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Water holding capacity is a meat quality attribute that can influence eating quality and can cause variation in weight. Low water holding capacity meat will lose weight in the form of purge, resulting in a loss of economic value as meat is sold on a per kg basis. Drip loss is an indicator of water holding capacity, measured using a variety of methods including the traditional bag method and newer EZ method (Honikel 1987; Rasmussen and Andersson 1996). Currently drip loss measurements have not been reported for alpaca meat. This study investigates two methods of determining drip loss as indicators of the water holding capacity of alpaca meat. The EZ method is more standardised and easier to be reproduced. This study assesses the viability of the new EZ drip loss method in alpaca meat by comparison to the bag method.

A total of 160 individual castrated male huacaya alpacas were sampled across a 10 month period with a total of 16 sample periods (*n* = 10/sample collection period) to account for seasonal variation. Twenty four hours after processing 300 g of *m. longissimus thoracis et lumborum* (LL) cranial to the 12/13th rib was removed and cut into two 60 g pieces and two 2.5 cm circular pieces, obtained using a cylindrical EZ borer. The 60 g pieces were suspended inside an inflated bag (bag method) and the 2.5 cm pieces placed inside EZ tubes. All samples were placed within a chiller for 48 hours. Drip loss was calculated as the initial sample weight minus the post sample weight. This amount was expressed as a percentage of the original amount so that the two methods could be accurately compared.

The data was analysed with a model that included method and season as fixed effects and with an interaction of method and season. There was no difference (P = 0.490) in drip loss percentage between bag method (3.39 ± 0.24 %) and EZ method (3.16 ± 0.22 %) showing they are both viable methods. There were higher drip loss percentages (P < 0.01) in summer (bag 4.00 ± 0.40 %, EZ 4.02 ± 0.40 %) than autumn (bag 3.03 ± 0.30 %, EZ 2.61 ± 0.26 %) and winter (bag 3.24 ± 0.32 %, EZ 2.88 ± 0.29 %) although there was no difference between any of the seasons and spring (bag 3.39 ± 0.34 %, EZ 3.29 ± 0.33 %) indicating the water holding capacity of alpaca meat can vary across the year and by method during these seasons. When just observing an effect of season on the drip loss of alpaca meat regardless of method, summer sampled loin recorded a higher drip loss percentage (4.0 ± 0.36 %) than autumn (2.81 ± 0.25 %) and winter (3.05 ± 0.27 %), showing that seasons across the year affected drip loss percentage in alpaca meat. The fact that there was no difference in the drip loss when measured by either the bag method or the EZ method is in line with the results of Otto et al. (2004) in pork. They reported drip loss when utilising the bag method of 3.33 ± 1.61 % s.d. and for the EZ method 4.97 ± 2.38 % s.d., and a correlation between methods (r = – 0.86). Water holding capacity was measured in alpaca meat previously using the filter paper press method (26.4 ± 4.22 %; Salva *et al.* 2009) which produced a much higher result, using the same method, than other species such as pork (6.4 ± 2.45 %; Correa *et al*. 2007). This is in contrast to the findings in this research which showed alpaca drip loss percentage measured by bag and EZ to be between 3.39 ± 0.24 % and 3.16 ± 0.22 % respectively, which is more in line with drip loss percentages recorded in pork (3.33 ± 1.61 % s.d.; Otto et al., 2004). Salva *et al.* (2009) stated that the moisture loss of 26.4 ± 4.22 % was the normal range for this measurement of water holding capacity in alpacas, but this was much greater than the results from the current experiment for drip loss. A level of over 20 % is very high and it suggests when compared to data for pork that the filter press method as applied gives higher values which is not unexpected as this subjects a sample to a significant weight, whereas both methods used in the current experiment rely on gravitational force. The bag and EZ methods are both accurate techniques for measuring drip loss. However, the EZ method is easier to reproduce and uses equipment that enables preparation of consistent sample sizes which require less sample to be taken from the carcass than when utilising the bag method. The EZ should be used in place of the bag method for measures of drip loss because of the ease of use whilst still being an accurate measure of drip loss.

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Carcass attributes of crossbred Wagyu steers

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Wagyu cattle have become a globally recognised breed in premium beef markets. The attributes of Wagyu beef can be utilized in crossbreeding programs to increase the value of other beef and dairy breeds. In the present study, purebred Wagyu bulls were mated to Angus, Brahman-cross, dairy-cross and Shorthorn cows to produce F1 progeny. F1 females and subsequent generations were mated to fullblood Wagyu bulls to produce F2, F3 and F4 genotypes with 75%, 87.5% and 93.75% Wagyu, respectively. 3695 steers entered a commercial long-fed (approx. 450 days) feedlot production system over multiple years. Hot standard carcass weight (HSCW) and marble score (AUS-MEAT) were recorded at slaughter and used to calculate a carcass index (CI). Data were analyzed using a mixed-effects linear model with % Wagyu, initial dam breed, and their interaction as fixed factors, and year as a random factor.

Linear regression was used to determine the effect of marbling and HSCW on CI (CI = –2425 + 420 × Marbling Score + 5.8 × HSCW; $P < 0.001$; $R^2 = 0.989$) and carcass index on carcass value in AU$ (Carcass Value = –11238 + 0.95 × CI; $P < 0.001$). All fixed effects were significant ($P < 0.001$; Table 1). Dairy cross steers showed no response to grading up Wagyu content ($P > 0.05$) in contrast to the other breeds. Shorthorn showed larger CI compared to Angus for F1 and F2 ($P < 0.05$). Dairy animals had the greatest variance within the dataset due to the low number of animals. Shorthorn had the greatest positive response from F1 to F2 ($P < 0.0001$) whereas Angus had greater response to the grading up process from F1 to F4 compared to Brahman and Dairy. Brahman cross animals showed significantly higher CI for F3 and F4 compared to F1 and F2 ($P < 0.05$) however their response to crossbreeding was lower than Angus or Shorthorn.

Results indicate that Carcass Index, and therefore Carcass Value can be significantly increased with the inclusion of Wagyu bulls however the magnitude of this increase depends on the breed of the dam. The limitations of the study included limited numbers of dairy animals and only two generations of Shorthorn animals as generations F3 and F4 had not been reached yet. Shorthorn responded the most to increasing Wagyu content from F1 to F2 and Angus from F1 to F4. However, dairy crosses showed the greatest Carcass Index for F2 and F3 and this could also be a valuable crossbreeding program to increase the value of dairy animals.

Table 1. Carcass value index (mean ± SEM) of crossbred steers with increasing Wagyu content

Dam Breed	F1	F2	F3	F4
Angus	$3225 \pm 106^{A, X}$ (*n* =108)	$3610 \pm 73^{A, X}$ (*n* = 228)	$4125 \pm 95^{B, C\ X}$ (*n* =134)	$4617 \pm 115^{C, X}$ (*n* =91)
Brahman Cross	$3548 \pm 65^{A, XY}$ (*n* = 286)	$3658 \pm 41^{A\ X}$ (*n* =722)	$4071 \pm 61^{B, X}$ (*n* =320)	$4221 \pm 77^{B, X}$ (*n* = 201)
Dairy	$4056 \pm 450^{A, XY}$ (*n* =6)	$4268 \pm 121^{A, Y}$ (*n* =82)	$4775 \pm 154^{A, Y}$ (*n* =51)	$4738 \pm 235^{A, X}$ (*n* =22)
Shorthorn	$3975 \pm 33^{A, Y}$ (*n* =1086)	$4543 \pm 102^{B, Y}$ (*n* = 115)	-	-

[A–C]Means within rows without a common superscript differ ($P < 0.05$).
[X,Y]Means within a column without a common superscript differ ($P < 0.05$).

Impact of mid-pregnancy shearing on lamb neonatal body surface temperature in cold conditions

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Exposure to cold and subsequent hypothermia is a potential threat to survival of newborn lambs in Australia. In this context, the ability to thermoregulate, including non-shivering thermogenesis, is essential (Dwyer and Morgan 2006). Previous studies have observed improved thermogenic abilities and an increase in brown adipose tissue deposition in lambs born to ewes cold-exposed during late-pregnancy (Symonds *et al.* 1992). Pregnant ewes commonly experience transient, short term and acute stressful experiences during on-farm husbandry procedures, and the effect of this on subsequent neonatal lamb heat production is not well understood.

Recently, infrared thermography has been identified as a technology suitable for the measurement and discrimination of levels of thermogenesis in newborn lambs (Labeur *et al.* 2017) and this approach was applied in the current study to assess the effects of a prenatal stressor. We tested the effects of shearing during mid-pregnancy on newborn lamb thermogenesis by subjecting single and twin bearing ewes (PD90; $n = 15$) to either shearing, or to a sham-shearing 'control' (mimicking the handling associated with shearing - seated on haunches, manual stroking of both sides of the body and rump; $n = 15$). During the 7-days post shearing, shorn ewes were also wetted using sprinklers for 30 min (~150 mm; water temperature 8-10˚C), on 3 occasions, not on consecutive days.

All lambs were subjected to a 1hr cold challenge 4 hrs after birth, in a temperature-controlled room at 4 ˚C, and held in a cradle to limit movement. During the cold challenge, thermography images were taken using an infrared thermography camera (ThermaCam T640, FLIR Systems AB, Danderyd, Sweden) every 10 min (Labeur *et al.* 2017) at a fixed distance from the dorsal midline. Body surface temperatures were taken for four fixed-size equidistant areas identified beforehand on each image (shoulder, mid loin, hips and rump). Body surface temperature was analyzed using a repeated measures ANOVA mixed model, with treatment, time-point, wool length, litter size, sex and their interactions included as fixed effects, birth weight as covariate and lamb as a random effect. Non-significant factors such as wool length and sex and covariates were subsequently removed.

Overall, lambs born to shorn and cold exposed ewes tended to have higher body surface temperatures across the midline ($P = 0.07$). Changes in temperature (ΔT, °C), used to assess evolution of heat production over time, showed lambs from mid-pregnancy cold-exposed ewes displayed positive ΔT, suggesting a greater heat production than heat loss, while ΔT was negative for control lambs (Figure 1). This suggests that lambs born to prenatally stressed ewes were better able to maintain their body temperature than control lambs.

Previous research has focused on the effect of late-pregnancy cold stress on lamb thermoregulation and while it might be triggering other mechanism(s) which need to be investigated, mid-pregnancy exposure to acute stressors seem to be positively impacting lamb thermoregulation with potential implications for lamb survival.

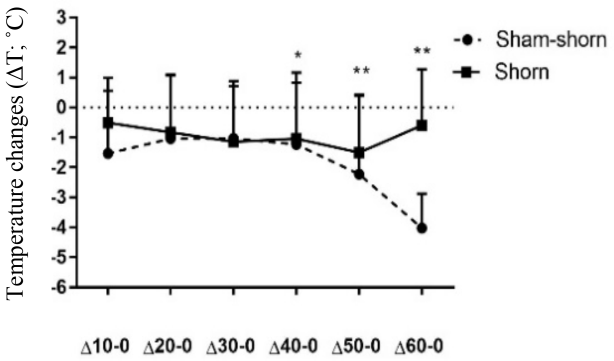

Fig. 1. Body surface temperature differences to baseline during a 1 hr cold challenge for neonatal lambs from ewes prenatally stressed. *$P < 0.1$; **$P < 0.05$.

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Quantifying the colour of meningeal lesions of the brain in autopsied neonatal lambs

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Recent autopsy studies affirm the most common causes of death among neonatal lambs are associated with difficult birth and starvation/mismothering (Refshauge *et al.* 2016). The placement of dead lambs into these categories relies on subjectively assessed lesion severity scores of the meninges, in particular the surface of the brain. Higher lesion scores imply hypoxic ischemia in association with a more difficult or prolonged birth. Colorimetric instrumentation could objectively quantify lamb brain colouration. This study examines the objective colour of the meninges of dead neonatal lambs across the range of subjectively assessed lesion scores.

Merino ewes (2 and 3 years old) were monitored twice daily during lambing. All lambs that died within 5 days of birth were collected for autopsy (n = 67). The autopsy method included removing the frontal bone from the skull and making a subjective assessment of the severity of meningeal lesions. Lesion scores range from 1 (pink coloured brain with red capillaries and no blood clots) to 5 (purplish coloured, congested meninges with many large, dark red blood clots). Immediately after the visual assessment, 10 measures were made using a Nix Color Sensor Pro™ colorimeter (aperture: 15 mm; Nix Sensor Ltd., Ontario, CAN) set to D65/10°, taken over all exposed dorsal surfaces of the brain, providing a mean value. All colour measurements were reported as CIE colorimetrics (L*, a* and b*), and hue and Chroma. Variation in colour was analysed using linear models with lesion score as the fixed effect, using R software (R Core Team 2017). Table 1 reports the mean colour values, where L* ($P < 0.001$) and Hue ($P < 0.05$) showed significant variation.

The lightness and hue of the meninges decrease as the lesion severity scores increase. Together, the L* and hue suggest the brain surface becomes darker and less yellow, and that significant differences emerge between 1, 2 and 3 score lesions. This finding offers credence to the subjective nature of lesion scoring. Further research is required to determine if the assessment of brain lesion scores can be simplified using a colorimeter. The objective would be to improve accuracy of the placement of dead lambs into death categories.

Table 1. Colour of the meninges of the brain (± s.e.) reported across the range of lesion severity scores

Lesion Score	Lightness (L*)	Redness (a*)	Yellowness (b*)	Hue (radians)	Chroma
1	55.0 ± 3.1^{a}	22.0 ± 2.0	10.5 ± 1.6	25.8 ± 2.8^{a}	24.5 ± 2.3
2	47.4 ± 3.3^{ab}	23.8 ± 0.6	8.0 ± 0.5	18.6 ± 0.9^{ab}	25.1 ± 0.7
3	44.1 ± 3.2^{b}	25.0 ± 0.8	7.7 ± 0.4	16.8 ± 0.8^{b}	26.3 ± 0.6
4	39.9 ± 3.3^{c}	25.2 ± 0.5	7.5 ± 0.6	16.5 ± 1.1^{b}	26.2 ± 0.9
5	30.6 ± 4.0^{d}	25.6 ± 1.7	7.4 ± 1.3	16.0 ± 2.3^{b}	26.7 ± 1.9
Mean ± s.d.	44.1 ± 6.1	24.6 ± 2.9	7.8 ± 2.2	25.9 ± 3.2	17.5 ± 4.2

Superscripts within column denote significant differences.

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Macroscopic assessment and meningeal brain colour in autopsied neonatal lambs

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One method of autopsy used to determine the cause of death of lambs relies on a subjective assessment of the severity of meningeal lesion scores. Holst (2004) proposed that severity scores (1–5) could be applied to meningeal congestion and vascular haemorrhage, and that the classification of lambs into a suite of dystocia causes of death could be made on that basis. Consequently, there are subjective differences in lamb brain colouration reported between severities – albeit anecdotal, at present. Lesion scores are considered to be of a significant degree of severity to impair survival when the scores reaches 3. Establishing a method to replace the subjective assessment of meningeal lesions of the brain requires investigation.

Merino ewes (2 and 3 years of age) were monitored twice daily during lambing. Birth weight, litter size and sex of lambs were recorded at ear tagging, which occurred within 15 h of birth. All lambs that died within 5 days of birth were collected for autopsy (n = 67). The autopsy method included removing the frontal bone from the skull and making a subjective assessment of the severity of meningeal lesions. Lesion scores range from 1 (pink coloured brain with red capillaries and no blood clots) to 5 (purplish coloured, congested meninges with many large, dark red blood clots). Immediately after the visual assessment, 10 technical replicate measures were made using a Nix Color Sensor Pro™ colorimeter (aperture: 15 mm; Nix Sensor Ltd., Ontario, CAN) set to D65/10°, taken over all exposed dorsal surfaces of the brain. All colour measurements were reported as CIE colorimetrics (L*, a* and b*), tone (Hue) and intensity (Chroma). Variation in colour was analysed using linear models with separate models used to test the fixed effect of factors including the presence or absence of perirenal brown adipose tissue (FatMet, Y; n = 38), and evidence the lamb had breathed (Breathed, Y; n = 52), walked (Walked, Y; n = 43) or suckled milk (Fed, Y; n = 19), in R (R Core Team 2017). Fixed effects for birth type, sex, birthweight and all two-way interactions were included in the base model. Non-significant terms were sequentially dropped.

Birthweight and birth type did not affect any models, while male lambs had higher Hue and yellowness values (p <0.05). Walking and suckling milk were associated with brains that were lighter, less red with less intense colour (Table 1). Lambs metabolising their fat reserves (FatMet Y) that have not suckled a sufficient amount of, or any, milk are expected to differ from lambs that had fed, which appears to be the case for L*, b* and hue values. The a* values for lambs that metabolised fat are in the same direction as the other sites, but were not significant (P=0.07), suggesting a deal of variation around these colour values. Lambs that breathed were expected to have higher L* values, but did not, suggesting brain injury affecting the ability to suckle and walk is more discernible at the meninges than the lesions of lambs failing to breathe or that metabolise perirenal brown adipose tissue.

Table 1. Colorimetric differences for lambs that had breathed, walked, metabolised perirenal fat or had fed prior to their death, contrasted (+/-) with those that did not

Site	Lightness (L*)	Redness (a*)	Yellowness (b*)	Hue (radians)	Chroma
Breathed (Y)	0.48 ± 1.8	–1.9 ± 0.8*	–0.7 ± 0.6	–0.1 ± 1.3	–2.0 ± 0.9*
Walked (Y)	3.9 ± 1.5 *	–2.2 ± 0.7**	–0.7 ± 0.5	–0.1 ± 1.0	–2.3 ± 0.8**
FatMet (Y)	0.48 ± 1.5	–1.3 ± 0.7	–1.4 ± 0.5**	–2.4 ± 1.0*	–1.7 ± 0.8*
Fed (Y)	4.1 ± 1.6 *	–1.8 ± 0.8*	0.1 ± 0.6	1.7 ± 1.1	–1.7 ± 0.8*

*P < 0.05; **P < 0.01 indicates significant difference within cell in terms of Y/N comparison.

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The meningeal colour of different categories of death in neonatal lambs

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The assignment of dead lambs to a particular cause of death relies in part, on the subjective assessment of lesion severity scores of the meninges, in particular the surface of the brain (Holst 2004). We hypothesise that the range of colours (L*, a* and b*) and their relative vividness (hue) and brightness (Chroma) would differ between lambs dying from different causes of death. Lambs dying from forms of difficult birth should present with different colour values, compared to lambs dying from starvation or other, largely environmental causes.

Lambs born to Merino ewes (2 and 3 years old) had birth weight, litter size and sex recorded within 15 h of birth. All lambs that died within 5 days of birth were collected for autopsy (n = 64). Macroscopic lesions were visually assessed for a severity score (1–5). Immediately after the visual assessment, 10 technical replicate measures were made using a Nix Color Sensor Pro™ colorimeter (aperture: 15 mm; Nix Sensor Ltd., Ontario, CAN) set to D65/10°, recording colorimetrics over all exposed dorsal surfaces of the brain. Variation in colour was analysed using linear models with death category, birth type, sex, birthweight and their interactions as fixed effects, in R (R Core Team 2017). Non-significant terms were sequentially dropped from the models. Data for dystocia (defined by presence of subcutaneous oedema), stillborn (≥3 score meningeal lesions without metabolising perirenal fat), birth injury (≥3 score meningeal lesions with metabolised perirenal fat) and starvation/mismothering (≤2 meningeal lesion score) were coded as separate categories, while primary predation without a damaged brain (n = 4), infection (n = 9) and undiagnosed (n = 1) were pooled.

Table 1 shows that lambs placed into the starvation/mismothering category did not differ consistently from lambs placed into the dystocia classes in the colour values observed. Lambs assigned to Other causes generally differed from the dystocia-assigned lambs but less so from the starvation/mismothering lambs ($P < 0.05$). When compared to female lambs ($P < 0.05$), males had higher yellow (1.1 ± 0.5) and greater hue values (+2.1 ± 0.9).

The placement of lambs into categories of death in the current study, relying on colorimetric values alone is not possible. The allocation of lambs into death categories relies on other factors, such as the presence of oedema and its colour, or the depletion of perirenal brown adipose tissue. Further research is required to refine the methodology, with reference to the number of technical replicates, as well as increasing the scale of such studies.

Table 1. Brain colorimetric means of groups of lambs in different death categories (±s.e.)

Death category	Lightness (L*)	Redness (a*)	Yellowness (b*)	Hue (radians)	Chroma
Dystocia, n = 8	39.3 ± 1.9 ^{a}	26.4 ± 1.0	8.5± 0.7 ^{ab}	16.6 ± 1.4 ^{ab}	27.8 ± 1.1
Stillborn, n = 11	42.3 ± 1.5 ^{a}	25.6 ± 1.3	8.4 ± 0.6 ^{ab}	16.9 ± 1.7 ^{ab}	27.0 ± 1.4
Birth injury, n = 15	41.4 ± 1.4 ^{a}	24.5 ± 1.2	6.8 ± 0.5 ^{a}	14.3 ± 1.6 ^{b}	25.5 ± 1.4
Starvation/mismothering, n = 16	45.1 ± 1.4 ^{ab}	23.9 ± 1.2	6.8 ± 0.5 ^{a}	14.6 ± 1.6 ^{b}	24.9 ± 1.4
Other, n = 14	49.1 ± 1.4 ^{b}	23.8 ± 1.2	9.1 ± 0.6 ^{b}	19.5 ± 1.6 ^{a}	25.5 ± 1.3

Superscripts denote difference within-column ($P < 0.05$).

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On farm validation of ASKBILL – a sheep wellbeing and productivity application for Australian industry

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Introduction

The most economically important endemic diseases impacting Australian sheep wellbeing and productivity include perinatal mortalities, internal parasites, dystocia, weaner ill-thrift and mortality, and flystrike. Collectively, these diseases cost the Australian sheep industry more than A$1.5 billion per annum (Lane *et al.* 2015).

ASKBILL is a web-based application developed to assist sheep producers to better manage these diseases and thereby improve flock wellbeing and productivity. The ASKBILL application encompasses numerous biophysical models that predict pasture growth, animal performance and risk from flystrike, worm infection and weather stress (Kahn *et al.* 2017). An important component in the on-going development of ASKBILL is on farm validation designed to allow comparison of measured and predicted values for a range of variables.

Experimental design

Validation activity is focused on 11 commercial farms across 3 different production environments: summer rainfall (northern tablelands NSW); winter rainfall (mid-north South Australia and southern NSW); and Mediterranean (south-west Western Australia). Two sheep enterprises are included in all regions: Merino x Merino (MxM; *n* = 6 farms); and Terminal x Maternal (TxM; *n* = 5 farms). Within each farm, mixed age single bearing Merino (n=100) or multiple bearing maternal (*n* = 100) ewes plus female MxM weaners (*n* = 100) or mixed sex TxM weaners (*n* = 100) were tagged and monitored.

Methods

Ewe live weight, body condition score and dag score were recorded at joining, pregnancy scanning, pre-lambing, lamb marking, and weaning. Weaner live weight and dag score were recorded at approximately monthly intervals from weaning for 7 months unless slaughtered (TxM only) prior. Breech cover, breech wrinkle and fleece rot were estimated using industry visual guides, post-shearing, and mulesing status was recorded. Greasy fleece weight of MxM and TxM ewes and MxM weaners were recorded at shearing and mid-side fleece samples taken and analysed for fibre diameter (FD), cvFD, yield, staple length and staple strength. Ultrasound measurements of C-site eye muscle depth and fat were taken from TxM weaners. Hot standard carcase weight, lean meat yield, intra muscular fat and loin weight were collected on these animals following slaughter.

Regular bulk faecal samples were taken from ewe and weaner mobs. A drench resistance test was conducted on each farm and flystrike incidence within mobs was recorded on a weekly basis. Australian Sheep Breeding Values were obtained for sires of weaner sheep and genomic profiling was undertaken. At the beginning and end of the validation period, ewe pregnancy status (single or multiple) was determined via ultrasound scanning. Neonatal and off-shears deaths attributed to exposure were kept. Details of supplements fed were recorded (type, amount, and frequency).

Pasture biomass was recorded at approximately 6-weekly intervals. Within each paddock, normalized difference vegetation index (NDVI) and pasture height (cm) were recorded every 2 ha (maximum of 30 measurements per paddock). In addition, 12 quadrats (0.5 × 0.5 m) per farm, were used to collect NDVI and pasture height before being cut to ground level and analyzed to determine dry weights to provide within-property calibration to determine pasture biomass values. On each occasion, composite samples were used for pasture quality. Pasture composition was determined via BOTANAL (Tothill *et al.* 1978) to estimate the percentage contribution to pasture biomass of the dominant pasture species. Soil chemical fertility was assessed from 20–25 core samples (0–10 cm) per paddock. Rainfall was recorded daily.

Analysis

The observed and predicted data will be used to determine the accuracy of model predictions for pasture and animal measures through procedures including regression and analysis of distributions. These data provide a validation data set for modelers to enable adjustment of model functions. They also provide user case studies for industry to assist in the adoption and uptake of the ASKBILL application.

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How accurate is foetal aging at pregnancy scanning to predict lambing date?

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Transabdominal ultrasound scanning to determine pregnancy status and litter size is common practice to assist in management of ewes. Accurate litter size data can also be used as data for genetic evaluation, substituting for data collection at birth (Bunter *et al.* 2016). At small additional cost, foetal age can also be estimated at pregnancy scanning. Accurate determination of foetal age at scanning would enable optimum management of ewes based on both litter size and expected date of lambing. In addition, foetal age could enable age adjustments when lambing date is unknown, improving accuracy of genetic evaluation for young animals.

Commercially, foetal aging at scanning is based on the size of the foetal skull, relative to grid lines applied on-screen which indicate skull size at specific ages. The expected relationship between skull size and foetal age is based on historical data for changes in the bi-parietal diameter (BPD) of the skull with age, combined with known dates for the start and end of joining. Based on current data recorded within the recommended foetal age range, there is no strong evidence that this relationship differs substantially by breed, litter size, or other ewe characteristics (AWI Project ON-00447, unpublished). However, lambing date is also influenced by gestation length, which is known to vary significantly by breed, and to a lesser extent litter size (Smith 1967).

To demonstrate the accuracy with which foetal age and lambing date can be predicted from scanning by a competent operator, a resource population of Merino (M) and crossbred (XB) ewes (N = 511), naturally mated to Merino (MxM) or White Suffolk (WS) rams (XBxWS) at the same site over 35 days, was recorded for conception date based on raddle marks at joining, confirmed against known lambing dates established by mothering up at lambing. Ewes were scanned when foetal age ranged between 54 to 88 days (mean: 78.8), to establish foetal age (SCAN, N=511). Subsets of ewes also had measurements recorded for BPD of a single lamb derived from scan images obtained on two separate occasions (BPD1 and BPD2), with mean foetal ages of 57 and 77 days. Foetal age was predicted using simple regression based on SCAN, BPD1 or BPD2 data. Lambing date was predicted from the estimates of foetal age, and assumed gestation lengths of 150 and 148 days (for M and WS sired lambs respectively). The differences between actual and predicted values were used to establish percentages of ewes with predicted values within 3.5, 7 or 8.5 days of actual foetal age or lambing dates. The percentages of ewes correctly allocated amongst three lambing groups (14 day splits) were also established.

The accuracy of prediction is influenced by both the amount and accuracy of the data available, which varied with the data source. Nevertheless, Table 1 shows that there was a tendency, as expected, for predicted lambing date to be less accurate than predicted foetal age, particularly at a low tolerance (e.g. 3.5 days), due to the impact of variation in gestation length on lambing date. However, 89.7 to 94.9% of ewes lambed within 7 days of their predicted lambing date, with high percentages of ewes (54 to 60%) lambing within 3.5 days. This translated to perfect discrimination of early from late lambing ewes, or between 78.1 to 83.8% of ewes accurately allocated across three lambing groups (not tabulated) depending on data source. For comparison, when mating date was observed (N = 463), the accuracy of allocation across three lambing groups was approximately 94%, but recording mating date was more labour intensive and costly than scanning, and not observed for all ewes.

Results demonstrate that foetal aging at scanning can enable lambing date to be predicted at useful accuracy provided the scan operator is accurate. The accuracy at scanning could potentially be increased through software and hardware development, to complement mechanisms (eg accreditation) to ensure operator competency. The potential cost-benefit of obtaining data on foetal age at scanning should be investigated further.

Table 1. The percentages of ewes with predicted values for foetal age (FA) or lambing date (LD) within designated intervals (days) from true values

Source	SCAN (N = 511)		BPD1 (N = 106)		BPD2 (N = 216)	
	FA	LD	FA	LD	FA	LD
3.5 days	61.8	57.5	63.2	53.8	57.6	59.8
7 days	93.4	92.4	88.7	88.7	89.1	85.3
8.5 days	98.4	94.9	97.2	94.3	94.6	89.7

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Estimates of the effects of temperatures and relative humidity on growth of the finishing pig

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Temperatures and relative humidity are known to impact the growth of pigs (Zumbach *et al.* 2008) which are often combined in a temperature humidity index. For farming purposes, a reliable approach is needed to quantify the effects of temperature and RH on performance of pigs. The aim of this study was to determine the best time period for measurement of temperature and relative humidity for estimating their effects on growth of finishing pigs.

Growth rate over a 50-day test period (ADG) was measured from May 1999 to January 2001 on 2918 boars from 3 terminal sire lines. Boars started the test period at 74 kg body weight when they were allocated to one of three feeding levels. Daily measures of maximum temperature (Tmax, °C) and relative humidity at 9am (RH, %) were obtained from the nearest meteorological station in Corowa. There were two parts of analysis. Firstly, the best time period to evaluate the effect of climate on growth was determined. A general linear model was fitted with the effects of breed, feed intake level and month at beginning of the test. Additional models were fitted with the inclusion of Tmax and RH of the test period, categorized into classes and calculated in four ways: the average of the whole test period, the last 7 days, the last 4 days, the last 3 days, and the last day. Secondly, the relationship of each climate variable with ADG was estimated. All analyses were conducted in SAS (v3.6, SAS Institute Inc., Cary, NC, USA).

The first model, without climate parameters, had a coefficient of determination (R^2) of 7.8%. The inclusion of Tmax, calculated from the whole test period, last 7 days, last 4 days, last 3 days and last day, increased the R^2 to 8.4%, 10.0%, 9.3%, 10.0% and 9.6%, respectively. Therefore, the last 3 days were selected for Tmax and RH. This reduces confounding between month of test and climatic parameters as was also observed by Lewis *et al.* (2011).

Least square means were used to predict ADG in response to increasing Tmax and RH, calculated as the last 3 days of test period (Fig. 1). The thresholds from which ADG decreased was 28-29°C for Tmax and 57–60% for RH. The threshold of Tmax reflects those previously identified for production and reproductive traits (Lewis *et al.* 2011).

This study identified a short time period of 3 days at the end of test to evaluate the effects of Tmax and RH on pig growth. Other studies could use this time period to specify the effects of heat stress on other production traits of pigs.

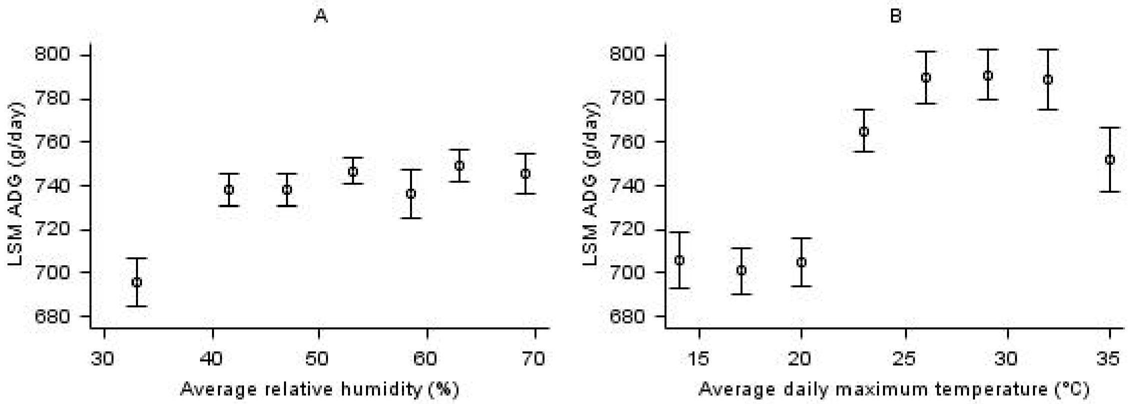

Fig. 1. Least square means ± SE of average daily gain (LSM ADG) in response to relative humidity (A) and daily maximum temperature (B).

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The opportunity to use NIRS to predict nitrogen, sulphur, phosphorous and anions in forages

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Near Infrared Spectroscopy (NIRS) is used by industry to predict the nutritional characteristics of feeds consumed by livestock. The method is based on the development of mathematical relationships between measured traits and light absorption properties in the near infrared region. Once calibration equations are developed, NIRS is rapid, inexpensive, non-destructive and can predict a large range of traits at the same time. For traits such as dry matter digestibility, crude protein and fibre content, there are some very good calibrations that are used by industry. For minerals and secondary compounds, the value of NIRS is less clear. The aim of this study was to utilise the existing CSIRO Floreat databases to investigate the opportunity to use NIRS to predict the total nitrogen (N), total phosphorous (P), total sulphur (S) and the anion content of pastures and forage shrubs.

The CSIRO Floreat databases contain spectra with associated wet chemistry data from more 2000 forage samples comprising annual and perennial grasses (and cereals), legumes, forbs and native shrubs. Spectra were collected using a Unity Spectrastar 2500X- rotating top window system (Unity Scientific). Predictions were generated using partial least squares regression for the wavelengths of 1100–2500 nm, with a range of pretreatment options using the software package Ucal (Unity Scientific). From this the best performing equations were selected. The performance of calibration equations was assessed using RPD (relative percent difference) values. The databases were not split in an attempt to optimise predictions. We have adopted the guide of Williams (2014) where RPD 0.0–1.9 is very poor, 2.0–2.4 is only of use for rough screening, 2.5–2.9 offers a fair screening potential, 3.0–3.4 is good, 3.5–4.0 is very good and 4.1+ is excellent. Total N was determined by combustion using a Leco CN628 N Analyser. The oxalate, phosphate, sulphate, nitrate and malate were measured according to the method described in Li *et al*. (2017).

Table 1 presents preliminary predictions. As we would expect, total N was predicted accurately with an RPD of 5.1 and the mean error of prediction was 0.2% units (equating to about 1.2% CP). We also achieved good predictions for oxalate in the dry matter (RPD 3.7, mean error of prediction of 0.80 mg/g). Oxalate is produced by chenopods and other forbs to maintain cation–anion balance in tissues (Norman *et al*. 2013). Rapid and inexpensive prediction of oxalate is useful as excessive quantities are toxic, reduce voluntary feed intake and bind calcium in the rumen. This is the first evidence of success in predicting oxalate using NIRS that we are aware of. The data suggest that a calibration for nitrate is feasible with a fair first attempt (RPD 2.4). We were not able to generate good calibrations for total P, phosphate, total S, sulphate or malate. The literature also indicates that it is difficult to predict total P and total S, with few studies that achieve performance statistics that offer more than a fair screening tool. Minerals can be difficult to predict with NIRS as they tend occur in forage in small quantities and they often exist in organic complexes, chelates with other minerals, salts and in ionic forms.

In summary, we were able to quickly develop broad, mutli-species NIRS calibrations to predict the concentrations of crude protein and oxalate in forage. Sulphur, phosphorous, nitrate and phosphate calibrations were poor but perhaps worthy of further investigation.

Table 1. Number samples with matched spectra used to develop calibrations, data range and chemistry and NIRS prediction performance statistics for nitrogen, sulphur, phosphorous and anions

Trait	n	range	R^2	1-VR	SECV	RPD
Total N (%)	1290	0.48-6.23	0.96	0.96	0.2	5.1 (Excellent)
Total S (%)	193	0.16-1.77	0.82	0.65	0.05	2.4 (Poor)
Total P (%)	201	0.110-0.34	0.80	0.74	0.03	2.2 (Poor)
Nitrate (mg/g)	358	0.1-63.4	0.82	0.74	3.7	2.4 (Poor)
Sulphate (mg/g)	541	0.2-12.04	0.45	0.39	1.4	1.4-(Very poor)
Oxalate (mg/g)	541	0.7-154.4	0.93	0.88	8.0	3.7 (Good)
Malate (mg/g)	105	0.3-9.2	0.21	0.14	1.1	1.1 (Very poor)
Phosphate (mg/g)	524	0.3-21.5	0.77	0.72	1.2	2.1 (Poor)

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Large variability in individual animal's intake of lick-block supplements is correlated with individual liveweight and growth rate in cattle

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Supplementation with molasses and mineral blocks offered as free choice have been less studied than traditional dry loose supplements (Bowman and Sowell 1997) with a major challenge being to measure individual supplement intake and feeding behaviour. Nowadays, this is possible using novel in-paddock technologies such as electronic feeders (EF). This study investigated the correlation between lick block supplement intake and cattle liveweight and growth.

Twenty-seven Charolais x Angus steers and heifers (initial weight 192 ± 37 kg) were rotationally grazed on 15 ha of temperate pastures and oat crops (10 paddocks) during 219 days from May to December (John Pye Farm, The University of Sydney, NSW). Lucerne, wheat and oat hay was offered for the last 74 days of the trial because of low rainfall. A yard was built enclosing the only water point where an EF (Smartfeed) was installed. A single cooked molasses lick block (40 kg; 4 Season Co. Pty Ltd, Creastmead, QLD) was available inside the EF throughout the experiment. Additionally, a walk-over-weighing scale (WoW, Precision Pastoral) was placed at the entry of the enclosure to measure cattle liveweight (LW) regularly. The EF records the electronic ID tag, date and time, feed consumed and duration of all visits. Animals were also mustered to central yard facilities and weighed at the start (Initial LW) and end (Final LW) of the trial to calculate ADG. A Pearson's correlational matrix was calculated to identify relationships between supplement intake, liveweight and growth rate.

Supplement intake was positively correlated with AGD, Initial and Final LW, visit frequency, total feeding duration and eating rate ($P < 0.05$). Supplement consumption showed a large variability among animals with minimum, average and maximum values of 0, 80 and 198 g/hd/day, respectively. Time spent licking the blocks was 0.0, 3.0 and 8.2 minutes/hd/day for minimum, average and maximum, respectively.

The large variability amongst animals in lick block intake, which affects growth rate, indicates that there is a need to study animal response to supplements at the individual level rather than at the group level. It is also important to ensure high lick block intake across all animals in group-fed conditions to achieve a high response to supplementation. Further research is needed to understand the reasons for such high variability in supplement intake amongst animals in a group.

Table 1. Pearson's correlation matrix among Supplement intake (g/hd/day), ADG (g/hd/day), Final LW (kg), Initial LW (kg), Visit Frequency (No/hd), Total duration (min), Visit Duration (min/visit) and Eating rate (g/min). Values below the diagonal show p-values and above it are correlation values

	Supplement intake	ADG	Final LW	Initial LW	Visit frequency	Total duration	Visit duration	Eating rate
Supplement intake	1	0.4079	0.6190	0.4743	0.9323	0.9491	0.3541	0.4843
ADG	0.0386	1	0.3869	-0.0625	0.5044	0.5072	0.2108	0.1141
Final LW	0.0007	0.0509	1	0.8958	0.5462	0.5507	-0.0432	0.2818
Initial LW	0.0144	0.7615	<.0001	1	0.3500	0.3532	-0.1475	0.2447
Visit frequency	<.0001	0.0086	0.0039	0.0797	1	0.9707	0.2856	0.3438
Total duration	<.0001	0.0082	0.0036	0.0767	<.0001	1	0.3769	0.2920
Visit duration	0.0760	0.3013	0.8342	0.4721	0.1573	0.0577	1	0.5158
Eating rate	0.0142	0.5871	0.1724	0.2385	0.0924	0.1568	0.0083	1

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Livestock Data Link – an online application for supply chain information sharing

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Livestock Data Link (LDL) is an online application that facilitates improved information sharing in the supply chain. The overall objective of LDL is to assist in optimising supply chain performance by turning complex information into simple decision-making. It is housed within the National Livestock Identification System (NLIS), a secure and robust platform with the ability to accept additional data fields. Records are uploaded into the NLIS and replicated into the LDL platform. Carcase data, available to producers, is efficiently analysed and compared to other results. Consignment performance data is linked to supporting materials, in order to assist producers to identify and understand the impact of on-farm management decisions.

Non-compliance to market specifications has been shown to cost the beef industry an estimated $127–$164 million per annum. This cost is due to downgrades for; out of specification carcases ($51 million per annum), carcase condemnations ($64 million per annum) and loss of meat and offal due to animal health and disease issues ($12–$49 million per annum; ProAnd 2012). Furthermore, the Australian lamb industry has a potential cost of non-compliance to market specifications in excess of $8.4 million per annum across two major markets *(ProAnd, 2014)*. It has also been estimated that over $110 million is lost annually due to ill health. The burden of cost varies by disease/condition, however overall the on-farm sector bears 86% of the cost (GHD 2011). Previously, feedback mechanisms to producers have been unable to translate non-compliance and animal health related costs.

Currently LDL offers two modules, 1. *'Carcase Compliance Analysis'* and 2. *'Animal Health Information'*. The carcase compliance analysis module allows users to analyse carcase performance, in relation to compliance to a processors payment grid. Users can then link performance outcomes to a library of tangible solutions to non-compliance issues. The animal health information module allows users to view animal health and disease conditions identified as part of post-mortem inspection (currently through processor associated with the National Sheep Health Monitoring project (NSHMP).

The use of LDL has enhanced information flow, providing a central information depository with a multitude of information available. Users can benchmark carcase performance at an enterprise, regional, state or national level, resulting in greater transparency and understanding of why carcase compliance may be low. This allows for targeted improvement strategies. Additionally, LDL allows for tailored research, development and extension activities for supply chains and geographic areas facing specific carcase performance and/or animal health issues.

While uptake of LDL by processors has been slow (8 processors releasing compliance data, 12 processors involved in the NSHMP and 1100 producers accounts), those that have released LDL through their supply chain have had positive feedback from users. Workshops offered by these processors have been valuable in ensuring the complete functionality and benefits of using LDL within a business are understood. The workshops have also provided a means of creating and fostering greater relationships between processor and supplier.

Whilst LDL requires further improvements to continue adding value to users and increased uptake by industry, it has become a valuable tool. Meat & Livestock Australia have formed an advisory committee consisting of stakeholders from the beef and sheepmeat supply chains. In consultation with the advisory committee, an 'Annual Development Plan' was implemented. Key future target areas for LDL include enabling breeders to view feedback on animals they have bred, notifications for users when new data is available, enabling feedlot access LDL, allowing information flow from LDL to genetic data bases and improving animal health and disease defect information by enabling direct data uploads to NLIS. The increased functionality, when these changes are executed, will ensure LDL continues to add value for all users in to the future.

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MLA gratefully acknowledges the support of processors and producers utilising LDL and the LDL Advisory Committee for their dedication, time and enthusiasm for the program.

Application of the Australian Beef Eating Quality Insights and MyMSA to identify, deliver and measure the impact of supply-chain driven producer engagement activities

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Meat Standards Australia (MSA) is a national and world-leading eating quality grading system with the ability to predict the eating quality of individual cuts within a carcase for the end consumer. Understanding what drives the eating quality of beef is important in being able to implement continuous improvement strategies and create opportunities for improved returns to flow through the value chain to the farm gate.

The 2017 Australian Beef Eating Quality Insights report (BEQI) was generated from the analysis of MSA grading results for more than 5.9 million cattle, processed and graded through 42 MSA-licensed processors during the 2015–17 fiscal years and is the second in a series of benchmarking analyses reports.

The BEQI forms an important platform for establishing new benchmarks and identifying opportunities for improvement. It complements MyMSA, an online tool, which gives producers the ability to access and engage with MSA carcase feedback for their consignments. Together, these resources allow producers to identify trends and contextualise their feedback by benchmarking themselves against regional, state and national outcomes.

The BEQI report and MyMSA are central in the facilitation of educational and resource development efforts from industry service providers, including Meat and Livestock Australia (MLA). Since the first BEQI release in 2016, almost 6000 beef producers have engaged with MSA information in over 100 forums or workshops. These producer-focussed engagement efforts focus on addressing major non-compliance issues. The data behind the BEQI is being used to identify the 'hotspots', peak times of non-compliance for each state and, in conjunction with MyMSA, the primary reason(s) for non-compliance (e.g. high ultimate pH or inadequate fat coverage). Based on this information, targeted campaigns are being developed and released, at critical times and in key locations, to bring attention to compliance issues and equip producers with more specific resources and management strategies to positively impact their enterprise. The campaigns combine a range of communication mediums including online, paper and verbal communications. The aim of this is to give producers improved access to information as well as support in the development of knowledge and skills to support on-farm practice changes, thus increasing the proportion of cattle eligible for MSA grading. Not only will improved results increase the proportion of cattle graded under MSA, they will also drive increased farm gate returns. In 2016/17, cattle that did not meet MSA minimum requirements and company specifications had an opportunity cost to the producer of approximately $65/head, while for grain-fed cattle it was $34/head (MLA 2017a). This was equivalent to approximately $12 million in lost farm gate returns.

Premiums for MSA product also exist further along the supply chain, with analysis of independent butcher stores finding that the average price differential between MSA and non-MSA product across all major primals was $1.50/kg over the 2016-17 fiscal years (MLA 2017b). Furthermore, an enhanced supply of MSA eligible cattle and subsequently, MSA-graded products, improves consumer access to beef of consistent and predicted eating quality. In turn, this increases the likelihood of customer satisfaction and repeat-purchases, thus benefitting not only the consumer, but also each participant in the value chain.

The BEQI data will also be used to assist the 42 MSA processors in benchmarking their supply chain. MSA will support these supply chains through offering producer-focussed workshops to jointly evaluate their production systems and identify the potential causes of their non-compliance. MSA will work collaboratively with both processors and producers to implement the necessary measures to address these issues and use MyMSA to track the impact of said changes. Key indicators of the effect of this engagement will be monitored over time and include utilisation of MyMSA by participating producers, changes in total non-compliance and improvement in the MSA Index of consigned cattle.

Both of these projects have been developed with the intention of attaining optimum value for investment and maximising marginal returns for stakeholders. Through tools such as myMSA, supply chains will easily be able to monitor and benchmark their progress, thus enhancing the quality of information available to producers and facilitating further practice changes for the sake of improved MSA compliance.

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New agricultural technologies – implications for applied livestock systems modelling

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Livestock systems modelling is often described as a dichotomy between empirical or mechanistic structures and development methodologies. Mechanistic models have taken precedence over the last few decades, particularly in intensive studies of system dynamics and management, but also in applications that underpin farm or advisor decision support. Arguably this is because of their ability to predict variables like animal intake and pasture growth in the data poor environment of the livestock farm. The underlying process based equations are seen to be readily transportable to new environments (for example locations, pasture species mixes and animal breeds). However evidence from a range of model verification studies shows that a universally transportable livestock systems model does not exist, and each of the main frameworks requires very cautious application in a new environment, or committing time to the difficult task of calibration or parameter estimation given the high levels of mathematical complexity in these models. In some circumstances revising the model structure and development of alternative or new fundamental equations, which is a lengthy process, may be required to support a new application.

New measurement systems underpinned by advancing sensor, data collection platforms (*in situ* sensors, satellites, robots , drones) and networking technologies are turning the formerly data poor livestock farm into a data rich environment. Although in its infancy, the development of 'big data' in livestock systems research and management is seeing the application of advanced empirical modelling techniques. In the scientific literature citations utilising techniques like Partial Least Squares Regression (PLS), Support Vector Machines (SVM) or Random Forests (RF) have been increasing over the past few years. When automated these approaches are known as 'machine learning' and have the ability to self-parameterise and even evolve their model structure when fed quality observations off the data rich farm. This has led to the observation that agricultural modelling is currently shifting, with the advent of predictive agricultural analytics and artificial intelligence.

This paper presents the application of a suite of machine learning algorithms embedded in a data assimilation framework (DPI AgriMod™) to three big data applications: firstly the NSW-wide optimisation of soil water and pasture growth algorithms to support the monitoring of seasonal conditions over large areas; secondly the cloud and edge deployment of algorithms, assimilating data from pasture, soil, animal and weather sensors across farm-scale low power wide area networks (LoRaWAN); and thirdly the assimilation of centimetre level multispectral pasture data collected from drones. These applications highlight the vast potential for this new suite of data collection, networking and analytics technologies, and particularly the provision of granular, precise and pertinent decision making metrics for farmers. They also highlight some ongoing challenges in this shift towards agricultural analytics, the most important being the need for model development and application to maintain the stringent verification standards currently applied to models in the scientific literature–even when the automated equations in the cloud are self-learning to feed advanced farm decision making dashboards.

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Big data for monogastrics – what is possible?

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Agricultural industries are on the cusp of a digital revolution. Driving the digital revolution of agriculture are advancements in sensor technology, faster and more powerful computing as well as the omnipresent requirement to produce more food from less inputs. To feed the world's population in 2050, food production will need to advance by 70% between 2007–2050 (FAO 2009), albeit with greater transparency of the production chain to consumers. Digital technologies and big data are proposed as key to fulfilling this challenge.

Efficient pig and poultry production is reliant on accurate data. Pig and poultry producers currently generate vast amounts of data, however, the method of capturing and recording is most often via manual inputs with little sharing amongst decision makers along the production chain. Analyses of batch performance which are used to determine financial and management decisions are most often performed in hindsight with missing and or inaccurate information. In a world where everything is connected, data is a critical asset. Food production is no different, yet agriculture has the lowest adoption of digital technologies of all industries. Access to reliable and fast internet is often cited as the predominant barrier to the adoption of technology on farms. However, as the roll out of fixed wireless and satellite internet services continues, pig and poultry producers will have access to a greater array of digital technologies enabling more informed decision-making. As internet access increases in pig and poultry producing areas, it is predicted an increase in the adoption of automation and sensor technologies will follow leading to the production of big data sets.

Big data refers to the production of large data sets that are so vast that traditional data processing software is insufficient to handle these data sets. Big data requires cloud-based platforms to accept data streams from multiple inputs and uses analytic software to provide information to decision makers. While big data may at first appear incongruous to pig and poultry production, by capturing, analysing and sharing data in real time, producers will be better informed in making decisions. For pig and poultry producers, the measurement of feed consumption, water intake and bodyweight in addition to environmental and behavioural indices that are likely in the near future will provide vast data sets and opportunities for improved decision-making.

This has already commenced in pig production via the installation of electronic feeding systems that are capable of feeding individual pigs a tailored feed program based on automatically acquired body weights, age or from staff observations. This technology may also be incorporated into grower/finisher production units whereby individual animals may be tracked daily for their feed intake and body weight and appropriately segregated into a separate pen when they reach market weight. These systems allow pig producers to market animals at an appropriate body weight to meet market grid specifications and thereby reduce financial penalties for pigs that are deemed less valuable by processors.

In contrast with pig production, the automation of key management processes beyond environmental control on poultry farms is less well resolved than pig production. For example, automatically weighing broilers becomes more problematic with age as birds tend to visit automatic weighing systems less as their body weight increases. This can result in an underestimation of the flock body weight by as much as 30% (Chedad *et al.* 2003) nearing the end of the batch cycle, a time which body weights are crucial to scheduling pick-ups from farms. Attempts to use visual sensing technologies are as yet to be proven accurate with some reporting errors of between 50–250 g of body weight (Mortensen *et al.* 2016) during the late stage of the batch cycle. Also, the measurement of feed consumption within a poultry shed is problematic and rarely performed. Feed consumption data provided in real time would enable feedback not only on nutrition changes but could also be used as an indicator of flock well-being. Despite their importance, it may be some time before these technologies become commercially available.

The adoption of sensors, technology and big data should be applied with the overarching objectives to explain a biological process, translate this information into a meaningful outcome, be cost effective, reliable, accurate and be solution focussed. Skilled people will be required to interpret the data and making decisions based on the information provided; big data is not a replacement for people it is rather a tool to enable informed decision-making. Producing meaningful data sets and the analyses thereof in real time will facilitate increased production efficiency enabling the pig and poultry industries to produce more from less.

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Productivity and profitability of alternative steer growth paths resulting from accessing high quality forage systems in central Queensland – a modelling approach

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Beef producers in central Queensland (CQ) generally only have a limited area of suitable soil on any particular property for sowing to high quality forages such as perennial legume-grass pastures or annual forage crops (Bowen *et al.* 2016). Therefore, they need to make choices about how best to allocate high quality forages amongst different age groups of steers in their herd. This study assessed the most profitable way of incorporating high quality forages, such as perennial legume-grass pastures or annual forage crops, into the whole-of-life steer growth path in CQ.

Twenty-two growth paths (liveweight change over time) from weaning to marketing were developed from interrogation of existing data sets. These were investigated for steers grazing buffel grass (*Cenchrus ciliaris*) with and without access to leucaena-grass pastures (*Leucaena leucocephala* spp. *glabrata* + perennial, tropical grass (C4) species) or forage oats (*Avena sativa*) for varying intervals throughout their growth path. The production, economic and financial effect of each growth path was assessed by comparison to a baseline scenario producing finished, slaughter steers (605 kg) from buffel grass pastures which is the typical production system for the region (Chudleigh *et al.* 2017). The relative profitability of marketing steers at feedlot entry (feed-on) weight (474 kg) instead of slaughter weights was also assessed. The growth paths were applied within two beef enterprises, (i) steer turnover enterprise and (ii) breeding and finishing beef enterprise, over a 30-year investment period. Integrated herd models and property level, discounted cash flow budgets were developed for each scenario using the Breedcow and Dynama software (Version 6.02; Holmes *et al*. 2017).

For both enterprises, grazing steers on leucaena-grass pastures from weaning until they achieved feedlot entry weight was substantially more profitable than any other growth path. Compared to the base scenario, this optimal growth path improved profitability by 121 and 37% for the steer turnover and the breeding and finishing enterprise, respectively. The purchase of additional breeders for the latter enterprise was required to optimise utilisation of the leucaena-grass pastures. The seven most profitable growth paths for both enterprises incorporated leucaena-grass pastures. These results are in agreement with those from gross margin analysis conducted for commercial properties, and whole-farm case study analysis, where leucaena-grass systems were identified as the most profitable forage option for beef cattle production in CQ (Bowen *et al.* 2015, 2016). However, incorporation of leucaena-grass in to steer growth paths also resulted in increased peak deficit levels and financial risk to the business compared to buffel grass-only production systems with payback periods for the most profitable growth path of 8 and 14 years, for the steer turnover and the breeding and finishing enterprise, respectively. While providing a high quality forage for any period during the growth path of steers reduced the age of turn-off compared to that expected on average from buffel grass-only pastures (26.2 and 34.0 months for feed-on and finished steers, respectively) it was not always more profitable to do so. For example, a growth path providing forage oats twice, in dry season 1 and 2 after weaning, and with leucaena-grass in between, resulted in the youngest age of turn-off at finished weights of any scenario (22.8 months). However, this growth path was only marginally more profitable than the base scenario for the steer turnover enterprise ($2,014 extra profit/annum) and resulted in $28,236 less profit/annum than the base scenario for the breeding and finishing enterprise. Incorporating forage oats into a buffel grass-only growth path always reduced the enterprise profitability. Furthermore, all growth paths that incorporated forage oats resulted in lower economic and financial performance than comparable growth paths that incorporated leucaena-grass. Additionally, implementing forage oats into either beef enterprise substantially increased peak deficit levels and financial risk. There were no meaningful relationships, across scenarios within an enterprise, between change in profit and the number of extra weaners produced or the amount of extra beef produced per ha. This finding reflects the principle that the most profitable level of output is achieved when marginal cost almost equals marginal revenue, never when production is maximised.

This analysis provides insights which can be used by beef producers to guide business investment decisions. Further research is required to better understand compensatory growth effects in northern cattle production systems and also effects of utilisation rates of buffel and other sown grass and legume species. This would allow improvement of existing modelling capabilities which, in turn, will better inform whole-farm economic analysis.

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Price and cost variability matters: Merino sheep enterprise economic insight using GrassGro

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CSIRO's GrassGro (Moore *et al.* 1997) is a computer program that simulates pasture and animal production in response to weather and management. Variability in production and risk in the grazing systems modelled can be assessed to assist farmers in making informed decisions. The program, however, assumes prices and costs to be constant for the duration of the analysis. Price variability (Kimura and Antón 2011) in Australian agriculture, however, is one of the biggest sources of risk to farm profitability.

To assess the impact of price variability, a 1000ha farm in Tarcutta, southern NSW was modelled. The farm consisted of three paddocks; two 400ha paddocks of phalaris and one 200ha paddock of lucerne. The enterprise simulated was a merino ewe flock, with replacement ewes purchased, at a stocking rate of 5 ewes/ha. The simulation used ewes weighing 55 kg, producing 20-micron wool. The ewes were joined on 1 February to a terminal ram to produce crossbred lambs which were born in July and sold on 15 December. The ewes were supplementary fed wheat grain when pastures were inadequate. Lambs post-weaning, were production fed as required to achieve a target 45 kg sale weight on 15 December.

Gross margins (GM) were calculated (Table 2) to compare the impact of price and cost variability. GrassGro was used to simulate production and calculate GM for the period 2012-15 with the costs and prices used being the mean (constant) value for the period. The output of the model was then extracted into an excel spreadsheet and GM calculated for each year using historical (variable) annual prices and costs (Table 1). GM calculations using variable prices and costs resulted in 150% higher coefficient of variation (CV) over the same four-year period compared with using constant prices and costs. The CV is an indicator of risk which is important in projecting economic and financial outcomes of changes in farming systems. The CV would be expected to increase when a longer time series is simulated, due to an increased likelihood of variations such as drought impacting on production, prices and costs.

Table 2. Gross margin comparison using constant versus variable prices and costs

	Prices of outputs					Cost of inputs						Gross margins based on	
	Wool 20 micron	Ewe sales (Cast for age)	Lamb sales	Ewe skin	Lamb skin	Shearing	Husbandry	Ewe Replacement	Rams	Pasture cost	Feed wheat	**constant** prices and costs	**variable** prices and costs
Calendar Year	Ac/kg	Ac/kg cwt	Ac/kg cwt	Ac/skin	Ac/skin	$/head	$/head	$/head	$/head	$/ha	$/t	$/ha	$/ha
2012	1232	250	415	1063	1330	10.7	7.6	169	942	39	227	432	243
2013	1190	205	423	998	1206	11.1	7.1	73	735	37	306	335	223
2014	1163	317	518	598	819	10.4	8.1	58	573	40	309	365	390
2015	1284	358	550	813	998	10.6	7.5	123	733	41	295	352	377
*Mean	1217	283	477	868	1088	10.7	7.6	106	746	39	284	371	308
SD	53	68	68	209	226	0.3	0.4	51	151	2	39	43	87
CV	0.04	0.24	0.14	0.24	0.21	0.02	0.05	0.48	0.20	0.04	0.14	0.11	0.28

Data sources: AWEX and MLA for output prices, ABARES and NSWDPI for cost estimates and wheat prices, AuctionsPlus and Abrona Suffolks and White Suffolks ram sale catalogue for replacement ewe and ram prices respectively.

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Investment in infrastructure and personnel in support of advanced feedback systems for producers and carcase optimisation for clients

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Gundagai Meat Processors (GMP) was established in 1974 by brothers Tony and Bill Barton, the sons of F. W. Barton who commenced his butcher's apprenticeship in South Gundagai in 1919. We remain a family owned and operated business with a passion for industry spanning nearly 100 years. Whilst initially processing cattle, sheep and pigs, the business now focuses exclusively on lamb for domestic and export clients.

The business is different from many others in industry in that we don't buy livestock or sell meat, we are a fee for service only operation. Our focus is therefore on service delivery to our clients which includes supporting the producers who supply them as well as ensuring we optimise carcase / cut yield outcomes.

In early 2017, GMP embarked on an ambitious expansion project, the main objectives of which were to:

- Advance from Tier 1 to Tier 2 Export Certification – facilitating access to additional export markets including the US, EU and Asia.
- Increase sustainable production capacity from 2350 to 4000 lambs per day.
- Improve processing efficiency and reduce the per unit cost of production.

The $30 million expansion project also included investment in infrastructure to develop advanced producer feedback systems and carcase optimisation for clients including, but not limited to;

- Hot & Cold Dual Energy X-Ray Absorptiometry (DEXA) units.
- Fully automated carcase chillers with RFID integration and automated carcase sortation.
- Integration of animal health recording with objective measurement data.

In addition to the foregoing, we have also appointed a Client Research Advisor (with a Meat Science and education background) to ensure that GMP is at the forefront of innovation in meat processing, specifically in areas related to meat science, as well as to provide technical and research advice to our clients regarding supply chain opportunities.

This work will be of increasing importance to our business as advancements in innovation and technology necessitates an understanding of the science behind animal health & welfare, meat yield and eating quality. The ability to bring these elements together using DEXA technology and innovation in carcase yield optimisation to provide meaningful outputs for our clients is viewed as a key factor in our ongoing success.

At an industry level, the deterioration in trust between producer and processor has become a well-documented issue. For the Australian red meat sector to remain viable, in what has become a highly competitive global market, producer and processor must work hand in hand. By combining objective carcase measurement data with animal health information, GMP will provide industry leading insights to producers and help industry rebuild trust along the supply chain. This initiative, combined with the provision of a Client Research Advisor, will make producer feedback more accessible and relevant.

Droughts in southern Australia have affected stock and feed prices

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Whilst many global factors affect the prices of Australian agricultural products, seasonal conditions in southern Australia can affect prices due to a change in supply and demand. Quantitative information on prices that may eventuate during and post drought could assist producers and their advisers assess management options with more realistic outcomes. Alternatively, more informed cash flow scenarios may assist in preparation for, and consideration of, worst case scenarios.

To investigate the effects of droughts on prices of commodities relevant to livestock production in south eastern Australia, a study was conducted using historic prices for cattle, sheep, feed grain and hay available since 1970.

A range of databases were used to source livestock prices (National Livestock Reporting Service from Newmarket saleyards and MLA livestock reports from Adelaide and Ballarat saleyards) for lambs, wethers, cows and vealers. Feed wheat prices were supplied by Jumbuk Trading, delivered to Melbourne (1985–2012) and for large square bales of pasture hay, delivered Shepparton (1989–2012). Given the number of factors that affect price and the limited data available (price data and number of 'droughts'), a simple approach was to examine prices in drought years and compare these with general trends in other years. Droughts were defined as occurring when annual pasture grown, rainfall, sale weight of stock, supplementary feed costs and gross margin were in the lowest decile for four case study sites in Victoria modelled in GrassGro™, described elsewhere (Court *et al.* 2015).

The droughts of 1982, 2002 and 2006, meeting the above definition, showed steeper price drops for livestock post July compared to other years, particularly for mature stock. Cows were approximately 30% cheaper in drought years by December, than in other years and mutton prices dropped by up to 50% of the price received in other years, by December. Hay and feed wheat prices increased by more than 100% in Victoria in (including the year after) the drought years 2002 and 2006, compared to other years (Fig. 1).

Farmers and consultants could capitalise on understanding historic drought price changes to inform tactical strategies, such as selling surplus stock before prices fall and early purchasing or forward contracting of feed, if there are reliable and early warning signs of droughts. Research indicates that soil moisture is a useful predictor of spring pasture growth (Cullen and Johnson, 2012) and could, together with other climate indicators provide early predictions of failed or poor springs, before significant price changes occur (Court *et al*. 2015).

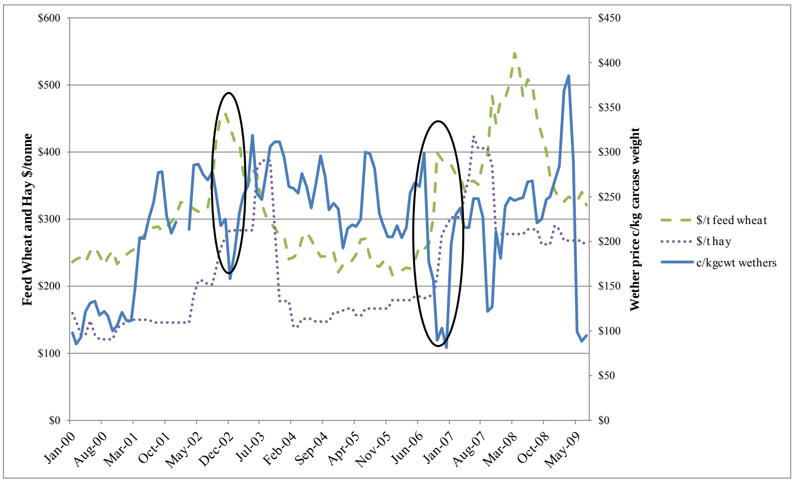

Fig. 1. Monthly prices for wethers, hay and feed wheat 2000-2009 adjusted for CPI (2002 and 2006 droughts circled).

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Building the value chain of the future with LambEx Young Guns

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In 2014, a new national 'Young Guns' competition highlighting the huge depth of talent and knowledge in the youth of the Australian lamb industry was initiated as part of LambEx, which was held in Adelaide. Upon its success the competition was repeated at LambEx 2016 in Albury. The Australian White Suffolk Association has sponsored the event to date as they recognised the importance of youth to the Australian lamb industry and the need to develop and build careers to ensure the lamb industry has young people excited and enthused about their future in the industry.

Youth from the Australian lamb industry were invited to share their experience, project, research, study, thoughts and ideas covering any activity along the whole lamb value chain. This included the likes of on-farm producer group projects/activities, Research Development and Extension projects on genetics, animal production, pasture and grazing management, marketing, environment, welfare, health, e-technology), and off-farm (transport, processing, storage, retail, food service, new product development, marketing and export), and social and cultural aspects. The competition aimed to identify the Young Guns, but included a component of training. The competition was segregated into three categories: high school and undergraduate students; honours, masters and PhD students; and early career professionals (less than 30 years old).

Applicants were asked to submit four pieces of written work covering their vision for the industry and a brief personal profile, a one slide PowerPoint poster and one page Word document on their topic/activity. Four finalists were selected by a four person industry panel using weighted selection criteria assessing their written content from each category to represent Australian lamb industry youth at LambEx. The finalists received free registration to LambEx and presented their posters to the industry panel the day prior to the commencement of LambEx and this assessment was added to the weighted selection criteria. The winners in each category received a cash prize and were introduced on stage in front of the 900 + LambEx attendees and were interviewed on their topics.

The finalists conveyed enthusiasm, passion and motivation for the industry. They showed innovation in their thinking and application and demonstrated a desire to be a servant of the industry. The 2014 cohort had heard about the event from a myriad of communication channels, indicating it requires a multi-pronged approach across teachers/schools, parents, Rural press, LambEx web, Farming Systems and Producer Groups. They gave the LambEx Young Guns Competition a score of 8.3 out of 10. They influenced at least a further 28 people to attend, and had over 1 million ewes under their management, influence or via their networks. Participants valued the chance to gather and present their thoughts and experience. Every single finalist took something positive out of the experience. The manner in which the peers all listened whilst the judging panel asked questions was valued. In terms of personal gain, most gathered new mentors and friends, it was an experience of a lifetime, gaining more confidence in public speaking and greater understanding of the industry.

In 2016, using the continuous review process established in 2014, changes were made in the following areas, finalists were given the opportunity to participate in a career development day which was run the day prior to LambEx commencing. The finalists were observed on how they conducted themselves throughout the day. The day consisted of presentations given on topics such as; Life after post grad, Insights into publishing, testimonials of Journeys and Roles in industry, Motivational tips on how to achieve personal goals and lastly, one of the 2014 Young Guns winner, Caris Jones spoke of her experience. The feedback from the 2016 competition was consistent with results in 2014. The professional development day was highly rated and was a truly valuable experience.

This initiative has demonstrated the benefit to industry by providing a platform to identify and develop the youth of the Australian lamb industry. With many finalists cementing careers within the industry, a strong foundation has been laid through building the value chain of the future with LambEx Young Guns.

We gratefully acknowledge LambEx and supporting organisations.

The place of the Nigerian youth in livestock industries and sustainable development

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With the increase in population and urbanization, agriculture production in Nigeria and related value chains need to grow and evolve quickly. Addressing these problems calls for various initiatives; spanning macro-economic policy, improvements and access to technologies that can catalyze adequate food production to meet the needs of the domestic market. Livestock are domesticated animals raised in a setting to produce commodities such as milk, meat and fibre while providing a source of employment for farm labour. Livestock are generally raised for profit. Raising animals (animal husbandry) is a component of modern agriculture. Livestock are comprised of species or population of animals kept by humans for a useful, commercial food and fibre production. They could be domestic species, semi-domestic animals, or captive wildlife. Domestic livestock (sheep and cattle) consume 70% of the animal feed resources available in Nigeria, thus there is a need to continuously increase the feed supply to sustain the supply of meat, milk and fibre for the Nigerian population. Unfortunately many of the farmers in Nigeria are unable to access quality feedstuffs for their commercial herds/flocks and so the price of livestock production in domestic food markets is increased. The current project is designed to engage youths in rural environment in livestock rearing activities with the objectives of increasing food production, improving livelihoods, and reducing unemployment in North Central and North East regions of Nigeria that have been destroyed by Boko Haram insurgents. This will be achieved through mentorship and capacity building with the introduction of new agricultural production technologies, entrepreneurship development, provision of starter packages, and facilitating access to credit.

The setting up of an efficient feed mill or plant that will engage some of these unemployed/homeless youths especially those living in Internally Displaced Persons (IDP) camps will provide a much needed vocational education program. The enterprise will increase the market supply of finished feeds at a price that will be affordable by farmers. All across the African continent, livestock have provided and continues to be a source of livelihood to many African youths. Livestock rearing has to be refined and promoted so that these newly trained youths can help the agricultural economy of the nation. Poverty reduction in Nigeria depends on a vibrant commercial agriculture sector that includes smallholder farmers. Nigeria needs to commit to investing adequate resources to training youths in agriculture related business entrepreneurship, including the livestock sector. This includes the need for micro credit facilities, and the promotion of effective market chains to connect to domestic consumers. It is important to promote and build capacity along the agriculture value chain, and to create and sustain opportunities in this sector for future generations.

Livestock as income generation for young people could also serve as a tool to attract youth to agriculture as this will help reduce unemployment, hunger and poverty. If the livestock sector in Nigeria is to be transformed as an income generating sector for youth, the government must take the initiative and harness the potential in livestock to boost the national economy and utilize some of the unique feed resources available for animal industry in the country.

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