

# final report

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Prepared by: Dr Viv Perry and Katrina Copping  
The University of Nottingham and The University of Adelaide

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## **Effect of maternal gestational nutrition on net feed intake and carcass traits**

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## **Abstract**

This project evaluated the effect of dietary protein in beef heifers calving at 2yo during the peri-conception period and first trimester on subsequent development of the bull calf progeny which were generated from a concurrent ARC/ S.Kidman/ Ridley funded research trial. The entire males were transported to Tullimba feedlot at 528 days of age weighing 536 kgs and their feed intakes and weight gains were individually monitored. After 70 days on feed they were slaughtered at an abattoir at Warwick and their carcass traits were evaluated. The effects of maternal dietary protein intake during the peri-conception period and first trimester section upon NFI and carcass traits are reported. High protein diet during the first trimester (23dpc to 98dpc) resulted in an increase in EMA, dressing %, estimated retail meat yield and tended to decrease subcutaneous fat in the entire male offspring. While the economic cost of protein supplementation to yearling heifers in a northern range environment would potentially be difficult to justify in terms of the change observed in carcass traits alone, in combination with other positive effects observed in this much larger study on increased conception rate, reduced fetal loss, improved calf health and early reproductive development in the male progeny, the manipulation of maternal nutrition may be cost-effective.

## Executive Summary

Protein is the major limiting nutrient during pregnancy in range heifers. This project examined the effect of protein supplementation during early gestation (60 days prior to conception to 98 days post conception) on the feedlot performance, feed efficiency and carcass characteristics of the bull progeny. The aim of the project was to examine the cost effectiveness of protein supplementation during this short period on the performance of the progeny.

Heifers (n=360) were selected from the Channel country of South Western Queensland and transported to a custom built feedlot in South Australia where they were individually fed for the entire pregnancy. The heifers calved and were monitored with their progeny monthly until weaning. Entire male progeny were transported to Armidale for the 70day NFI trial. At the end of this stage they were slaughtered at a commercial abattoir. All organs were sampled and weighed and standard carcass assessments completed.

Protein supplementation to the heifer from 23dpc (days post conception) to 98dpc (HPOST) resulted in a larger EMA, with EMA being a measure of muscling in the progeny. Consequently these HPOST bulls showed improvement in estimated retail meat yield compared with LPOST animals as differences in eye muscle are reflected in retail beef yield (McKiernan *et al*, 2009). Interestingly, the effects of HPOST maternal diet on EMA were still observed with EMA adjusted for HSCWT ( $P<0.05$ ) suggesting that the HPOST bulls had increased muscularity independent of overall bodyweight. This period of nutritional intervention (23dpc-98dpc) corresponds to the period of primary myogenesis and early secondary myogenesis - when it is suggested maximum fetal muscle fibres are developing in the bovine.

The observed tendency for the progeny of the LPOST dams to be fatter is in agreeance with previous reports of progeny of nutrient restricted dams being predisposed to adiposity (Micke *et al.*, 2011). As proposed by the thrifty phenotype hypothesis (Hales and Barker, 1992) this may be a survival advantage under poor nutritional conditions. Adipogenesis in beef cattle starts to occur before mid gestation in cattle with adipocytes reported to be first detected in visceral fat depots as early as 80dpc followed sequentially by subcutaneous, intermuscular and finally intramuscular depots by 180dpc (Taga *et al*, 2011). The 23dpc to 98dpc nutritional supplementation window in the current study corresponds to the start of the window for formation of adipocytes in the visceral and subcutaneous depots. The observed tendency for the progeny of HPOST dams to be leaner, have improved dressing percentage and estimated retail beef yield ( $P<0.05$ ) but not different in either pre-slaughter liveweight or HSCWT when compared to offspring from LPOST dams, suggests a shift in fat deposition that may improve carcass value. Of note, there was no difference observed in AUSMEAT marble score; despite the HH group having a 3 fold increase in marbling score this was not significant. This may have been influenced by the discrete categorical nature of the AUSMEAT score compared to the continuous MSA scoring that we had previously used. The scores were low overall. More comprehensive laboratory evaluation of the intra-muscular fat (IMF) content of samples is being undertaken.

The effects of carcass characteristics of progeny after maternal dietary interventions have reported inconsistent effects (Mohrhauser *et al*, 2015, Long *et al*, 2012, Larson *et al*, 2009, Underwood *et al*, 2010, Micke *et al*, 2010, Greenwood *et al*, 2009, ). The inconsistent results may be attributed to differences in the timing and degree of nutrient restriction, the specific nutrient evaluated, the sample size and sex evaluated. The study reported here-in being

unique in that the individual level of controlled intake occurred from the peri-conception period through to parturition with the time-window of gestation evaluated starting earlier than in other studies.

Whilst changes to body composition in beef cattle may be desirable to improve production efficiency, they have also been shown to influence meat quality. Minimum levels of fatness, and in particular marbling, are known to be required for good meat quality (Hocquette *et al*, 2010). In addition, tenderness is a desired quality for beef and increased connective tissue contributes to the toughness of meat (Du *et al*, 2013). Samples have been collected from the carcasses for meat quality testing and results will be published in the future.

These studies show that opportunities exist for the livestock industries to manipulate maternal nutrition to enhance muscling and alter fat deposition leading to improvement in efficiency for meat production in beef cattle. Mechanisms regulating fetal cell differentiation into myogenic, adipogenic and fibrogenic cells in the bovine are not well understood (Du *et al*, 2013). Improved understanding of the mechanisms is needed to maximise the benefits of manipulating production and carcass traits in beef cattle through nutrient supplementation targeted to a specific developmental stage. Ongoing work on the brains and muscle of these cattle (funded by the ARC) should elucidate these mechanisms.

The economic cost of protein supplementation to yearling heifers in a northern range environment would potentially be difficult to justify in terms of the change observed in carcass traits alone. However in combination with other positive effects observed in this much larger study on increased conception rate, reduced fetal loss, improved calf health and early reproductive development in the male progeny, the manipulation of maternal nutrition has been calculated to be cost-effective.

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# 1 Background

Beef cattle are produced in Australia under systems where nutrition can be highly variable throughout the production cycle, with protein often deficient in the diet. We have previously shown that nutrition during gestation may play a significant role in beef cattle productivity (Micke *et al*, 2010a,b;2011a,b; 2014) Such perturbations to the maternal environment mean that the fetus is rarely able to express its full genetic potential. The main factors influencing nutrient partitioning between the dam and fetus include age of the dam, number of fetuses, production demand and environmental stress (Funston and Summers, 2013). These factors play a role in programming the fetus for its future environment and available resources. Furthermore, fetal programming has been shown to impact neonatal mortality and morbidity, postnatal growth rate, body composition, and health (Micke *et al*, 2010a,b;2011b).

## 1.1 Appetite regulation and NFI

Appetite and food intake is essential for weight gain, growth, health and welfare, particularly during periods of stress. Depressed appetite during such periods, for example; neonatal life, feedlot entry and live export transportation, result in increased susceptibility to diseases at these critical times and is a major source of economic loss to the feedlot and export industries. The hypothalamic region of the brain plays a pivotal role in the control of voluntary food intake and appetite drive in ruminants. The activity of these neural pathways is modulated by factors such as leptin that circulate in the bloodstream providing information on the body's nutritional status. In cattle these neural pathways develop early in gestation and are susceptible to maternal nutrition at this early stage. The postnatal persistence of such changes may contribute to the programming of an altered adult appetitive phenotype, (this hypothesis forming the basis for many investigations into the fetal origins of human obesity (Mühlhäusler and Ong, 2011)

Feed is also the largest recurring input cost in a feedlot operation. Net Feed Intake (NFI) is a measure of the difference between the amount of feed eaten by an animal and that predicted to be eaten at a given size and level of production. Animals that eat less than expected are considered to be more efficient. Improvement in feed efficiency represents an opportunity to improve feedlot profitability as do improvements in other key production traits including growth rate, dry matter intake (DMI) (which is a measure of appetite) and feed conversion ratio (FCR).

Importantly, the molecular basis for differences in NFI is yet to be determined. Various candidates such as IGF-1, leptin, ghrelin, GHR, UCP 2 and 3 have been proposed with varying success. We have reported previously that some of these factors can be enhanced by nutrition in utero (Micke *et al*, 2010). We have also clearly shown in both cattle and sheep that maternal diet in the first trimester alters appetite regulation in the offspring (Sullivan *et al*, 2010; Yuen *et al*, 2003)

## 1.2 Carcass traits

The proportion of lean and muscle mass is a critical determinant of carcass quality; a high percentage of lean tissue being paramount to the economically produced carcass. Furthermore, while excess waste (subcutaneous) fat is undesirable, intramuscular fat is essential to the palatability of beef. Excessive connective tissue also reduces palatability and increases toughness (Du *et al*, 2013)

Studies to date show that nutritional interventions applied to cows during early pregnancy is a promising new method of improving carcass value (Du *et al*, 2010; Micke *et al*, 2011) as well as performance:

Recent studies have shown that myocytes, adipocytes and fibroblasts (cells of muscle, fat and connective tissue lineage, respectively) are all derived from a common pool of progenitor cells during embryonic development (Du *et al*, 2010). Critically, the fate of these progenitor cells, and therefore the balance between muscle, fat and connective tissue in the animal, is heavily impacted by alterations to the maternal diet during gestation and specifically protein in the diet (Micke *et al*, 2010a). Importantly muscle fibre formation in cattle is completed by the middle of gestation (Rehfeldt *et al*, 2011). Increases in muscle after birth therefore are only in fibre size (i.e. hypertrophy) rather than fibre number (Buttery *et al*, 2000). Furthermore, abundance of all progenitor cells declines with age making manipulation of progenitor cell differentiation vastly more effective during early development in utero.

Perhaps surprisingly the development of adipose tissue is far less well characterised than that of muscle. In general, adipocytes can be divided into two types, white and brown. Brown adipose tissue (BAT) adipocytes contain numerous small lipid droplets, have large numbers of mitochondria and provide the main mechanism for maintaining body temperature via heat production in cold exposed neonates. White adipose tissue (WAT) adipocytes contain a single large fat droplet and are the classical fat cell type used for long term storage of excess energy. BAT, but not WAT, has been shown to derive from early myoblasts (Seale *et al*, 2008), so shares an origin with muscle cells, but the source of WAT adipocyte precursor cells remains largely unknown. Studies in sheep to date show that increased protein during first trimester of gestation, results in increased measures of (WAT) adiposity in offspring, particularly in males (Duffield *et al*, 2009). This suggests long-term “programming” of adiposity, particularly in the normally leaner males, and that this is not associated with differences in birth weight.

The project aims to evaluate the effect of dietary protein in beef heifers calving at 2yo during the peri-conception period and first trimester on development of the calf. The effects of maternal dietary protein intake during the peri-conception period and first trimester section upon NFI and carcass traits are reported here. Providing information on the effects of maternal dietary protein will assist in determining appropriate nutritional strategies for yearling heifers, prior to mating and during early pregnancy, to maximise productivity both in female and male progeny.

## 2 Projective objectives

Objectives of the experiment were:

- To have measured NFI characteristics of male progeny of heifers that have experienced varying nutritional inputs during their pregnancy.
- To have measured the carcass characteristics of male progeny of heifers that have experienced varying nutritional inputs during their pregnancy.

## 3 Methodology

### 3.1 Experimental animals

This project utilized entire male progeny generated from a concurrent ARC/ S.Kidman/ Ridley funded research trial outlined in 3.2. Use of animals and the procedures performed in this project were approved by The University of Adelaide and The University of New England Animal Ethics Committees. (Approval numbers: S2012-249 and AEC14-037).

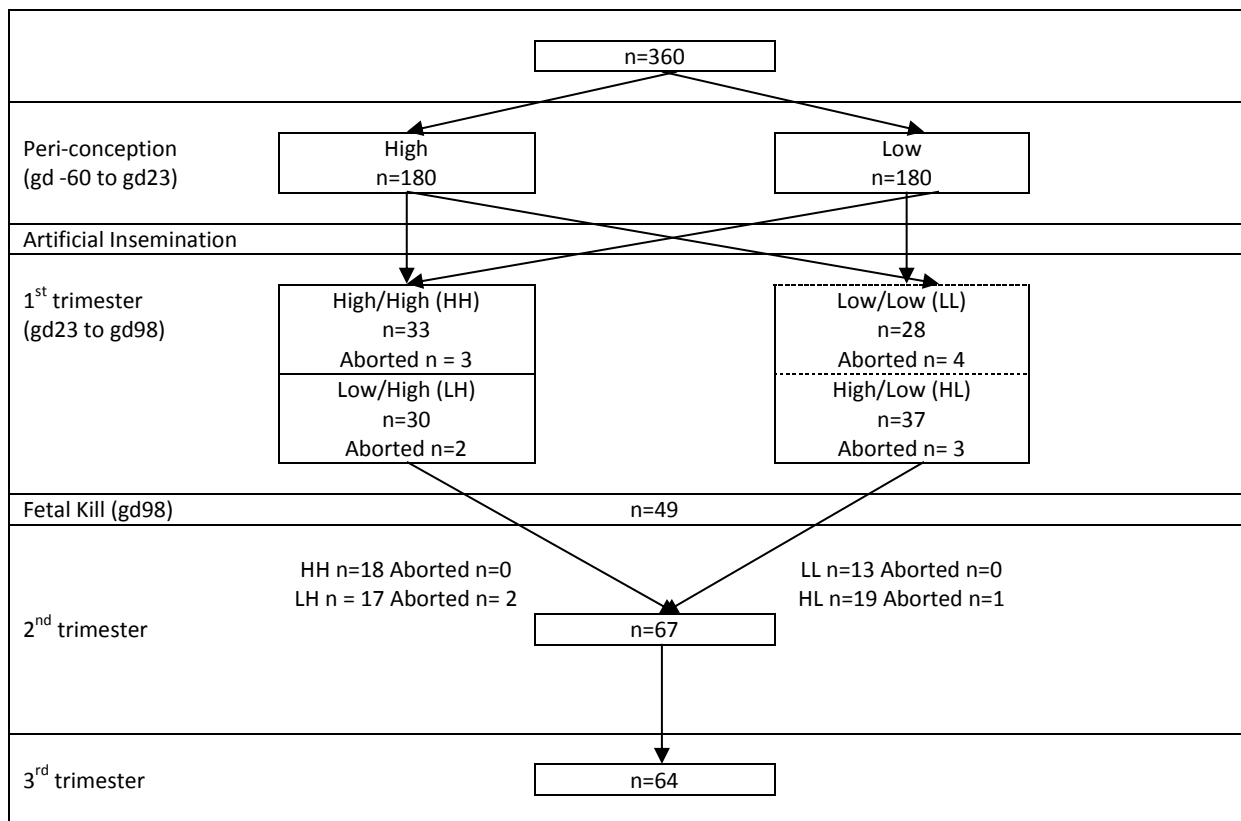
### 3.2 Background experimental design

Three hundred and sixty primiparous twelve month old Santa Gertrudis (*Bos taurus x Bos indicus*) heifers were selected based on weight and age from SK Kidman herds at Glengyle and Morney Plains, south western Queensland. They were transported from Queensland to purpose built shaded feedlot pens in Sedan, South Australia in November 2011. They were acclimatized to individual stall feeding for 60 days whereby they were fed a mixture of hay and straw ad libitum in their pens and allowed into the stalls daily for the grain portion of their ration.

The study was a two-by-two factorial design. At twelve months of age, 60 days prior to artificial insemination (AI), heifers were stratified by bodyweight and randomly assigned to two equal peri-conception (PERI) treatment groups, high and low protein (HPeri and LPeri). Each heifer was fed a high (14%CP) or low (7%CP) protein diet consisting of pellet diet individually fed in stalls and straw (5%) ad libitum in pens. The ration was as isocaloric as possible in the ruminant and supplemented with a vitamin and mineral commercial preparation (Table 1). At Day -8, Heifers underwent an eight day progesterone based estrous synchronization program. On Day 0, the heifers were inseminated with semen from the same Santa Gertrudis bull with known EBVs for growth and birthweight. At gestation day (gd) 23, half of each nutritional treatment group changed to an alternative post-conception (POST) treatment, high and low protein (HPost and LPost), giving rise to four treatment groups: high/high (HH), high/low (HL), low/high (LH), low/low (LL).

Pregnancy was confirmed at gd 36 and sex of fetus determined at gd 60 by rectal ultrasound. From the end of the first trimester of gestation (gd 98), all heifers were fed the same NRC recommended ration diet individually receiving the pellet portion of their diet daily until parturition (Fig.1).





**Figure 1.** Experimental design illustrating nutritional treatment groups and numbers of heifers in each feed regimen from the peri-conception period until the end of gestation. There were 43 male progeny, twins and a cryptorchid bull were excluded from this section of the experiment yielding 40 male progeny for inclusion.

**Table 1.** Ingredients and nutrient content of heifer rations for peri-conception and during the first trimester of gestation

	Induction	Peri-conception		First trimester	
		High	Low	High	Low
Ration as fed					
Wheat (kg)	0.66	0.48	1.81	0.56	2.12
Canola meal (kg)	2.23	–	–	–	–
Soybean meal (kg)	–	1.83	0.48	2.14	0.56
Barley straw (kg)	7 <sup>B</sup>	6.7	5.5	10.7	10.2
Molasses (g)	90	72	72	84	84
Biofos MDCP (g)	–	–	19	–	22
Salt (g)	15	12	12	14	14
Vitamin/trace mineral premix (g)	3	2	2	3	3
Dry matter	9.1 <sup>C</sup>	8.3	7.2	12.3	11.8
Total energy (MJ ME)	–	71	63	102	98
% of energy requirements <sup>A</sup>	–	96	85	142	136
Total crude protein (kg)	–	1.18	0.62	1.49	0.88
% of protein requirements <sup>A</sup>	–	127	67	123	72
% CP (total diet)	–	14.2	8.6	12.1	7.4
Total calcium (g)	–	26	22	38	37
% of calcium requirements <sup>A</sup>	–	130	110	190	185
Total phosphorus (g)	–	17	17	21	21
% of phosphorus requirements <sup>A</sup>	–	130	130	160	160

<sup>A</sup>Dietary requirements were calculated using Nutrient Requirements of Domesticated Ruminants (2007, CSIRO). Input values were based upon nutrient analysis of component ingredients in the total diet, liveweight and age of heifers at each diet change, mature cow weight of 550 kg and the desired growth target.

<sup>B</sup>Assumed value.

<sup>C</sup>Predicted value.

After calving, individual feeding ceased and all the heifer dams and their progeny were run together on pasture until weaning at 6 months of age. Post-weaning, the male and female progeny were separated and remained at Sedan on pasture until the commencement of the NFI Test.

### 3.3 NFI test

In May 2014, 40 male progeny were transported from Sedan, South Australia to the 'Tullimba' Research Feedlot near Kingstown, NSW, several weeks prior to the commencement a feed efficiency test. Following a pre-test adjustment period of 21 days to allow for the animals to adapt to the feeding system and diet, the animals commenced a standard 70 day NFI test (Exton, 2001). Briefly, during the test animals had access to *ad libitum* access to the typical Tullimba finisher ration (13.5MJ and 90%DM). Individual feed intake was measured using computerised automatic feeders with each animal fitted with an electronic eartag and individual feeding events recorded over the duration of the test period. Bulls were randomly allocated to two, adjacent feedlot pens at the beginning of the trial. The average age ( $\pm$  sd) at the start of the test was  $528 \pm 5$  days and weight of  $537 \pm 31$  kg. Animal liveweight was measured regularly throughout the test period as per the standard NFI protocol. Animals had access to feed until removed from the pens and walked to nearby facilities. Average daily gain (ADG) for each animal was calculated as the difference in weight gained over the entire feedlot test by the total number of days on test. NFI was calculated using records of Daily Feed Intake (FI) taken during the test as detailed by Arthur *et al* (2001). Feed Conversion Ratio (FCR) was calculated as FI divided by average daily gain (ADG).

One bull was removed from the feedlot pens at the end of the pre-test adjustment period after failing to adjust to the feeding environment. He remained on feed in the open bunk pen and was slaughtered as part of his contemporary group however he is has been excluded from these analyses for both feedlot performance and carcass traits.

Following the completion of the NFI test, the male progeny were transported to a commercial abattoir at Warwick, Queensland where they were humanely slaughtered and assessed for carcass traits.

### 3.4 Carcass traits

After stunning and exsanguination, the body was weighed to give a hot standard carcass weight (HSCW). Following commercial AUS-MEAT carcass preparation (Anon. 2007), rump (P8) fat was recorded, before the sides being chilled overnight. The next morning the carcasses was quartered between the 12<sup>th</sup> and 13<sup>th</sup> ribs and graded by an accredited assessor following standard procedures. Traits measured were eye muscle area (EMA), AUS-MEAT marble score (AusMS: 0 (nil) to 6 (abundant)), fat colour (from 0 (near white) to 4 (dark cream) by units of 1) and meat colour (1A (pale pink) to 1C (dark pink); 2 (pale red); 3 red)). Estimated Retail beef yield (RBY%) was calculated using the prediction equation  $Yield = 64.8 - (0.2 * P8) - (0.14 * EMA)$  (Wilkins JF, pers comm., January 2015). Dressing percentage was calculated as hot standard carcass weight divided by the final non-fasted weight at the feedlot. The descriptive statistics for the live animal measurements are presented in Table 2.

**Table 2.** Means, standard deviations and ranges in values for live-animal measurements for the bulls during NFI test

	Mean	sd	Min.	Max.
Age at start test (days)	528	5	517	539
Weight at start test (kg)	537	31	478	611
Weight at end test (kg)	665	43	567	765
ADG on test (kg/day) <sup>1</sup>	1.84	0.33	0.57	2.35
Feed intake (kg DM/day)	13.14	1.26	10.51	16.09
FCR (kg/kg)	7.40	1.94	6.17	18.44
NFI (kg/day)	0.038	0.638	-1.31	1.53

<sup>1</sup> Average daily gain

### 3.5 Statistical analyses

The dataset analysed for this report was for the 39 bulls that successfully completed the NFI test protocol. Two- way ANOVA (STATA/IC 13.0) was used to interpret the main effects of PERI and POST conception diet and first order interactions on Liveweight, Feed Intake, Average Daily Gain (ADG), FCR, DMI, NFI, EMA, P8 Fat depth, fat colour, meat colour, dressing % and estimated retail beef yield (RBY%). All traits were analysed as if continuous in nature. For this purpose, meat colour was coded: 1A=1, 1B=1.3, 1C=1.7, 2=2, 3=3. Individual bull was considered the experimental unit, and the statistical model included dam treatment during peri-conception and dam treatment post-conception as fixed effects with feedlot pen and animal age included in the model as a co-variate. The effect of PERI and POST- conception diet was always retained in the final model, whilst non significant ( $P>0.1$ ) interactions were sequentially removed in order of least significance. Statistical significance was accepted at  $P < 0.05$ , and a tendency at  $P < 0.1$ .

## 4 Results

### 4.1 Feedlot growth and efficiency

Mean age, start and final liveweight, average daily gain (ADG), feed intake, feed conversion ratio (FCR) and Net Feed Intake are presented in Table 3. There were no significant differences ( $P>0.05$ ) in age, liveweight at the start or end of the feedlot period or feed conversion ratio (FCR) between bulls from the different maternal nutrition treatment groups. Feed Intake varied with a significant interaction ( $P<0.05$ ) between maternal PRE and POST diet such that those animals whose dams had a change in diet (LH and HL) had 9% daily higher feed intake on test than those whose dams received low diet throughout the PERI- and POST-conception period (LL). A similar pattern was apparent in feedlot growth rate (ADG) and NFI but the differences were not significant.

**Table 3.** Means ( $\pm$  se) for age, liveweight, feed intake, average daily gain (ADG), feed conversion ratio (FCR) and NFI.

	LL	LH	HL	HH
Age at start test (days)	528 $\pm$ 2.4	528 $\pm$ 1.5	530 $\pm$ 1.0	526 $\pm$ 1.4
Age at end test (days)	598 $\pm$ 2.4	598 $\pm$ 1.5	600 $\pm$ 1.0	596 $\pm$ 1.4
Weight at start test (kg)	533 $\pm$ 6.3	545 $\pm$ 16.5	542 $\pm$ 7.6	530 $\pm$ 9.3
Weight at end test (kg)	647 $\pm$ 15.5	679 $\pm$ 19.1	677 $\pm$ 10.8	652 $\pm$ 11.4
ADG on test (kg/day)	1.66 $\pm$ 0.19	1.94 $\pm$ 0.08	1.96 $\pm$ 0.07	1.77 $\pm$ 0.08
Feed intake (kg DM/day)	12.4 $\pm$ 0.4 <sup>a</sup>	13.6 $\pm$ 0.4 <sup>b</sup>	13.6 $\pm$ 0.3 <sup>b</sup>	12.7 $\pm$ 0.4 <sup>ab</sup>
FCR (kg/kg)	8.5 $\pm$ 1.5	7.1 $\pm$ 0.17	7.0 $\pm$ 0.15	7.3 $\pm$ 0.26
NFI (kg/day)	-0.12 $\pm$ 0.22	0.18 $\pm$ 0.26	0.15 $\pm$ 0.16	-0.10 $\pm$ 0.21

Means within rows with different superscripts differ significantly ( $P<0.05$ ).

## 4.2 Carcass traits

Liveweight prior to slaughter (Table 3), HSCW, Ausmeat marble score, meat colour or fat colour (Table 4) did not differ ( $P>0.05$ ) as the result of PERI- and POST-conception maternal protein diet.

**Table 4.** Means ( $\pm$  sem) for HSCW, meat colour, marbling and fat colour as the result of maternal nutritional treatment.

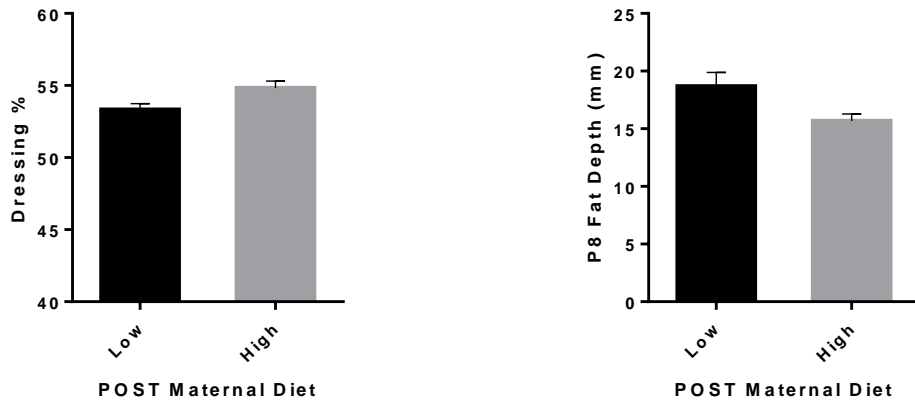
	LL	LH	HL	HH
HSCW (kg) <sup>1</sup>	344 $\pm$ 8.9	373 $\pm$ 13.1	361 $\pm$ 6.7	357 $\pm$ 8.0
Meat colour code	1.76 $\pm$ 0.08	1.77 $\pm$ 0.05	1.88 $\pm$ 0.04	1.81 $\pm$ 0.07
Fat Colour code	1.50 $\pm$ 0.27	1.00 $\pm$ 0.19	1.20 $\pm$ 0.10	1.15 $\pm$ 0.18
Ausmeat marble score	0.13 $\pm$ 0.13	0.13 $\pm$ 0.13	0.15 $\pm$ 0.10	0.50 $\pm$ 0.17

<sup>1</sup> Hot Standard Carcass Weight

Dressing% increased ( $P<0.05$ ) (Fig.2) in those animals whose dams received a high protein diet during first trimester (23 dpc – 98 dpc), with HPOST bulls having a 1.5 percentage point increase over LPOST bulls. P8 Fat Depth did not differ as the result of maternal nutritional treatment although those animals born to dams receiving Low Protein during first trimester tended ( $P=0.06$ ) to have higher P8 Fat Depth (Fig.2). When adjusted for HSCWT, there was no difference in fatness although animals born to dams receiving LPOST diet during first trimester still tended ( $P=0.07$ ) to be fatter.

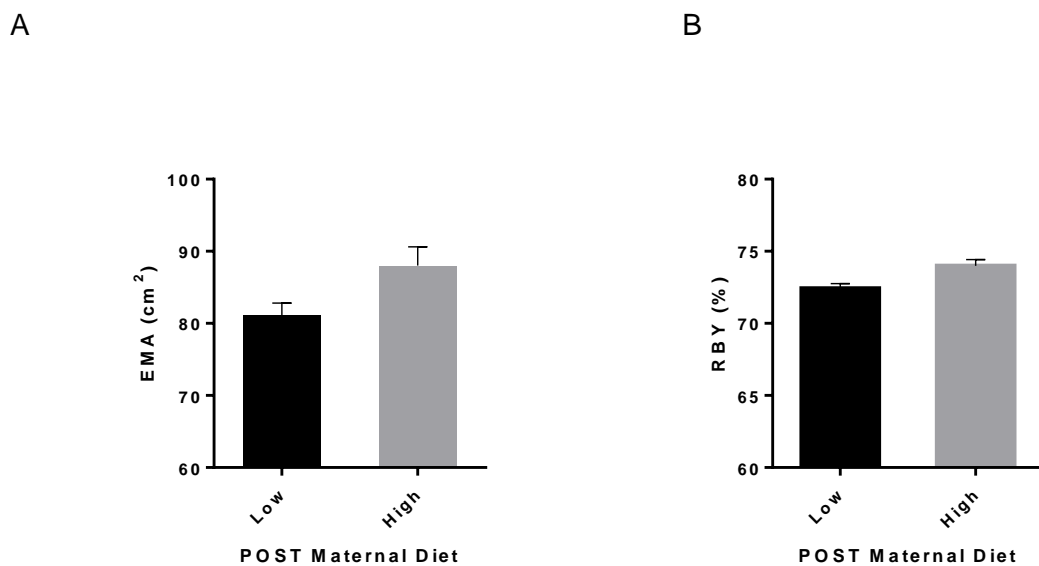
A

B



**Figure 2.** Dressing%(A) and P8 Fat Depth(B) by maternal nutrition during the first trimester (23 dpc - 98 dpc). Values are unadjusted mean $\pm$ SEM.

EMA was significantly greater ( $P < 0.05$ ) (Fig.3) in those animals whose dams received a High Protein diet during first trimester (23 dpc – 98 dpc), with HPOST bulls showing a 6.9  $\text{cm}^2$  increase over LPOST bulls. This difference was significant both without, and with, adjustment for HSCWT.



**Figure 3.** Eye Muscle Area (A) and estimated Retail Beef Yield (B) by maternal nutrition during the first trimester (23 dpc - 98 dpc). Values are unadjusted mean $\pm$ SEM.

Estimated RBY% was significantly greater ( $P < 0.01$ ) (Fig. 3) in those animals whose dams received a High Protein diet during first trimester (23 dpc – 98 dpc) with HPOST bulls having a 1.5 percentage point increase over LPOST bulls. This was despite there being no difference in liveweight at slaughter or in HSCW.

## 5 Discussion

The results from this study demonstrate that nutritional management of cows during pregnancy has the potential to alter progeny appetite and carcass composition at slaughter. We have shown that a high protein diet during the first trimester (23dpc to 98dpc) resulted in an increase in EMA, dressing %, estimated retail meat yield and tended to decrease subcutaneous fat in the entire male offspring. Maternal protein nutrition during the peri-conception period and first trimester also resulted in changes in progeny appetite.

### 5.1 Maternal nutrition and offspring feed intake and efficiency

Altered levels of nutrient supply during prenatal and early postnatal development have been shown to program offspring appetite and body composition. Interestingly, exposure to both excessive over-nutrition and under-nutrition before birth has been reported to permanently alter appetite regulation in rodents, humans and sheep (Mulhausler *et al* 2008). In the current study, feed intake during the feedlot period varied with a significant interaction ( $P < 0.05$ ) between maternal PRE and POST diet such that those animals whose dams had a change in diet (LH and HL) had 9% daily higher feed intake on test than those whose dams received low diet throughout the PERI- and POST-conception period (LL). A similar pattern was apparent in NFI but the differences were not significant. As feed is a major cost in livestock production, these differences in feed intake may have the potential to improve production efficiency but currently our understanding of the mechanisms regulating the differences in appetite are poorly understood, especially in the bovine. Ongoing work on the brains of these cattle (funded by the ARC) should elucidate these mechanisms.

### 5.2 Maternal nutrition and offspring growth

In the present study, protein nutrition during either the PERI (-60dpc to 23dpc) or POST (23dpc-98dpc) periods had no effect ( $P > 1.0$ ) on either liveweight (at the commencement and finish of the feedlot period), ADG nor on HSCWT at slaughter (Table 3). These results are consistent with Long *et al* (2010) who reported nutritional restriction for energy and CP during early pregnancy in heifers did not affect offspring postnatal growth but are different to our previous findings in steers (Micke *et al*, 2010a). Such inconsistencies may be from differences in the age of the dams and the castrate status of the progeny. In addition, they may be the result of the timing of maternal nutrition supplementation with Micke *et al* (2010a) reporting on protein supplementation during the first and second trimester as compared to the much earlier period of supplementation explored in the current study.

### 5.3 Maternal nutrition and offspring carcass characteristics

In utero development of fetal skeletal muscle is crucial to final muscle definition as there is no net increase in muscle fibre numbers after birth. Skeletal muscle is of a lower priority during gestational nutrient partitioning to the fetus, compared to major organs such as the heart or brain, and is therefore more vulnerable to deficiencies in maternal nutrition (Zhu *et al*, 2006). If the number of muscle fibres is decreased in the fetus it has been suggested this permanently reduces muscle mass. In the bovine fetus, primary myogenesis occurs within the first two to three months of conception with the majority of secondary myogenesis occurring between 2 months and 8 months of gestation (Russel and Oteruelo, 1981; Du *et*



*al*, 2010). During primary myogenesis, a limited number of muscle fibres form with majority created during secondary myogenesis. Recent studies show that myocytes, adipocytes, and fibroblasts are all derived from a common pool of progenitor cells during embryonic development. It appears that during early embryogenesis, multipotent mesenchymal stem cells first diverge into either myogenic or adipogenic-fibrogenic lineage (Du *et al*, 2013). Nutrition, environmental factors and genetics all influence progenitor cell differentiation.

In the present study, high protein maternal nutrition from 23dpc to 98dpc (first trimester) resulted in a larger EMA, with EMA being a measure of muscling in the progeny. This period of nutritional intervention corresponds to the period of primary myogenesis and early secondary myogenesis - when it is suggested maximum fetal muscle fibres are developing in the bovine (Bonnet *et al*, 2010). HPOST bulls showed improvement in estimated retail meat yield compared with LPOST animals. Differences in eye muscle are known to be reflected in retail beef yield (McKiernan *et al*, 2009) and the observed larger EMA, combined with a tendency to be leaner, contributed to the increased retail beef yield in the HPOST bulls. Interestingly, the effects of HPOST maternal diet on EMA were still observed with EMA adjusted for HSCWT ( $P < 0.05$ ) suggesting that the HPOST bulls had increased muscularity independent of overall bodyweight.

The observed tendency for the progeny of the LPOST dams to be fatter is in agreement with previous reports of progeny of nutrient restricted dams being predisposed to adiposity. As proposed by the thrifty phenotype hypothesis (Hales and Barker, 1992), this may be a survival advantage under poor nutritional conditions. Adipogenesis in beef cattle starts to occur before mid gestation in cattle with adipocytes reported to be first detected in visceral fat depots as early as 80dpc followed sequentially by subcutaneous, intermuscular and finally intramuscular depots by 180dpc (Taga *et al*, 2012). The 23dpc to 98dpc nutritional supplementation window in the current study corresponds to the very start of the window for formation of adipocytes in the visceral and subcutaneous depots. The observed tendency for the progeny of HPOST dams to be leaner, have improved dressing percentage and higher estimated retail beef yield ( $P < 0.05$ ) but not different in either pre-slaughter liveweight or HSCWT when compared to offspring from LPOST dams, suggests a shift in fat deposition that may improve carcass value. Of note, there was no difference observed in AUSMEAT marble score despite the HH group having a 3 fold increase in marbling score this was not significant and scores were low overall (Table 4). The formation of intramuscular adipocytes is estimated to mainly occur during late fetal-neonatal stage through to about 250 days post-natal, this being outside the supplementation window of the current study. More comprehensive laboratory evaluation of the intra-muscular fat (IMF%) content of samples is being undertaken.

In other species such as pigs, similar changes in body composition, as indicated by smaller loin area and increased fatness have been reported in the offspring of sows fed a low protein diet during gestation (Rehfeldt *et al*, 2012). Zhu *et al* (2006) reported lambs from dams subjected to nutrient restriction during mid-gestation were fatter and had decreased lean-to-fat ratio compared with their counterparts. However, previous studies in the bovine evaluating maternal nutrition effects on the carcass characteristics of offspring have reported inconsistent effects (Mohrhauser *et al*, 2015, Long *et al*, 2012, Larson *et al*, 2009, Underwood *et al*, 2010, Micke *et al*, 2010, Greenwood *et al*, 2009). The inconsistent results may be attributed to differences in the timing and degree of nutrient restriction, the specific nutrient evaluated, the sample size and sex evaluated. The study reported here-in being

unique in that the individual level of controlled intake occurred from the peri-conception period through to parturition time-window of gestation evaluated commencing earlier than in other studies.

Whilst changes to body composition in beef cattle may be desirable to improve production efficiency, they have also been shown to influence meat quality. Minimum levels of fatness and in particular marbling, are known to be required for good meat quality (Hocquette *et al* 2010). In addition, tenderness is a desired quality for beef and increased connective tissue contributes to the toughness of meat (Du *et al*, 2013). As with IMF, samples have been collected from the carcasses for meat quality testing and results will be published in the future.

There clearly exists opportunities for the livestock industries to manipulate maternal nutrition to enhance muscling and alter fat deposition leading to improvement in efficiency for meat production in beef cattle. Mechanisms regulating fetal cell differentiation into myogenic, adipogenic and fibrogenic cells in the bovine are, however, not well understood (Du *et al*, 2013). Improved understanding of the mechanisms is needed to maximise the benefits of manipulating production and carcass traits in beef cattle through nutrient supplementation targeted to a specific developmental stage.

## 6 Conclusions/recommendations

The results from this study demonstrate that nutritional management of cows during pregnancy has the potential to alter progeny appetite and carcass composition at slaughter.

Maternal protein supplementation during early pregnancy in the current study improved progeny EMA, dressing% and retail beef yield as compared to low maternal protein intake. The levels of low protein intake were similar to what could be encountered under extensive northern Australian grazing conditions where protein is often limiting (Bortolussi *et al*, 2005). Therefore, maternal nutrition during early gestation could be a critical management window to maximise offspring carcass returns.

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## 7 Key Messages

- Opportunities for the livestock industries to manipulate maternal nutrition to enhance muscling and alter fat deposition leading to improvement in efficiency for meat production in beef cattle.

- Improved understanding of the mechanisms is needed to maximise the benefits of manipulating production and carcass traits in beef cattle through nutrient supplementation targeted to a specific developmental stage. Ongoing work on the brains and muscle of these cattle (funded by the ARC) should elucidate these mechanisms.
- The economic cost of protein supplementation to yearling heifers in a northern range environment would potentially be difficult to justify in terms of the change observed in carcass traits alone. However in combination with other positive effects observed in this much larger study (data not presented) on increased conception rate, reduced fetal loss, improved calf health and early reproductive development in the male progeny, the manipulation of maternal nutrition has been calculated to be cost-effective

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