Bi-phasic feeding to improve pig performance and body composition

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Executive Summary

The profitability of intensive production systems is dependent on growth rates, feed conversion efficiencies and leanness of animals generated from contemporary commercial genotypes. These studies describe a bi-phasic feeding strategy where pigs were fed at two succinct intervals consisting of two one hourly periods when compared to feeding *ad libitum*. Pigs that were fed bi-phasically resulted in a substantial reduction in feed intake and this would significantly improve cost competiveness for the Australian pork industry. Although *ad libitum* feeding is the most common feeding pattern used in commercial pig production and is a major management strategy used to optimize feed intakes these studies suggest that this feeding pattern may be metabolically inefficient and that a bi-phasic feeding approach be considered for commercial production.

Results from the intensive bi phasic feeding experiment conducted at Rivalea Australia, confirmed our earlier studies that showed a substantial reduction in average daily feed intake ($P < 0.51$) in pigs fed twice daily when compared to animals fed *ad libitum*. This reduction in feed intake was without a compromise in body weight, a finding consistent with our previous studies. This same feeding strategy was then applied to a group-housed environment where pigs were fed for a similar duration ie 2 x 60 min feeding periods, one in the morning and the other in the afternoon. On the whole, the results from these group-housed studies showed a similar response to what was observed previously in our single pen studies. Feed intakes for pigs fed bi-phasically were substantially reduced when compared to feeding *ad libitum*.

The results from these experiments suggest that feeding pigs twice daily would improve productivity by reducing total feed consumption resulting in a substantial reduction in feed costs of up to $60 million per year. This would impact favourably on commercial piggeries. However, the practicalities of the implementation of such a feeding regimen in a commercial environment still needs to be explored and warrants further investigation.

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1. Introduction

The profitability of intensive production systems is dependent on growth rates, feed conversion efficiencies and leanness of animals generated from contemporary commercial genotypes. To meet these conditions animals have been fed *ad libitum* which is the most common feeding pattern used in commercial pig production and a major management strategy used to optimize both pig performance and efficiency of feed utilisation. A principal objective for most pig producers is to increase lean gain while limiting fat tissue deposition (Quiniou *et al*. 1999). In this respect, feeding pattern has been shown to have effects not only on feed efficiency (Cohn *et al*. 1962; Scrimgeour *et al*. 2008) but also on carcass composition (Leville 1970; Partridge *et al*. 1985; Persson *et al*. 2008).

For optimal protein deposition in growing animals a balanced supply of amino acids and energy is required (Van Den Borne *et al* 2007). However, it is the metabolic hormones such as insulin that regulate metabolism which has an important role in the metabolism of glucose, fats and proteins (Stockhorst *et al*. 2004). Metabolic hormone secretion patterns and concentrations, particularly growth hormone and insulin, are altered with differing feeding strategies, and this appears to have important consequences for performance (Steffens 1970; Scrimgeour *et al*. 2008). A recent study in pigs fed *ad libitum*, identified that insulin secretion was not aligned to either feeding behavior or to plasma glucose concentrations (Scrimgeour *et al*. 2008). Insulin concentrations remained relatively constant throughout the 24 h sampling period. However, when pigs were entrained to feed either twice daily or once daily, the pattern of insulin secretion responded to the period of feeding with significant increases occurring approximately 1 h after the onset of feed ingestion (Scrimgeour *et al*. 2008). In the same study, feed efficiency (FCR) was also improved in pigs fed twice daily when compared to those fed *ad libitum*.

Our previous studies (Project 2F 101 “Effects of fatty acids and feeding strategies on the performance and carcass composition of growing pigs”) confirmed the findings of Scrimgeour and co-workers (2008). This work showed that feeding pigs at distinct morning and afternoon periods stimulated insulin secretion that resulted in a distinct spike following each feeding period. Whereas, plasma insulin concentrations remained unresponsive for pigs fed *ad libitum*. This altered insulin status was associated with an enhanced productivity that resulted in improvements in both FCR and carcass composition. Importantly, we have also shown the duration of the feeding bout is critical as it influences the pattern of insulin secretion (Newman *et al*. 2011). Increasing the feeding period from 60 min to 90 min duration substantially reduced the rise in plasma insulin following each feeding bout and this in turn negated the positive production outcomes observed in our earlier studies.

As insulin is an important metabolic hormone involved in promoting a range of growth processes including feeding behavior (Benoit *et al*. 2004) protein deposition (Fuller *et al*. 1977) and metabolism (Koopmans *et al*. 2005), our results suggest that twice daily feeding may promote more efficient utilization of energy substrate for metabolism and growth in pigs. This increase in efficiency can be as high as 7% during the finishing period resulting in savings of $60 million across the Australian pig industry. Therefore, the objectives of the present studies were firstly to investigate the influence of twice daily feeding in a single pen study on a larger cohort of animals and secondly to apply this bi-phasic feeding regimen to pigs housed in a group pen in a commercial environment.

2. Methodology

Single Pen Studies

Experiment 1

Experimental Design

One hundred female pigs (Large white x Landrace, PrimeGro™ Genetics) with a starting weight of 58.8 ± 0.48 kg (mean ± SE) were randomly allocated to single pens. Pens were partially slatted in an uninsulated building with side shutters controlled by temperature. Pigs were acclimatized to the facility and their allocated feeding pattern, *ad libitum* (n = 50) or bi-phasically (n = 50) for a period of 7 days prior to the start of the test period and fed a commercial grower diet during this time (Table 1). Pigs were randomly allocated to an *ad libitum* or bi-phasic feeding pattern. The bi-phasic feeding pattern consisted of two 60-min feeding periods per day, one in the morning and the other in the afternoon, 0800 to 0900 h and 1400 to 1500 h respectively. Pigs were offered a commercial grower diet to day 14 of the test period, and a commercial finisher diet thereafter to slaughter (Table 1). Feed intakes and body weights were measured at two weekly intervals for 42 days (day 0-14, 14-28 and 28-42). On day 43, a sub sample of pigs from both treatment groups fed either *ad libitum* (n = 8) or bi-phasically (n = 8) were randomly selected and the external jugular vein of each pig catheterized via an ear vein (Anderson and Elsley 1969). On day 44, blood samples (3 ml) were collected from each pig at hourly intervals for 11 h commencing at 0700 h in tubes containing K_3 EDTA.

Hormone and Metabolite Analysis

Plasma insulin concentrations were determined in duplicate using a commercial double-antibody RIA with a primary antibody raised against porcine insulin and ^{125}I-labelled insulin as the tracer (kit # PI-12K; Linco Research, MO, USA). Circulating non-esterified fatty acids (NEFA) concentrations were determined by the acyl-CoA synthetase/acyl-CoA oxidase method (NEFA C-test; Wako Chemicals USA, Inc. Richmond, VA, USA). Plasma glucose measurements were determined by the glucose oxidase method (Huggett and Nixon 1957) for experiments 1 and 2. For experiment 3, plasma glucose concentrations were measured using a Konelab 20XTi biochemical analyser (Thermo Electron Oy, Clinical diagnostics, Clinical Chemistry & Automation Systems, Ratastie, Finland) with a reagent kit from Thermo Trace (Victoria, Australia) that used the Hexokinase/Glucose-6-phosphate dehydrogenase method.

Group-Housed Studies

Experiment 2 (Electronic Feeder Study)

Experimental Design

One hundred and twenty female male pigs (Large white x Landrace, PrimeGro™ Genetics) with an average body weight of 43.6 ± 0.2 kg (mean ± SEM)were randomly allocated to two treatment groups (n=60/treatment). Pigs were housed in group pens (n=15/pen) with 4 pens/treatment and exposed to both the prevailing photoperiod and environmental conditions. However, as a result of behavioural difficulties with the more dominant pigs from the bi-phasic fed group blocking the feeders from their subordinate counterparts this number was reduced from 60 pigs to 24 pigs/treatment before the beginning of the experimental period. The experimental design was altered to accommodate the reduced number of animals to 4 replicates of 6 pigs/pen for each treatment. All pigs had free access to water and fed a commercial grower/finisher diet (Table 1) throughout the course of the study (0-56 days).The pigs were fed either *ad libitum* or bi-phasically. The bi-phasic feeding pattern consisted of two 2 hourly feeding periods (0700-0900 h and 1400-1600 h). Prior to the test period (42 days) all pigs were acclimatized for a period of 3 days to the electronic feeders and the bi-phasic fed pigs acclimatized to the bi-phasic feeding pattern for a period of 14 days prior to experimental evaluation. Measurements consisted of individual body weights, determined on days -14, 0, 21 and 42 and feed intakes determined on days -14 to 0, 0 to 21 and day 21 to 42. Pigs were transferred to the abattoir at the completion of the experiment for the measurement of hot standard carcass weight (HSCW), carcass P2 and dressing percentage.

Experiments 3 and 4

Experimental Design

Sixty female pigs (Large white x Landrace, PrimeGro™ Genetics) with a starting weight of 41.8 ± 0.01 kg (mean ± SEM) for experiment 3 and 34.3 ± 0.02 kg (mean ± SEM) for experiment 4 were randomly allocated to two treatment groups (n=30/treatment) and fed either *ad libitum* or bi-phasically (fed for two 1 h periods). The two treatment groups were housed in six group pens (n=10/pen) with 3 replicates per treatment. The pens were exposed to both the prevailing photoperiod and environmental conditions. All pigs had free access to water and fed a commercial grower/finisher diet (Table 1) throughout the course of the study 0-49 days for Experiment 3 and 0-70 days for Experiment 4. The feeder design was circular with the capacity to accommodate a single feeding space for all pigs in the initial stages of both experiments (figure 1). However, as each experiment progressed and as the animals grew the feeding space was reduced so that not all pigs could feed freely at any one time. Prior to the commencement of both experimental periods, pigs were acclimatised to the two feeding patterns. The bi-phasic feeding pattern consisted of two 60 min feeding periods; one in the morning (0800-0900 h) and the other in the afternoon (1400-1500 h). Whereas, pigs fed *ad libitum* had constant access to feed. Both experiments measured production indices including individual body weights and feed intakes and these were measured for days 0 – 14, 14 – 28 and 28 – 49 for Experiment 3 and days 0 – 14, 14 – 28, 28 – 49 and 49 – 70 for Experiment 4. Following completion of both experiments pigs were transferred to the abattoir and HSCW, carcass P2 and dress percentage determined.

Statistical analysis

Linear mixed models were used to analyze all the traits, with logarithmic transformations used where necessary (FCR). Models included fixed effects for treatment (ad libitum vs bi-phasic feeding regimens), day of feeding, and their interaction (to test for different shaped time profiles for the two feeding patterns). In addition, random terms were included for Pen (nested within the Room). All analyses were undertaken using the REML procedure of GenStat Release 11 (VSN Intl., Hemel Hemstead UK). The experimental unit for all analysis was the individual animal Student's t-tests were performed to identify differences in total feed consumption between treatments.

Figure 1 - Feeder type used for Experiments 3 and 4

Table 1 - Dietary ingredients (%), as-fed basis

Ingredient (%)	Grower diet	Finisher diet
Wheat	71.0	56.8
Canola meal (36%)	12.4	4.1
Barley		10.0
Mill mix	5.0	20.0
Meat meal	4.5	1.7
Blood meal	2.2	
Tallow	2.0	2.0
Water	2.0	1.0
Tallow enzyme		1.7
Limestone	1.1	1.7
Lysine-HCl	0.35	0.4
Salt	0.2	0.2
Copper proteinate	0.1	0.1
Rumensin 100[1]	0.1	0.1
Betaine		0.1
Threonine	0.08	0.13
Vitamin mineral premix	0.07[2]	0.07[3]
DL-Methionine	0.02	
Porzyme 9310[4]	0.02	
Natuphos 5000[5]	0.01	0.01

[1] Coccidiostat (Elanco Animal Health, West Ryde, New South Wales, Australia).
[2] Provided the following quantities of vitamins and minerals per kg of air-dry diet; vitamin A, 2500 IU, vitamin D3, 1000 IU; vitamin E, 30 mg; Ca-D-Pantothenate, 5 mg; riboflavin, 2 mg; vitamin B12, 0.005 mg; selenium, 0.2 mg; copper, 10 mg; iron, 60 mg; manganese, 25 mg; zinc, 50 mg, iodine, 0.2 mg and Endox, 20 mg.
[3] Provided the following quantities of vitamins and minerals per kg of air-dry diet; vitamin A, 1500 IU; vitamin D3, 500 IU; vitamin E, 10 mg; Ca-D-Pantothenate, 2.5 mg; riboflavin, 2mg; selenium, 0.15 mg; copper, 10 mg; iron, 60 mg; manganese, 10 mg; zinc, 50 mg; iodine, 0.2 mg and Endox, 20 mg.
[4] Xylanase (Danisco Animal Nutrition, UK)
[5] Phytase (BASF Australia, Southbank, Victoria, Australia)

3. Outcomes

Experiment 1- Single Pen Study

Growth Performance

There was no significant difference (P = 0.63) in body weight for the two treatment groups (Table 2). However, feed intakes over the experimental period for pigs fed bi-phasically were substantially reduced (P = 0.051) when compared to those pigs fed *ad libitum* (Table 2). There was no significant improvement in feed utilization (P = 0.46) nor a significant reduction in back fat depth (P = 0.65) when compared to feeding *ad libitum* (Table 2).

Table 2 - Performance characteristics for female pigs with a starting weight of 58.8 ± 0.5 kg (mean ± SEM) fed *ad libitum* or twice daily (bi-phasic) for 42 days

	Treatment		
	Ad libitum	Bi-Phasic[A]	*P*-value
n	50	50	
Final live wt, kg	107.60 ± 1.1	107.04 ± 0.8	0.63
Daily feed intakes, kg/day	2.91 ± 0.02	2.82 ± 0.01	<0.001
Total feed consumption	122.22 ± 0.92	118.68 ± 0.85	0.051
FCR, kg/kg	3.05 ± 0.03	2.86 ± 0.05	0.46
ADG, kg	0.97 ± 0.01	1.00 ± 0.2	0.30
Backfat thickness[B], mm	9.52 ± 0.12	9.40 ± 0.13	0.65

[A]Bi-phasic group entrained to two 60-min feeding periods (0800 to 0900 h and 1500 to 1600 h)
[B]Backfat thickness was measured at the P2 position (left side of the 10th rib and 6 cm away from the spine).

Hormones and metabolites

Plasma Insulin

Over the 11 h period, the plasma insulin profile for animals fed *ad libitum* remained relatively constant throughout the sampling period whereas, the post-prandial insulin concentrations for pigs fed bi-phasically were significantly elevated (P < 0.001) 1 h following each feeding bout (Figure 2). In addition, the plasma insulin concentrations for the bi-phasic pigs were significantly elevated (P < 0.001) following the morning feed when compared to the insulin response for these same animals following the afternoon feed (Figure 2).

Plasma Glucose

Although plasma glucose concentrations were reduced for the bi-phasic fed group, the glucose profiles for both treatments were similar (P = 0.69) with little variation over the 11 h sampling period (Figure 3).

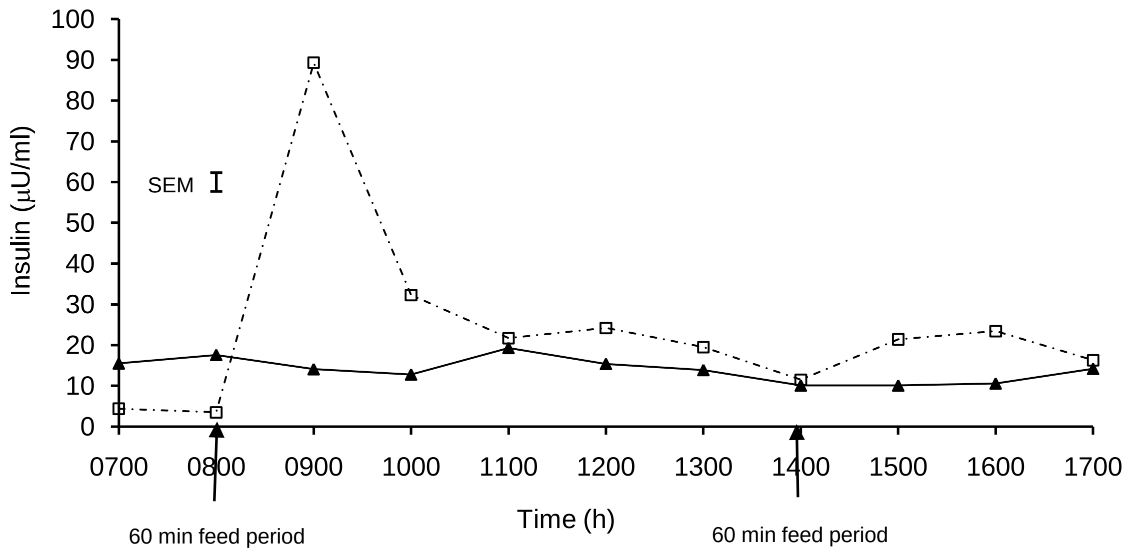

Figure 2 - Circulating concentrations of plasma insulin for pigs fed at two 60-min feeding periods (□) or *ad libitum* (▲). Standard error of the mean (SEM) shown as the error bar.

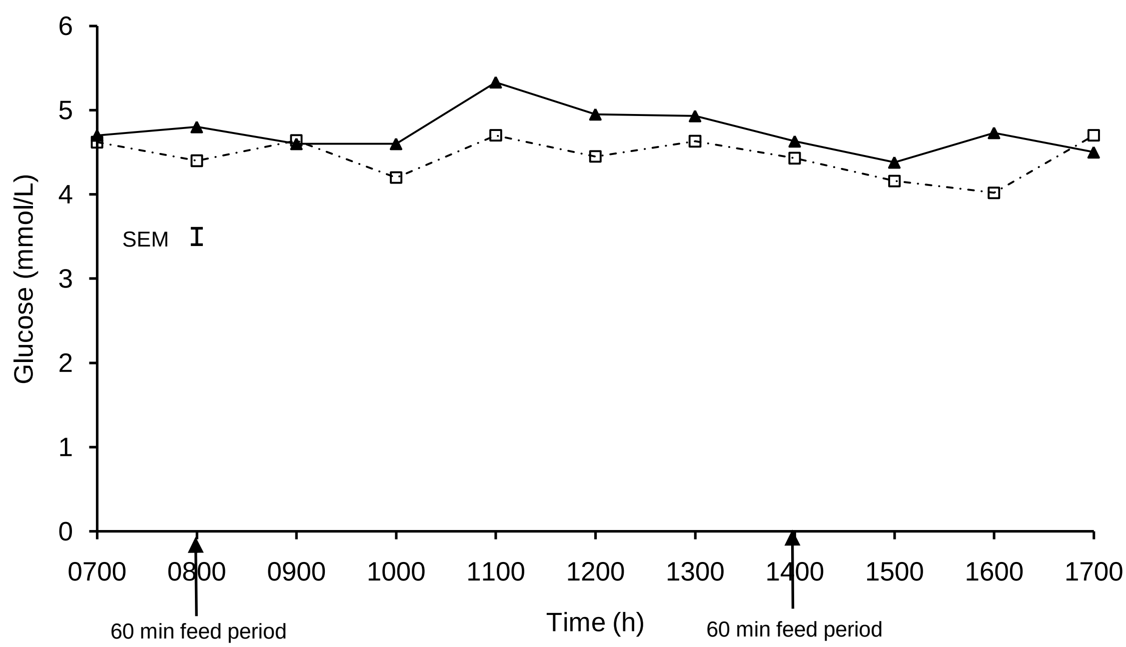

Figure 3 - Circulating concentrations of plasma glucose for pigs fed at two 60-min feeding periods (□) or ad libitum (▲). Standard error of the mean (SEM) shown as the error bar.

Group-Housed Studies
Experiment 2 - Electronic Feeder Study

The results show an improvement in FCR as an outcome of both the reduction in feed intake without a compromise in body weight (Table 3). In addition, feeding pigs bi-phasically resulted in a reduction in P2 and an increase in the dressing percentage (Table 3). Although these results show a similar pattern to what we have previously observed in our single pen studies in respect to reduced feed intakes for animal fed bi-phasically the results need to be viewed with caution. This experiment experienced behavioral difficulties with the group housed pigs fed the bi-phasic feeding strategy. The more dominant pigs from this group blocked access to the feeders resulting in the less dominant animals being unable to feed. As a result of these behavioral problems the more dominant pigs were removed from the bi phasic treatment groups. As a consequence, the heavier pigs were also removed from the *ad libitum* treatment groups so that pigs of similar body weight were maintained in both treatments. In addition, the bi-phasic feeding window was doubled from 2 x 60 min feeding periods to 2 x120 min feeding periods to accommodate for these behavioral aberrations. However, this modified experimental design did allow for the determination of stocking density on feeder space. This study showed that 6 pigs/pen was the maximum number of animals that could be subjected to this feeding system using the electronic feeders. This result confirms our original observation that shows a single feeding space may be a requirement for the bi phasic feeding pattern to be achieved (see illustration 1).

Table 3 - Performance characteristics for female pigs with a starting weight of 43.6 ± 0.2 kg (mean ± SEM) fed *ad libitum* or twice daily (bi-phasic) for 42 days

	Treatment		
	Ad libitum	Bi-Phasic[A]	*SEM*
n	n=24(6/pen)	n=24(6/pen)	
Final live wt, kg	76.7	77.2	1.14
Daily feed intakes, kg/day	1.99	1.86	0.05
Total feed consumption kg	490.8	467.9	15.8
FCR, kg/kg	2.46	2.38	0.08
ADG, kg	0.81	0.80	0.04
Backfat thickness[B], mm	7.6	7.3	0.25
HSCW kg	64.7	65.0	0.9
Dressing %	75.9	77.4	0.66

[A]Bi-phasic group entrained to two 120-min feeding periods (0800 to 1000 h and 1400 to 1600 h)
[B]Backfat thickness was measured at the P2 position (left side of the 10th rib and 6 cm away from the spine).

Experiment 3 - Group-Housed Pen Study

Growth Performance

There was no significant difference in final live weight between the treatment groups however there was a substantial decrease in the total feed consumption of the pigs fed bi-phasically over the experimental period although this was not significant (Table 4).Although showing a slight improvement for pigs fed bi-phasically, feed efficiency was not significantly different between the two treatment groups. In addition feeding bi-phasically also showed slightly improved hot score carcass weight (HSCW) and dressing percentage.

Table 4 - Performance characteristics for female pigs with a starting weight of 41.8 ± 0.1 kg (mean ± SEM) fed *ad libitum* or twice daily (bi-phasic) for 49 days

	Treatment		
	Ad libitum	Bi-Phasic[A]	*SEM*
n	n=30(10/pen)	n=30(10/pen)	
Final live wt, kg	76.7	77.2	1.14
Daily feed intakes, kg/day	1.77	1.77	0.01
Total feed consumption kg	845.3	804.1	27.9
FCR, kg/kg	2.50	2.46	0.03
ADG, kg	0.71	0.72	0.01
Backfat thickness[B], mm	6.9	6.8	0.28
HSCW kg	58.1	59.8	0.9
Dressing %	75.8	77.4	1.07

[A]Bi-phasic group entrained to two 60-min feeding periods (0800 to 0900 h and 1400 to 1500 h)
[B]Backfat thickness was measured at the P2 position (left side of the 10th rib and 6 cm away from the spine).

Experiment 4 – Group-Housed Pen Study

Growth Performance

Unlike all 3 previous experiments, feeding pigs bi-phasically resulted in a significant reduced ($P < 0.01$) final live weight when compared to feeding *ad libitum* (Table 5). The lower body weights for the pigs fed bi-phasically also reflected the reduced hot score carcass weight (Table 5) The lower body weight was associated with a reduced total feed consumption and as a consequence feed efficiency was also compromised (Table 5). Similar to previous experiments the dressing percentage and carcass P2 for pigs fed bi-phasically was slightly improved when compared to feeding ad libitum although this was not significant (Table 5).

Table 5 - Performance characteristics for female pigs with a starting weight of 34.3 ± 0.02 kg (mean ± SEM) fed *ad libitum* or twice daily (bi-phasic) for 70 days

	Treatment		
	Ad libitum	Bi-Phasic[A]	*SEM*
n	n=30(10/pen)	n=30(10/pen)	
Final live wt, kg	86.2	82.2	1.14
Daily feed intakes, kg/day	1.79	1.70	0.01
Total feed consumption kg	1209.0	1151.3	27.9
FCR, kg/kg	2.41	2.50	0.03
ADG, kg	0.74	0.68	0.01
Backfat thickness[B], mm	6.9	6.8	0.28
HSCW kg	63.2	60.7	0.9
Carcass P2	7.2	7.1	0.28
Dressing %	75.9	76.2	1.07

[A]Bi-phasic group entrained to two 60-min feeding periods (0800 to 0900 h and 1400 to 1500 h)
[B]Backfat thickness was measured at the P2 position (left side of the 10th rib and 6 cm away from the spine).

4. Application of Research

Summary of Results

A significant finding from these experiments has been to confirm our earlier studies that show a substantial reduction in feed intakes without a compromise in body weight when pigs are fed for two 1 hourly periods, one in the morning and one in the afternoon compared to feeding pigs *ad libitum*. The positive impact on production performance observed for the single pen study was related to the significant elevation in plasma insulin following each feeding bout, a finding that we have previously reported (Newman et al., 2011). Results from our single pen studies show a requirement for plasma insulin and that a specific threshold in its concentration appears to be necessary to orchestrate the positive impact this feeding regimen has on production performance. In this regard, our previous studies have shown that a feeding bout longer than 60 min alters the insulin secretion pattern and negates the improved performance (Newman et al 2011). The studies detailed in this report were all carried out using two feeding bouts of 60 min duration. On the whole, the results from three of the four studies show a consistent pattern with pigs fed bi-phasically consuming less feed when compared to their *ad libitum* counterparts and this was without a reduction in body weight. However, the results from the group-housed studies need to be viewed with caution firstly as a result of the small numbers of replicates for each treatment (n=3 pens/treatment) for experiments 3 and 4 and secondly in respect to the alteration in pig population dynamics for the electronic feeder study (experiment 2). In addition, observations from experiment 2 also showed an aberrant feeding behaviour when pigs were exposed to a reduction in feeder space. The more dominant pigs blocked access to the feeders and prevented the capacity of the subordinate pigs to feed. The results from this study suggest that an individual feeder space may be required for each pig. Although our subsequent experiments (experiments 3 and 4) suggest that at least 2 pigs may be able to feed from single feeder space. These findings need to be explored in any subsequent experiments.

An equally important finding from our previous studies was to demonstrate the difference in energy partitioning for pigs fed these two feeding regimens (Newman et al. 2011). These studies showed that feeding pigs bi-phasically significantly decreased the percentage of fat deposited in the carcass and significantly increased the percentage of muscle. Although carcass composition was not able to be determined for the experiments in the current project there may have been a similar response. The P2 was marginally reduced in all four studies for animals fed bi-phasically when compared to those fed *ad libitum*. In concert with the reduced P2 was the increase in the dressing percentage for pigs fed bi-phasically when compared to feeding *ad libitum*. Although not significant these results suggest that a change in energy partitioning may also have occurred in the bi-phasic fed pigs. This finding also warrants further investigation.

The reduction in feeding behaviour and the shift in energy partitioning are associated with distinct differences in the plasma insulin secretory profile (Newman *et al* 2011). Insulin secretion is significantly increased following each feeding bout for pigs fed bi-phasically whereas insulin secretion remains unresponsive for pigs fed *ad libitum* (Newman *et al.* 2011). These findings were corroborated in the current study for experiment 1. Insulin concentrations were significantly increased following each feeding bout compared to animals fed ad libitum with insulin concentrations remaining indifferent throughout the sampling period. Therefore, the difference in the insulin secretory profile between the two treatment groups may modify insulin action and this appears to provide a link between feeding pattern and the way the pig partitions energy.

5. Conclusions

Feeding pigs at distinct morning and afternoon periods stimulates insulin secretion that results in a distinct spike following each feeding period whereas plasma insulin concentrations remain unresponsive in pigs fed *ad libitum*. This altered insulin status was associated with enhanced productivity resulting in substantial reduction in feed intakes. The results from these studies suggest that a bi-phasic feeding could significantly impact on the cost of production by substantially reducing feed costs by up to $60 million per year across the Australian pig industry. Although these studies suggest that a bi-phasic feeding pattern may be able to be used successfully in a group-housed environment the cost of implementing such a feeding regimen would need to be considered particularly in respect to the requirement of feeder space.

6. Limitations and Risks

The effectiveness of this feeding strategy will be determined by the feeding environment. Our initial bi-phasic feeding experiments were carried out using single pens and as such were not subject to any behavioural difficulties. The subsequent group housed studies detailed in this report suggest that the feeder design will be a critical factor for the successful implementation of this feeding pattern into industry. In addition, the number of pigs for each feeder space will also be a consideration. We do not envisage any risks associated with this feeding system.

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

- To increase the number of feeders for a group-housed study so that a more detailed evaluation of this feeing regimen can be performed.
- To use this feeding pattern as a model so that a greater understanding of the regulation of feeding behaviour can be explored.

8. References

Anderson DM, Elsley FWH (1969) A note on the use of indwelling catheters in conscious adult pigs. *Journal of Agricultural Science* **72**, 475-477.

Fuller MF, Weekes TEC, Cadenhead A Bruce JB (1977) Protein-Sparing Effect of Carbohydrate .2. Role of Insulin. *British Journal of Nutrition,* 38**,** 489-496.

Huggett AStG, Nixon DA (1957) The use of glucose oxidase, peroxidase, and o-dianisidine in determination of blood and urinary glucose. *Lancet* **273**, 368-370.

Koopmans SJ, Van Der Meulen, J, Dekker R, Corbijn H, Mroz Z (2005) Diurnal rhythms in plasma cortisol, insulin, glucose, lactate and urea in pigs fed identical meals at 12-hourly intervals. *Physiology & Behavior,* **84,** 497-503.

Leveille GA (1970) Adipose tissue metabolism: influence of periodicity of eating and diet composition. *Federation Proceedings* **29**, 1294-1301.

Newman RE, Downing JA, Thomson PC, Collins CL, Henman DJ, Wilkinson SJ (2011) Insulin secretion, pig performance and body composition are altered by the feeding pattern. Animal Production Science (submitted).

Partridge IG, Low AG, Keal HD (1985) A note on the effect of feeding frequency on nitrogen use in growing boars given diets with varying levels of free lysine. *Animal Production* **40**, 375-377.

Persson E, Wulbers-Mindermann M, Berg C, Algers B (2008) Increasing daily feeding occasions in restricted feeding strategies does not improve performance or well being of fattening pigs. *Acta Veterinaria Scandinavica* **50**, 1-6.

Quiniou N, Richard S, Mourot I, Etienne M (2008) Effect of dietary fat or starch supply during gestation and/or lactation on the performance of sows, piglets' survival and on the performance of progeny after weaning. *Animal* **2,** 1633-1644.

Scrimgeour K, Gresham MJ, Giles LR, Thomson PC, Wynn PC, Newman RE (2008) Ghrelin secretion is more closely aligned to energy balance than with feeding behavior in the grower pig. *Journal of Endocrinology* **198**, 135-145.

Steffens AB (1970) Plasma insulin content in relation to blood glucose level and meal pattern in the normal and hypothalamic hyperphargic rat. *Physiology and Behavior* **5**, 147-151.

Stockhorst U, De Fries D, Steingrueber H-J, Scherbaum W A (2004) Insulin and the CNS: effects on food intake, memory, and endocrine parameters and the role of intranasal insulin administration in humans. *Physiology and Behavior* **83,** 47-54.

Van Den Borne J, Schrama J W, Heetkamp M J W, Verstegen M WA, Gerrits W J J(2007) Synchronising the availability of amino acids and glucose increases protein retention in pigs. *Animal* **1,** 666-674.