Effects of fatty acids and feeding strategies on the performance and carcass composition of growing pigs

Report prepared for the
Co-operative Research Centre for an Internationally Competitive Pork Industry

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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. To this end we have used two different experimental approaches to enhance production efficiency and improve cost competiveness for the Australian pork industry. The first approach was to alter the conventional *ad libitum* feeding pattern to a twice daily feeding strategy where pigs were fed at two one hourly periods. 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 our previous studies suggested that this regimen may be metabolic inefficient. Our second approach was the strategic use of dietary omega 3 (n-3 PUFA) and omega 6 fatty (n-6 PUFA) acids. These fatty acid acids have the potential to influence the growth and development of animals via a number of diverse pathways that include gene expression, metabolic hormone secretion and prostaglandin synthesis. Sources of omega 3, omega 6 and saturated fatty acids were fed to pregnant gilts prior to and then throughout gestation. Similar fatty acid diets were then fed to the progeny for the length of their production cycle.

Results from our bi phasic feeding strategy demonstrated a substantial reduction in average daily feed intake of approximately 8% in pigs fed twice daily when compared to animals fed *ad libitum*. More importantly both treatment groups had similar body weights and this resulted in a 10% improvement in feed efficiency. Feeding pigs phasically also favorably altered carcass composition producing a leaner animal when compared to pigs fed *ad libitum*. Our fatty acid studies show a consistent but differential effect of fatty acid source on growth and development of the progeny. Notably it is the type of fat fed before birth that influences post natal growth performance with major effects on reproduction, cognitive development, energy utilization, adaptation to weaning, and the modulation of production performance throughout the grower/finisher phases. On the whole, diets containing a higher proportion of n-6 PUFA have a detrimental effect on growth and development while diets containing a higher proportion of n-3 PUFA have a more positive result.

Feeding pigs twice daily results in enhanced productivity with substantial improvements in both feed to gain and carcass composition. A bi phasic feeding pattern would impact favourably on commercial piggeries. However, the practicalities of the implementation of such a feeding regimen in a commercial environment would need to be explored and warrants further investigation. Fatty acids have the potential to manipulate reproductive performance and can impart negative or positive outcomes in production responses for the progeny. The optimum dietary n-6:n-3 ratio is critical for growth and development of the pig. A high n-6:n-3 ratio negatively impacts on reproductive performance and growth while diets with a low n-6:n-3 ratio or high PUFA balance has a positive impact. These findings highlight the practical importance of diet formulation in providing an adequate supply and balance of n-3 and n-6 PUFA during gestation, lactation and development.

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Introduction

The profitability of intensive production systems is dependent on growth rates, feed conversion efficiencies and leanness of animals generated from contemporary commercial genotypes. The most formidable period of the production growth cycle is the time through to weaning during which both growth patterns and feed efficiency are established through neonatal interactions with the sow which are conveyed either *in utero* or through the pattern of nutrients via signalling molecules present in both colostrum and milk post-partum. We have previously shown in the chicken that the manipulation of dietary nutrients can play a role in influencing carcass composition, growth and feed efficiency (Newman *et al*., 2002a). In particular, specific fatty acid sub-types have the potential to influence both gene expression and prostaglandin synthesis with significant effects in growing animals on protein synthesis and lipid metabolism. In further categorizing these effects; n-3 fatty acids significantly decrease fat deposition while n-6 fatty acids improve both feed conversion efficiency and muscle mass (Newman *et al* 2002). In more recent studies, we have optimised both fatty acid sub-types in specific ratios to achieve improvements in carcass composition and feeding efficiency (Newman 2004)

Our previous investigations in the growing pig into the relationship between metabolic hormone status, feeding patterns and growth efficiency have shown significantly improved feed to gain and growth rates in pigs offered feed *ad libitum* at succinct intervals throughout the day compared with animals allowed voluntary access to feed. In association with this improved feed conversion, plasma insulin secretion was shown to be more tightly aligned to feeding behaviour and glucose status and this is indicative of a higher metabolic efficiency. In contrast, no such relationship exists in either insulin secretion or glucose status in animals allowed voluntary access to feed. This improved feed efficiency is associated with elevated nonesterified fatty acid (NEFA) concentrations suggesting that the propensity for lipolysis is enhanced in these animals, a result which may influence carcass composition.

Methodology

This project was carried out using two strategies to modulate production. The first phase (**phase 1**) was to improve feed to gain by using specific feeding strategies to improve metabolic efficiency. The second phase (**phase 2**) was the use of specific fatty acids given to gilts prior to mating and then fed throughout the period of gestation. These dietary fatty acids were continued throughout the lifetime of the gilt progeny.

Phase 1 Biphasic Feeding

Twenty entire male pigs (Large white x Landrace), with a live weight of 35.25 ± 2.94 kg (mean ± S.E.M.) were used in the experiment. Upon arrival

at the experimental facility, the pigs were weighed and allocated to individual pens located in one of four separate climate controlled rooms with two rooms sharing one of two common air spaces. Each air space was provided with 100% fresh air with ammonia concentrations kept below 2 ppm. All four rooms were maintained at 23 ± 1°C and pigs exposed to a 12:12 light:dark photoperiod with lights on at 0600 h. Pigs were fed a commercial grower diet (Table 1) estimated to contain 10 g of available lysine and 13.4 MJ apparent digestible energy per kg. Each pig was fed either *ad libitum* (control) or a similar amount of feed offered with unrestricted access in two 60-min feeding periods (0900 to 1000 h and 1600 to 1700 h) per day (phasic) with both treatments equally represented in each air space. Feed was offered to maintain approximately 2 kg in each trough and residues were recorded daily or after each 60-min feeding period. Water was provided using nipple drinkers. Pigs were maintained on these two feeding patterns for 49 days. On day 45, a catheter was placed into the external jugular vein of each pig via an ear vein (Anderson & Elsley 1969). On day 46, blood samples (3 ml), were collected in tubes containing K_3 EDTA, from each pig at hourly intervals for 24 h. Blood sampling commenced at 1100 h following food withdrawal from the phasic fed pigs. The blood was centrifuged at 1048 x *g* for 20 min at 4°C and plasma stored immediately after sampling at -20°C until assayed. All pigs were transported to a commercial abattoir on day 50, slaughtered and P2 determined by a commercial operator. The dress weight for each pig was recorded and the carcasses split longitudinally through the spine and kept refrigerated at 4°C. On day 52 the left half of the carcasses underwent CT scanning for latter determination of carcass composition.

Feed Intake and Body Weights

Estimates of daily feed intake for the *ad libitum* fed pigs were obtained by subtracting the daily residue weight from the weight of the feed offered the previous day. Similarly, feed residues collected at 1000 and 1700 h were subtracted from feed offered at 0900 and 1600 h respectively during twice daily feeding. Body weights of pigs were recorded on days 0, 7, 14, 21, 28, 35, 42, and 49.

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 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 & Nixon 1957).

Computed tomography

Changes in body components were determined by CT (Giles *et al*. 2009) using a Picker PQ 2000 spiral CT scanner (model PQ 2000, Philips Medical Systems, Picker International Inc, Highland Heights, OH, USA).

Statistical analysis

Linear mixed models were used to analyze all the traits, with logarithmic transformations used where necessary (feed to gain). Models included fixed effects for treatment (*ad libitum* vs 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 Room and Pen (nested within the Room). All analyses were undertaken using the REML procedure of GenStat Release 11 (VSN Intl., Hemel Hemstead UK).

Phase 2 Dietary Fatty Acids

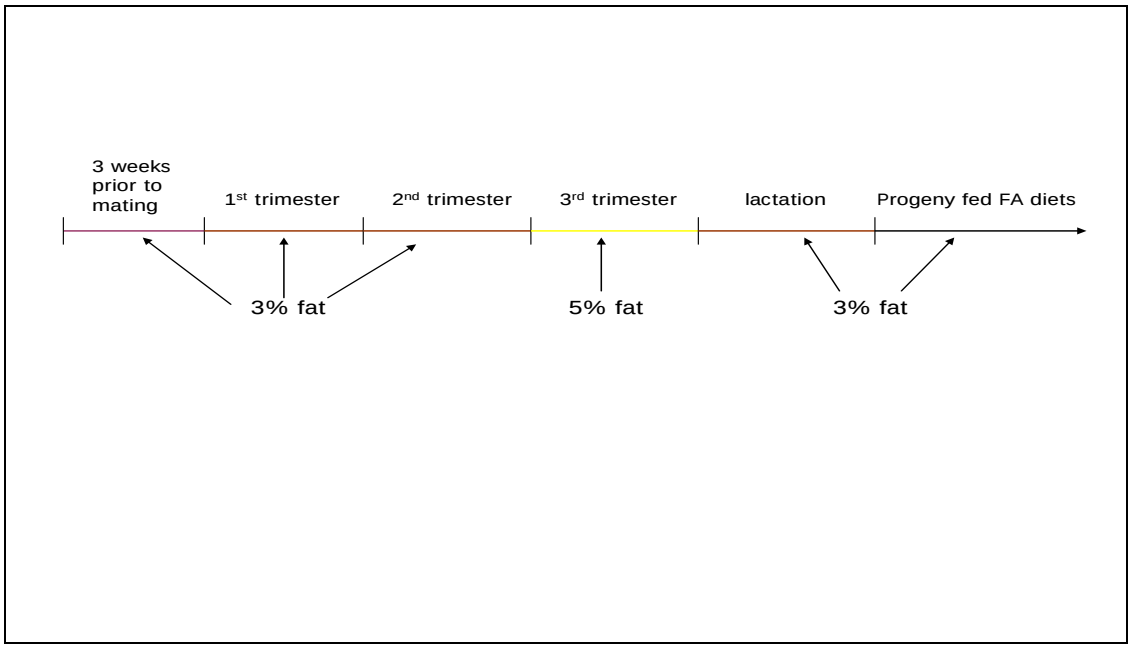
Experiment1

Gestation to Day 49 of Progeny

Animals and Diets

Thirty pubertal gilts (26 weeks of age) were selected from Rivalea Corowa and allocated to one of 3 treatment groups (n=10/group) and fed experimental diets 3 weeks prior to mating containing either 3% safflower oil, 3% Salmate®, or 3% tallow, sources of n-6, n-3 and saturated fatty acids respectively. These diets were maintained throughout the 1st and 2nd trimesters and then again throughout lactation (Figure 1). During the 3rd trimester the dietary fat concentration was increased to 5% for all treatment groups. The gilts were housed in individual pens and synchronized for oestrus using Regumate® and then mated using AI techniques. To determine successful matings, the gilts were ultrasounded at 4 weeks post AI and then reassessed 2 weeks later. Prior to the onset of the 3rd trimester the gilts were transported to NSW Dept of Primary Industries, EMAI Camden and housed individually in group pens in the Low Security Area. Two weeks prior to farrowing the gilts were transported to the Controlled Environment Facility and allocated randomly to individual farrowing crates. The gilts were allocated over 3 rooms and the rooms maintained at 22.0 ± 0.7ºC with a 24L:0D photoperiod regimen. Litters were provided supplementary heat by way of infra-red hover lamps.

Figure 1 Feeding regimen for gilts fed n-6 fatty acids (safflower oil), n-3 fatty acids (Salmate®) or saturated fatty acids (tallow)



Progeny
Behavioural Observations
Farrowing for all treatment groups was allowed to occur without interference. The gilts were observed continuously and the following behavioural observations recorded at the onset of farrowing for each littermate:

Time of birth
Body temperature (time 0 min)
Body weight
Time to udder contact
Time to suckling
Body temperature (time 60 min)
Number born
Sex

The litter size from each treatment group was standardized to a total of 10 piglets per gilt with no cross fostering performed. The litter size for 2 gilts fed tallow was not able to be made up to 10 piglets due to the smaller numbers of piglets born to these animals with only 7 and 9 piglets. Excess piglets were sacrificed using CO_2 at Day 1 and a 5 ml blood sample collected for insulin, glucose, and NEFA determination. Tissue samples (brain, muscle & liver) were also collected from these animals for fatty acid analysis. Piglet body weights were recorded at weekly intervals throughout the period of lactation (Day 0 to Day 28). At Day 28 the female progeny from all treatment groups (10 tallow, 19 Safflower oil and 19 Salmate®) were selected and placed into individual weaner cages in the controlled environment facility. To assess if specific fatty acid subtypes

influence the stress imposed at weaning a saliva sample was taken from all female piglets for the determination of cortisol. A salivary sample was collected prior to and then at 90 min after being placed into cages. The piglets were exposed to a an ambient temperature of 25.0 ± 0.7ºC and a photoperiod regimen of 12L:12D. A subset of male progeny from each treatment group was euthanased using CO_2 and blood and tissue samples collected for endocrine and biochemical analysis as per day 1 collection. Weekly feed intake and body weight measurements were collected on the female progeny for a period of 3 weeks (Day 49).

RQ determination

Subsets of male piglets from each treatment group were selected for determination of resting respiratory quotient and metabolic rate using open-system respirometry. O_2 consumption and CO_2 production rates were determined by measuring O_2 and CO_2 concentrations of both inlet and outlet chamber air using Sable Systems FC-1 O_2 and CA-1 CO_2 analysers (Sable Systems International Inc., Henderson, Nevada, USA). The respirometry chambers consisted of rectangular Perspex boxes (645 x 355 x 615 mm) with a transparent top to provide illumination and opaque sides to minimise interaction between adjacent pigs. Piglets were selected and removed from the gilt immediately post suckling and placed in a respiratory chamber furnished with a heat source and wood shavings. Piglets were allowed to adapt to their surroundings (approximately 30 min) prior to the commencement of data acquisition. No feed or water was provided during the acquisition period. Measurements occurred over a three hour period after the acclimation period. Air was provided to each chamber at 3.0 L/min using calibrated rotameters (Tylan Corporation,)and selectively sampled for air composition using a Sable Systems Respirometer Multiplexer (V 2.0) (Sable Systems International, Inc., Henderson, Nevada, USA). Voltage output from the O_2 and CO_2 analysers were recorded at 2s intervals and each pig was sampled for 12 min/hour. Values for O_2 consumption and CO_2 production were corrected to standard temperature and pressure after appropriate adjustment for volume effects associated with RQ different from unity (Withers, 1977). RQ (CO_2 production/O_2 consumption) were based on 3 hour averages of CO_2 production and O_2 consumption.

Stress response to weaning

At approximately day 2X ± SEM of lactation, a subset of female piglets from each treatment group (n=10 SFA, n=19 n-3 PUFA, and n=19 n-6 PUFA) were transferred to individual weaner cages. A salivary sample was obtained before transfer (to establish a baseline salivary cortisol value) and 90 minutes post transfer (response to weaning) by allowing each piglet to chew on a cotton swab (Salivettes®, Sarstedt Australia) till sufficiently saturated (approximately 2 minutes). Saturated Salivettes® were stored on ice till being centrifuged (2000 rpm, 10 minutes). Recovered saliva was then stored at -20°C until analysis. Concentrations of cortisol in saliva were determined by radioimmunoassay using a modified protocol adapted from Clarke et al. All samples and internal standards were assayed in duplicate and standards for the standard curve in triplicate.

Grower (Day 49-Day 92) to Finisher (Day 92-127)

Animals and Diets

Forty seven female weaner pigs, 19 n-6 PUFA, 9 saturated fatty acids and 19 n-3 PUFA were randomly allocated to single grower pens in three rooms within the climate controlled building at EMAI (NSW DPI), Environmental conditions consisted of a photoperiod regimen of 12L:12D with an ambient temperature of 22.0 ± 0.7ºC. A grower ration containing either, 3% safflower oil, Salmate® or tallow, sources of n-6 PUFA, n-3 PUFA and saturated fatty acids respectively was fed *ad libitum* throughout the grower period (Day 49-92). Body weights and feed intakes were determined weekly. On Day 70 the pigs were anaesthetized and body composition determined using computed tomography (CT scanning). On day 92 pigs were offered finisher diets containing, 3% safflower oil, Salmate® or tallow. Body composition was determined on Day 120 using CT scanning. On Day 125, 8 pigs from each treatment group were catheterized via the ear vein and hourly blood samples taken over a 12h period on Day 126. Six pigs from each treatment group were fed these fatty acid diets for a further 4 weeks and then slaughtered at Wollondilly abattoir. Carcasses were weighed (hot standard carcass weight), P2 measurements carried out and fat (subcutaneous and renal) and muscle samples taken for fatty acid analysis. The ovaries were also collected for the determination of ovarian weight and antral and luteinized follicle distribution. Because of the constraints encountered within the abattoir some animals were not identified reducing numbers for the tallow group to 4 and to 5 for the safflower oil fed group.

Growth, Feed Intake and Feed to Gain

Individual voluntary feed intake was calculated by offering a weighed amount of feed into a bucket at the beginning of a 7 day recording period and subtracting the residual amount of feed at the conclusion of the recording period. Live body weight was recorded at the commencement and the conclusion of each recording period to provide live body weight gain. Feed to gain was calculated by dividing the amount of feed consumed in a 7 day period by the live body weight gain for the same period.

$$\text{Feed to gain (Kg/Kg)} = \frac{(\text{Feed in } (T_0) - \text{Feed out } (T_1))\ \text{Kg}}{(\text{Body weight } T_1 - \text{Body weight } T_0)\ \text{Kg}}$$

Extraction and analysis of lipids

Total lipids were extracted from 1-1.5 g of muscle tissue with chloroform: methanol (2:1 v/v) containing 0.01% butylated hydroxy toluene using procedures described previously by Ashes *et al*. (1992) and Folch *et al* (1957). Fatty acid methyl esters were prepared on an aliquot taken from the extracts using the toluene / sulphuric acid procedure as described by Christie (1989). This procedure was also used to prepare

fatty acid methyl esters from 50-100 mg of abdominal fat tissue as well as 500 mg of diet samples and individual dietary fat additives. Individual fatty acids were separated and quantified by gas chromatography (Shimadzu GC-17A, FID and SS420x Scientific Software data system, Shimadzu Pty Ltd, Japan), fitted with a J&W Scientific DB-23 Capillary column (30 m x 0.25 mm x 0.25 μm) (Agilent Technologies, Pty Ltd). Helium was used as the carrier gas with an injection split ratio of 100:1. The GC was temperature programmed from 160° C to 240° C at a rate of 5°C per minute with an injection temperature of 250 °C and a detector temperature of 300 °C. Peaks separated were identified by comparison with standard samples of known composition.

Statistical Analysis

Data was analysed for statistical significance using a REML procedure in Genstat for Windows 10th Edition (VSN International). Log transformations were performed for endocrine data sets. Values are presented as treatment means ± standard error of mean. Levels of significance are determined at $P<0.05$ unless specified.

Experiment 2

Background

The results from Experiment 1 suggest that a growth setback occurred in pigs fed n-6 PUFA (safflower oil) during the period of wean. This reduced growth rate was maintained for the duration of the experiment through to slaughter. Possible explanations for this growth disparity include 1: differences in cognition between the treatment groups, 2: differences in the development of the gastrointestinal tract between treatment groups and 3: the palatability of the n-6 PUFA diet.

Experimental Protocol

Animals and Diets

The experiment was carried out in the R & I unit Rivalea, Australia. The methodology was similar for the previous experiment conducted at EMAI with safflower oil used as the source of n-6 PUFA and tallow as the source of saturated fatty acids. The modifications to Experiment 2 were:
1: the source of n-3 PUFA, Optigen® rather than Salmate®.
2: changing the diet at the point of wean. On day 23, diets for half of the progeny fed the n-3 and n-6 PUFA were changed to one containing saturated fatty acids (tallow). This alteration in dietary fatty acid source was used to determine any carry over effect of the PUFA diets and secondly to determine palatability of the n-6 PUFA diet.

Female progeny from all 3 dietary treatments were used to make up litters containing 10 piglets/litter for each treatment. Litters were maintained up until the day of weaning (Day 23). Body weight of progeny was determined weekly and P2 was measured to determine any differences in the rate of fat utilization between the fatty acid dietary sources for gilts at days 0, 7, 14, 21 and at wean.

Weaning

Weaning was performed at Day 23, the progeny transferred from the farrowing house to individual metabolism cages at the R & I unit, QAF. Progeny were maintained in these cages for a period of 28 days and weekly body weights and feed intakes determined. In addition, the gastrointestinal tract from pigs from each treatment group (n=6) were taken for gut micro flora examination at the following days, day 23 (wean), day 5 and day 28 post-wean. Blood and tissue samples (pancreas and muscle) were also taken for hormone and fatty acid determination at these time points.

Grower/Finisher Period

Pigs were transferred from individual cages to group weaner/grower pens. Pigs were maintained in individual pens located within the "Boar Test Unit" at Rivalea, Corowa, for a period of 27 days during the finisher period. Individual body weights, feed intakes, P2 and leg fat measurements were determined for all pigs. Following completion of the finisher period, pigs were transferred to the Rivalea abattoir. Dressed weight, carcass P2, loin depth and dressing percentage were determined on each carcass.

Outcomes

PHASE 1 Interval Feeding

Growth performance

Body weights increased over the experimental period but no significant difference in body weight between the 2 treatment groups was observed. The final live weight (P = 0.90) and the dress carcass weight (P = 0.96) for the bi? phasic fed and *ad libitum* fed pigs were similar with no significant difference in ADG (P = 0.88) between the 2 treatment groups for the experimental period (Table 2). There was a decrease (P = 0.057) in the amount of feed consumed when pigs were fed phasically compared to pigs fed *ad libitum* with a reduction of approximately 200 g/d per pig over the 49 d treatment period (Table 2). The efficiency of feed utilization expressed as weight of feed consumed (kg) relative to live weight gain (kg) for the same period is given in Table 1. There was an improvement in feed to gain for pigs fed phasically when compared to pigs fed *ad libitum* (P = 0.032). Although not significant (P = 0.18) the back fat depth at the P2 position was lower in the phasic fed pigs when compared to pigs fed *ad libitum* (Table 2). There was a reduction (P = 0.027) in the percentage of total carcass fat and an increase (P = 0.015) in the total percentage of muscle as determined by CT analysis for the phasic fed pigs when compared to those fed *ad libitum* (Table 2). There were no significant differences (all P > 0.3) in the total percentage of bone, skin or free water (Table 2).

Hormones and metabolites

Plasma insulin

Plasma insulin concentrations for the *ad libitum* fed pigs remained relatively constant over the 24 h sampling period with a mean value of 15.9 ± 1.08 µU/mL (Figure 1). In contrast, insulin concentrations for the phasic fed pigs increased (P = 0.002) approximately 1 h after each of the 2 feeding periods from 7.64 ± 2.52µ U/mL at 1600 h to 31.27 ± 5.38 µU/mL at 1700 h and from 5.81 ± 0.95 µU/mL at 0900 h to 39.34 ± 5.21 µU/mL at 1000 h. Insulin concentrations for the phasic fed pigs were lower when compared to animal fed *ad libitum* from 0400 h to the onset of the 0900 h to 1000 h feeding period with a mean value for this period of 7.21 ± 0.71 µU/mL for the phasic and 16.74 ± 2.44 µU/mL for the *ad libitum* fed pigs. However, this difference failed to reach threshold significance at any single hour comparison.

Plasma glucose

There was no significant difference in plasma glucose concentrations (P = 0.85) for pigs fed phasically or *ad libitum* over the 24 h sampling period (Figure 2). However, plasma glucose concentrations tended to rise during the period of darkness for the phasic fed pigs.

Plasma NEFA

There were no significant differences in NEFA concentrations (P = 0.34) for pigs fed phasically or *ad libitum* over the 24 h sampling period (Figure 3). However, circulating NEFA concentrations appeared more variable for pigs fed *ad libitum* compared to the phasic fed pigs between the hours of 0200 h and 0400 h.

Table 1. Dietary and nutrient specification, as-fed basis

Ingredients (%)	
Wheat (12.5% CP)	66.8
Canola meal full fat	5
Soybean meal (48% CP)	8.3
Millrun (15% CP)	16.3
Limestone	1.1
Dicalcium phosphate	1.7
Salt	0.25
Pig breeder premix	0.25
Choline chloride	0.04
Lysine-HCl	0.20
Nutrient specification (calculated), %	
Protein	16.89
Fat	2.50
Fiber	4.04
Ca	0.94
Total P	0.78
Available P	0.50

Table 2. Performance and carcass composition as determined by CT[1] scan analysis for pigs fed *ad libitum* or twice daily (phasic) for 49 d

Item	Treatment[2] Ad libitum	Phasic	SEM	*P*-value
n	10	10		
Final live wt, kg	92.7	92.5	1.10	0.90
Daily feed intakes, kg/day	2.68	2.49	0.065	0.057
Feed to gain[3], kg/kg	2.63	2.39	1,1% [3]	0.032
ADG, kg	1.04	1.05	0.35	0.88
Dress wt, kg	66.0	65.9	1.6	0.96

Backfat thickness[4], mm	14.8	12.2	0.8	0.18
Bone, %	11.1	11.2	0.4	0.89
Fat, %	14.7	12.3	0.8	0.027
Muscle, %	63.8	66.4	0.8	0.015
Skin, %	2.78	2.96	0.14	0.36
Free water, %	7.54	7.22	0.38	0.53

[1]Computed tomography.
[2]Phasic group entrained to two 60-min feeding periods (0900 to 1000 h and 1600 to 1700 h)
[3]SEM for feed to gain expressed as percentage of mean, due to analysis of logarithmic scale
[4]Backfat thickness was measured at the P2 position (left side of the 10th rib and 6 cm away from the spine).

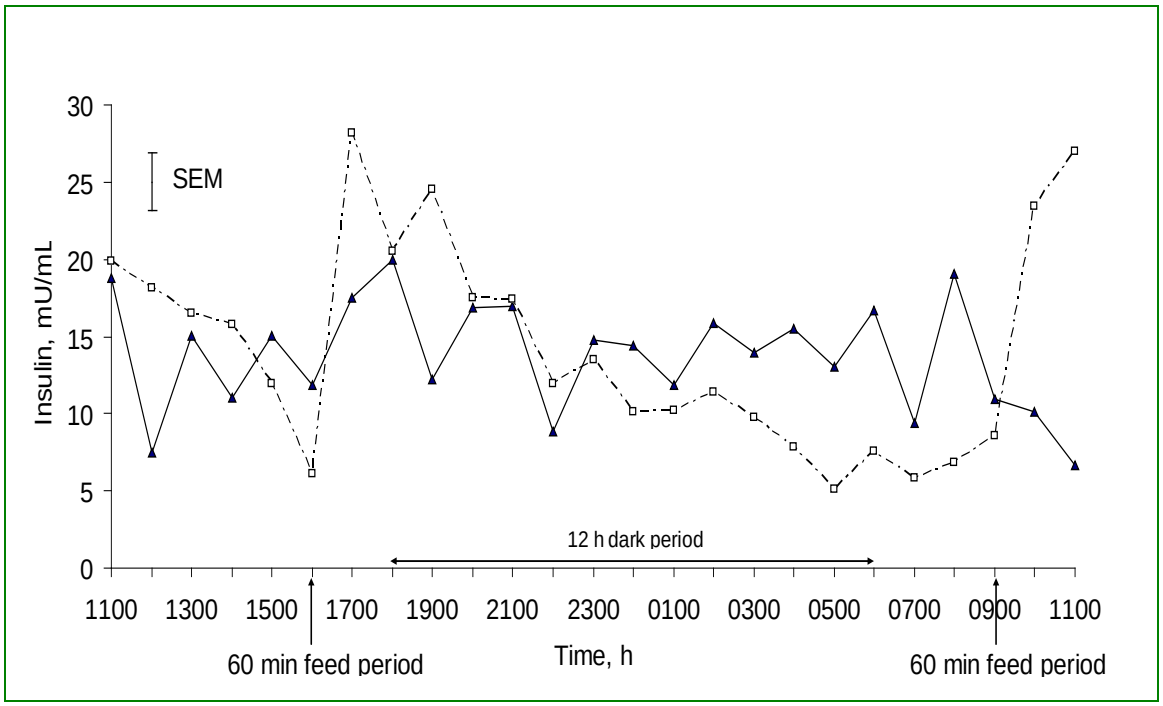


Figure 1. Circulating concentrations of plasma insulin for pigs fed at two 60-min feeding periods (□) or *ad libitum* (▲). Standard error of the mean (SEM) shown as the error bar.

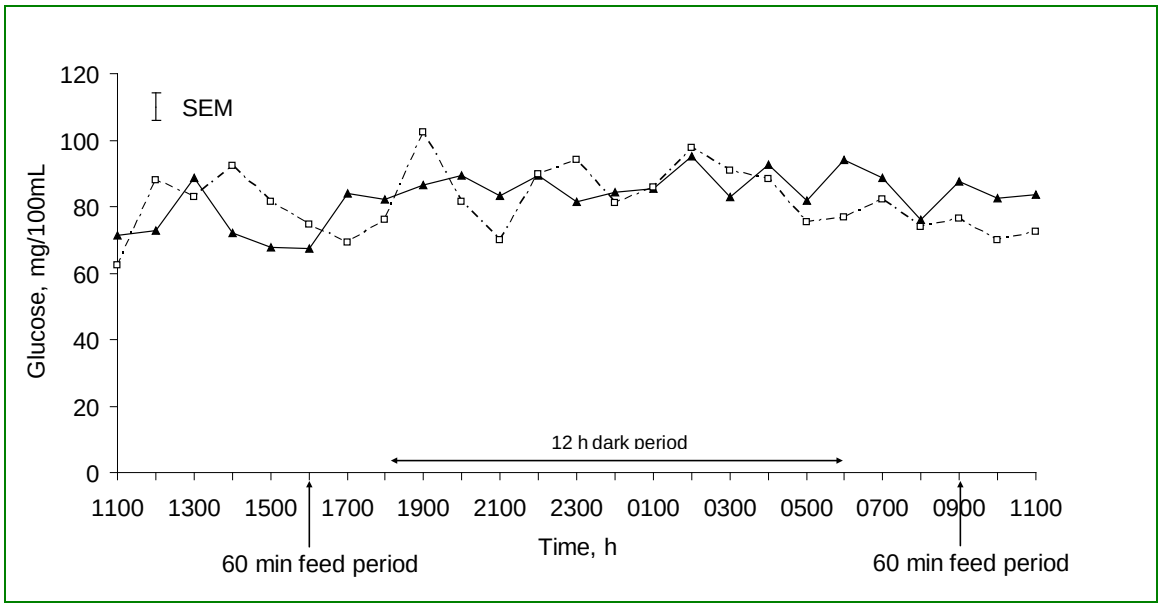


Figure 2. Circulating concentrations of plasma glucose for pigs fed at two 60-min feeding periods (□) or *ad libitum* (▲).Standard error of the mean (SEM) shown as the error bar.

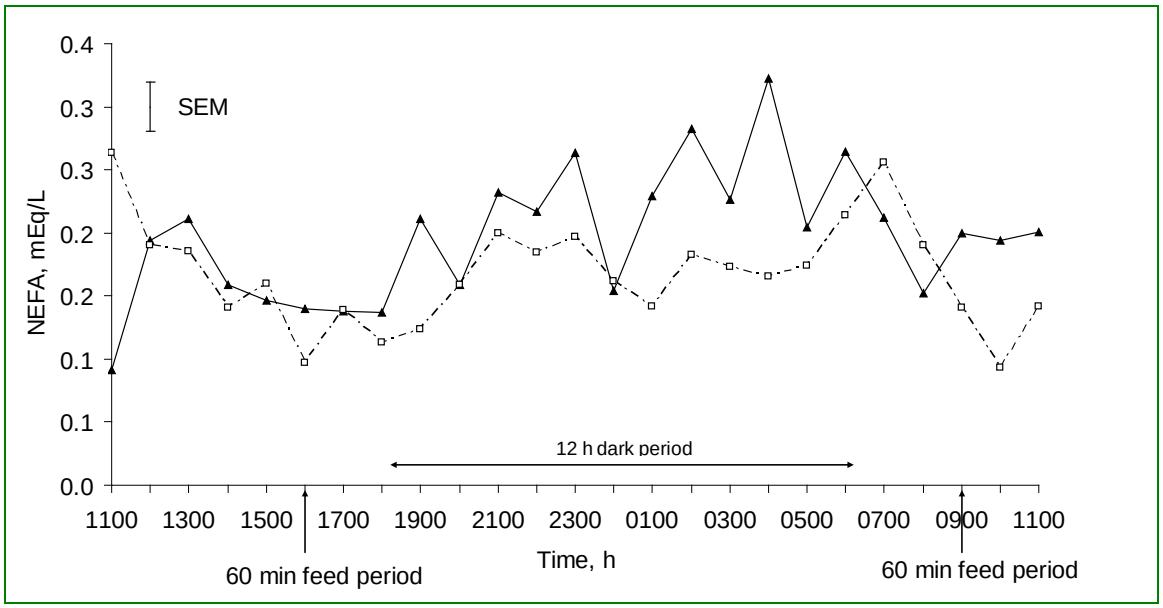


Figure 3. Circulating concentrations of plasma NEFA for pigs fed at two 60-min feeding periods (□) or *ad libitum* (▲).Standard error of the mean (SEM) shown as the error bar.

Farrowing Data

The number of gilts that were successfully mated for each treatment group was 5 tallow, 6 safflower oil and 8 Salmate® fed gilts. However, this number was further reduced as a consequence of both transport stress and lameness. Two gilts from the safflower oil treatment died during transport from Rivalea Australia to EMAI and 3 (1 from the Salmate® group and 2 from the tallow fed group) were euthanased in response to lameness. Therefore, the number of gilts that successfully farrowed were 3 tallow, 4 safflower oil and 7 Salmate® fed gilts.

Birth Characteristics

Birth characteristics for gilts fed tallow, safflower or Salmate® are shown in Table 1. The gestational length tended to be shorter for the gilts fed the safflower oil diet (n-6 PUFA) compared to gilts fed tallow (saturated fatty acids) or Salmate® (n-3 PUFA). The number of piglets born tended to be higher for the safflower oil and Salmate® fed gilts when compared to gilts fed tallow. Whereas, the body weight for the tallow fed group tended to be greater (P=0.093) when compared to the safflower oil and Salmate® fed gilts. The number of still born and mummified piglets also tended to be higher for the tallow fed gilts.

Table 1 Birth characteristics for gilts fed tallow, safflower oil or Salmate®

	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower (n-6 PUFA)
Gestation length (days)	115.67 ± 1.15	115.29 ± 1.11	113.75 ± 1.50
Piglet born/gilt	8.67 ± 0.88	10.86 ± 0.46	11.75 ± 0.85
Still born	1.67 ± 0.67	1.0 ± 0.44	1.0 ± 0.41
Mummies	1.0 ± 1.0	0.0± 00	0.75 ± 0.48
Total female	10.0	35.0	20.0
Total male	14.0	29.0	20.0
Body weight (kg)	1.80 ± 0.17	1.51 ± 0.09	1.43 ± 0.04

Treatment mean values ± SEM

Fatty Acid Composition of the Experimental Diets

The fatty acid composition for the experimental diets is given in Tables 2 and 3. Dietary composition is provided in Tables 4 and 5. The tallow diets contained a greater proportion of saturated (16:0 and 18:0) and monounsaturated fatty acids (18:1) compared to the safflower oil or Salmate® diets. The Safflower oil diets contained a greater proportion of linoleic acid (18:2n-6) when compared to either Salmate® or tallow whereas, the Salmate® diets contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6. Increasing the concentration of the dietary fats from 3% to 5% increased the concentration of saturated fatty acid (14:0; 16:0; 18:0) for the tallow diet, the n-6 PUFA (18:2n-6) for the safflower oil diet and the n-3PUFA (20:5n-3; 22:6n-3) for the Salmate® diet. The PUFA balance for both the 3% and 5% diets were similar for all experimental diets.

Table 2 Determined fatty acid composition (g/100g) of the experimental diets

Fatty acid	3% Tallow	3% Salmate®	3% Safflower oil
C14:0	1.14	1.33	
C16:0	20.84	17.03	16.32
C16:1	1.20	2.76	0.69
C18:0	9.39	3.48	4.98
C18:1	30.31	27.73	22.22
C18:2(n-6)	33.01	37.37	52.32
C18:3(n-3)	2.85	3.19	2.75
C20:1	0.63	1.72	
C20:2		0.49	
C20:5(n-3)		1.54	
C22:1		1.08	
C24:0		0.89	
C22:6(n-3)		1.38	
Σ Sat	32.00	22.74	21.31
Σ Monounsat	32.13	33.29	22.92
Σ Poly n-6	33.01	37.37	52.32
Σ Poly n-3	2.85	6.11	2.75
n-6:n-3	11.58	6.12	19.03
*P/S	1.12	1.93	2.62
PUFA Balance %	7.9	13.9	4.9

Table 3 Determined fatty acid composition (g/100g) of the experimental diets

Fatty acid	5% Tallow	5% Salmate®	5% Safflower oil
C14:0	1.81	2.59	
C16:0	22.33	17.94	14.73
C16:1	0.39	2.74	
C18:0	12.98	6.13	2.44
C18:1	33.21	29.31	18.04
C18:2(n-6)	24.08	26.16	60.83
C18:3(n-3)	1.90	2.28	2.80
C20:1	0.58	2.29	0.61
C20:2			
C20:5(n-3)		1.84	
C24:0			
C22:6(n-3)		2.26	

Σ Sat	32.00	22.74	17.18
Σ Monounsat	32.13	33.29	18.65
Σ Poly n-6	33.02	37.86	60.83
Σ Poly n-3	2.85	6.11	3.35
n-6:n-3	11.59	6.20	18.16
*P/S	1.12	1.93	3.74
PUFA Balance %	7.9	13.9	5.2

Table 4 Composition (g/Kg) of Trimester 1 and 2 Gestational Diets

Ingredient	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)
Wheat	467.4	467.4	467.4
Barley	149.3	149.3	149.3
Lupin Kernels (33%)	80.0	80.0	80.0
Mill mix	55.3	55.3	55.3
Canola meal (36%)	50.0	50.0	50.0
Soyabean meal (48%)	48.7	48.7	48.7
Meat meal	66.7	66.7	66.7
Water	10.0	10.0	10.0
Natuphos 5000	0.1	0.1	0.1
Porzyme 9310	0.2	0.2	0.2
Molasses	20.0	20.0	20.0
Tallow-Mixer	30.0		
Salmate		30.0	
Safflower (Linoleic)			30.0
Salt	3.3	3.3	3.3
Limestone	10.0	10.0	10.0
Lysine-HCl	1.8	1.8	1.8
DL-Methionine	0.3	0.3	0.3
Threonine	0.3	0.3	0.3
Potassium Chloride	4.2	4.2	4.2
QAF Breeder Premix	1.2	1.2	1.2

QAF Lac Sow Plus	1.0	1.0	1.0
Endox	0.2	0.2	0.2
Elancoban G	1.5	1.0	1.0
Red Micro Grits	1.5		
Blue Micro Grits		1.0	
Green Micro Grits			1.0

Table 5 Composition of 3rd Trimester Diets (g/Kg)

Ingredient	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)
Wheat	693.5	693.5	693.5
Mill mix	174.0	174.0	174.0
Meat meal	52.0	52.0	52.0
Water	10.0	10.0	10.0
Tallow-Mixer	50.0		
Salmate		50.0	
Safflower (Linoleic)			50.0
Salt	2.0	2.0	2.0
Limestone	10.1	10.1	10.1
Lysine-HCl	3.8	3.8	3.8
DL-Methionine	0.5	0.5	0.5
Threonine	1.4	1.4	1.4
QAF Breeder Premix	1.4	1.4	1.4
QAF Lac Sow Plus	1.0	1.0	1.0
Elancoban G	1.0	1.0	1.0
Red Micro Grits	1.0		
Blue Micro Grits		1.0	
Green Micro Grits			1.0
Feedzyme Phytase 1000G	0.7	0.7	0.7
Ronozyme	0.3	0.3	0.3

Behavioral Responses

The progeny from the Salmate® fed gilts tended to contact the udder and to begin suckling earlier than the progeny from the safflower oil or tallow fed groups although these differences were non significant (Table 6). The rectal temperatures at birth was significantly lower (P=0.043) for the progeny from the Salmate® fed gilts when compared to progeny from the other two dietary treatments. However, the rectal temperature at 60 min post-farrowing increased for the Salmate® fed gilts while decreased for progeny from the safflower oil or tallow fed groups.

Table 6 Piglet vigour and rectal temperatures for gilts fed tallow, safflower oil or Salmate®

Treatment	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower (n-6 PUFA)	P - value
Time to udder contact (min)	11.82 ± 1.30	10.19 ± 1.19	14.41 ± 1.25	0.177
Time to 1st suckle (min)	29.20 ± 1.29	19.59 ± 1.16	27.49 ± 1.25	0.451
Rectal temp 0 min (ºC)	36.82 ± 0.54	35.75 ± 0.39	36.42 ± 0.46	0.043
Rectal temp 60 min (ºC)	36.38 ± 0.51	36.16 ± 0.43	36.00 ± 0.48	0.905
Difference At 60 min (ºC)	-0.32 ± 0.50	+0.40 ± 0.25	-0.58 ± 0.42	0.068

Treatment mean values ± SEM

Effect of Birth weight on Time to Udder Contact and Time to 1st Suckling

A significant interaction ($P<0.05$) was observed for birth weight and time to udder contact (Figure 1). A similar trend was also observed for birth weight and time to suckle (Figure 2) however, this interaction was not significant. This relationship suggests that heavier pigs contact the udder and begin suckling earlier than lighter pigs. However the progeny from the gilts fed safflower oil did not conform to this relationship and was found to be contrary to what was observed for the progeny from Salmate® and tallow fed gilts. A non-significant trend was observed for birth weight and time to udder contact (Figure 3) however a significant interaction ($P=0.037$) was observed for the type of fatty acid treatment and sucking behaviour (Figure 4).

Figure 1

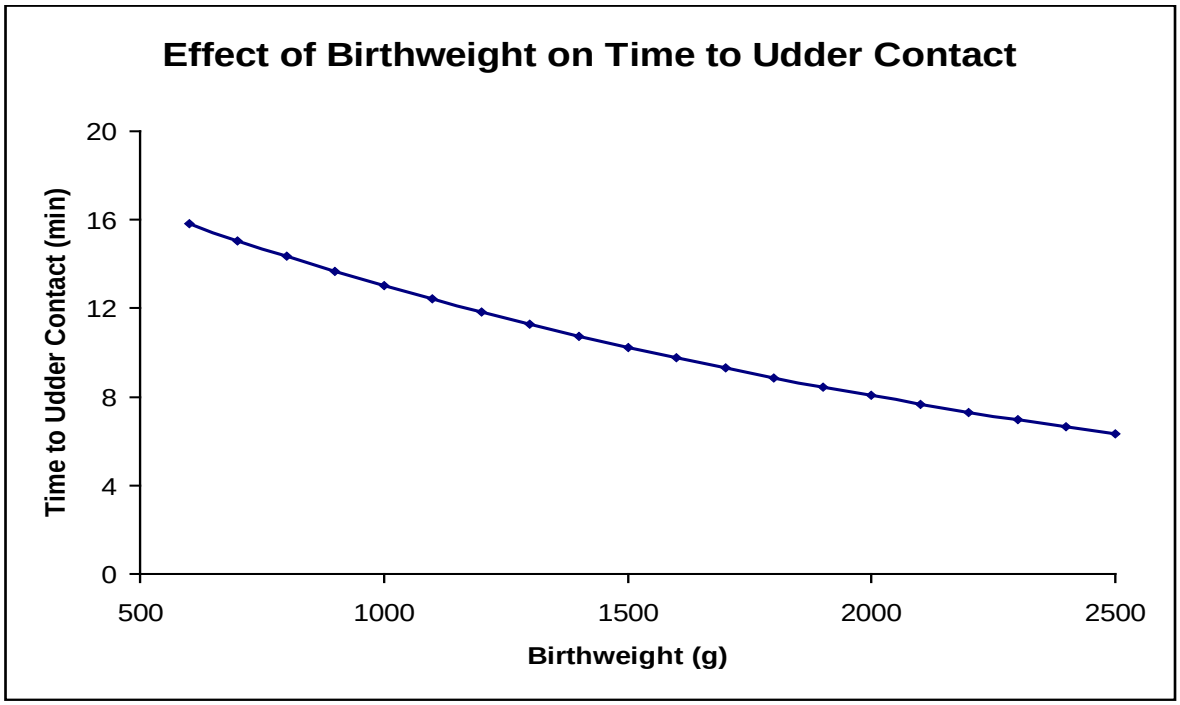


Figure 2

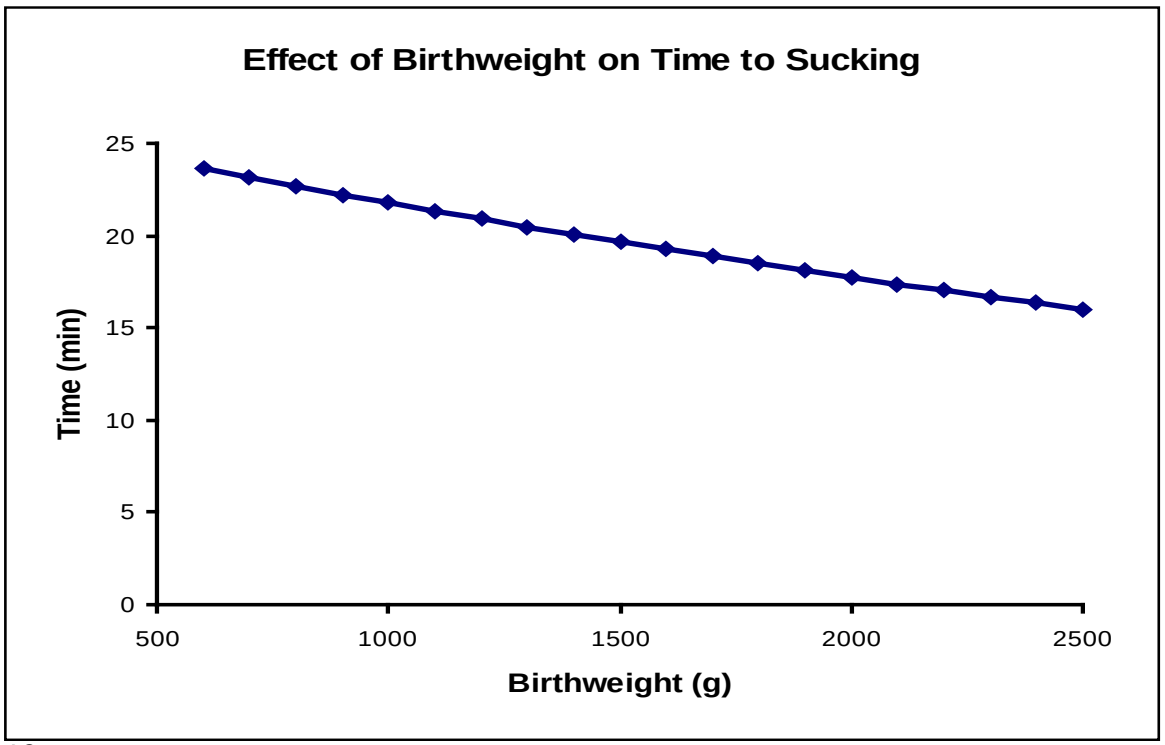


Figure 3

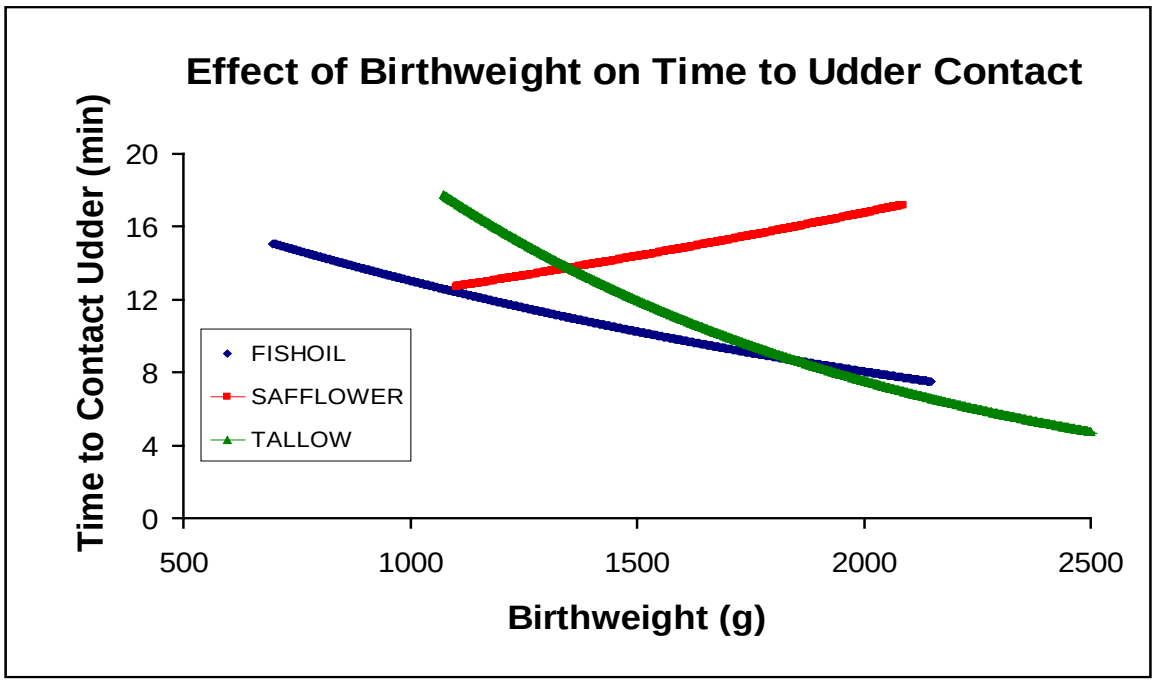
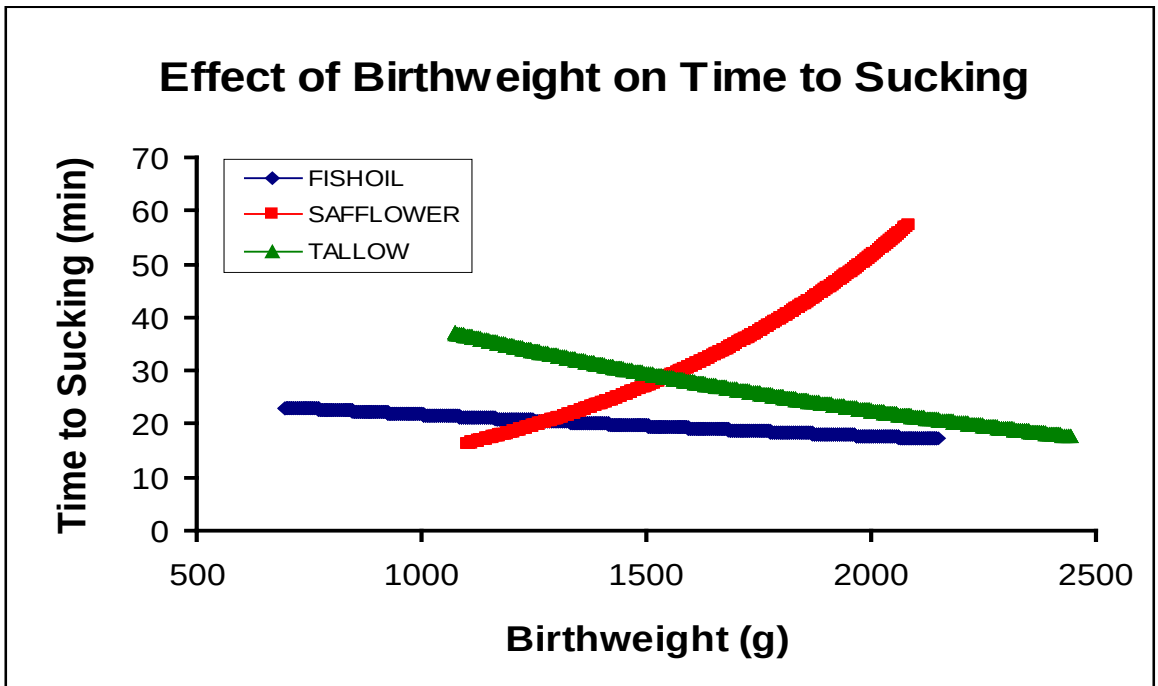


Figure 4



Brain fatty acid profile

The fatty acid profile for whole brain tissue for the 3 treatment groups is given in Table 7. There was no significant difference in SFA and MUFA incorporation between treatment groups. The principal fatty acids that were incorporated were 16:0, 18:0, 18:1 cis, 18:1 trans with all 3 treatment groups having similar concentrations of these fatty acid subtypes. Feeding n-3 PUFA to gestating gilts significantly altered the incorporation of long chain n-3 and n-6PUFA into brain tissue (Figure 5). Whole brain tissue from the Salmate® treatment group had a significantly greater ($P<0.01$) incorporation of the long chain n-3 PUFA's EPA (20:5n-3), DPA (22:5n-3) and DHA (22:6n-3) and significantly decreased n-6 PUFA, AA (20:4n-6) compared to the tallow and safflower oil treatment groups. The ratio of PUFA to SFA was similar for the saturated and safflower oil treatment groups although this was moderately increased with maternal dietary supplementation of n-3 PUFA. The PUFA balance of whole brain tissue was greater for the Salmate® group (41.5%) while the Tallow and Safflower oil groups were similar (34.7% and 36.9 % respectively).

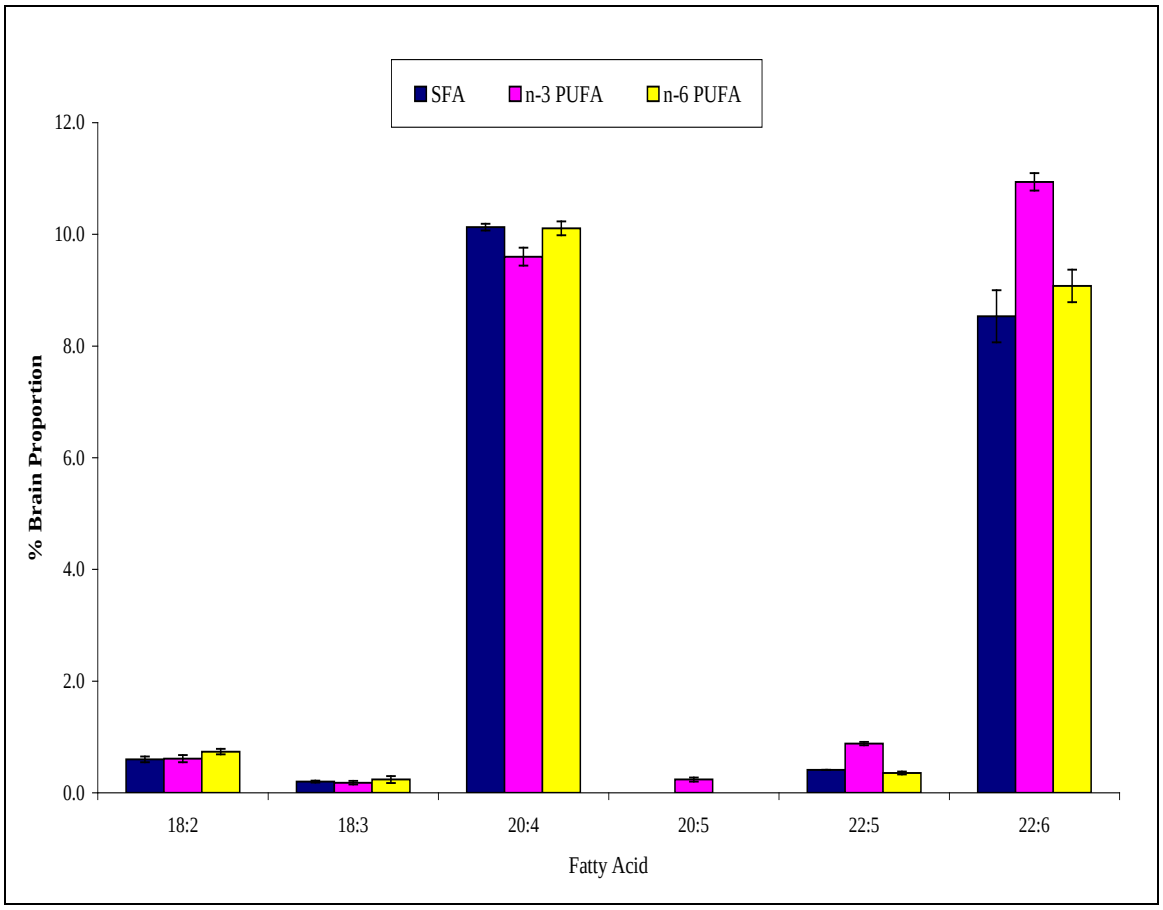


Figure 5 One day old piglet whole brain tissue fatty acid profile for selected fatty acids

Table 7 Determined fatty acid composition (g/100g) of whole brain tissue from day-old piglets of gilts fed saturated fatty acids, n-3 PUFA or n-6 PUFA

Fatty acid	Tallow (SFA) n=2	Salmate® (n-3 PUFA) n=5	Safflower oil (n-6 PUFA) n=5
14:0	0.93 ± 0.07	0.92 ± 0.02	0.92 ± 0.03
14:1	0.17 ± 0.01	0.18 ± 0.03	0.17 ± 0.01
16:0	23.27 ± 0.38	23.01 ± 0.17	23.23 ± 0.39
16:1	1.30 ± 0.21	1.26 ± 0.07	1.25 ± 0.11
17:0	0.24 ± 0.01	0.20 ± 0.01	0.22 ± 0.01
18:0	19.11 ± 0.17	18.53 ± 0.19	18.57 ± 0.28
18:1 cis	12.37 ± 0.07	12.31 ± 0.23	12.01 ± 0.25
18:1 trans	4.24 ± 0.17	4.20 ± 0.09	4.20 ± 0.09

18:2	0.60 ± 0.05	0.61 ± 0.06	0.74 ± 0.05
18:3	0.20 ± 0.02	0.18 ± 0.03	0.24 ± 0.06
20:0	0.55 ± 0.04	0.43 ± 0.11	0.31 ± 0.11
20:1	0.22 ± 0.00	0.29 ± 0.03	0.31 ± 0.06
20:2	0.44 ± 0.01	0.62 ± 0.05	0.44 ± 0.05
20:3	0.36 ± 0.01	0.62 ± 0.04	0.40 ± 0.01
20:4	10.13 ± 0.06	9.60 ± 0.16	10.11 ± 0.12
20:5		0.24 ± 0.04	
22:0	0.26 ± 0.00	0.16 ± 0.00	
22:1	0.13 ± 0.00	0.17 ± 0.03	0.20 ± 0.02
24:0		0.29 ± 0.00	
22:4	4.55 ± 0.06	3.56 ± 0.06	3.66 ± 0.80
22:5	0.36 ± 0.00	0.88 ± 0.03	0.35 ± 0.03
22:6	8.53 ± 0.47	10.94 ± 0.16	9.08 ± 0.29
24:1	0.37 ± 0.22	0.46 ± 0.15	0.57 ± 0.13
SFA	44.22 ± 0.45	43.10 ± 0.32	43.26 ± 0.69
MUFA	18.74 ± 0.60	18.87 ± 0.19	18.71 ± 0.34
PUFA (n-3)	8.73 ± 0.45	11.29 ± 0.10	9.22 ± 0.25
PUFA (n-6)	16.43 ± 0.13	15.90 ± 0.18	15.71 ± 0.98
P/S	0.57 ± 0.02	0.63 ± 0.01	0.58 ± 0.02
n-6 : n-3	8.73 ± 0.45	11.29 ± 0.10	9.22 ± 0.25
22:6/22:5	23.82 ± 1.87	12.47 ± 0.55	26.14 ± 2.10
22:6/20:4	1.19 ± 0.06	0.88 ± 0.02	1.12 ± 0.03
PUFA Balance %	34.7	41.5	36.9

Treatment mean values ± SEM. Values within rows with different superscripts indicate significance [a] $P<0.05$, [aa] $P< 0.01$.

Respiratory Quotient

Feeding different dietary fatty acids to gilts had a differential effect on the RQ value of male progeny (Table 8). Piglets from the n-6 PUFA treatment group had greater RQ values, indicating a greater oxidation of carbohydrate as an energy substrate when compared to piglets from both the SFA and n-3 PUFA treatment groups. There was no significant difference between the SFA and n-3 PUFA treatment groups.

Table 8 Treatment mean Respiratory Quotient values of male piglets from gilts fed SFA, n-3 PUFA or n-6 PUFA.

	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)	P-value
RQ Value	0.75 ± 0.01	0.77 ± 0.01	0.79 ± 0.01	0.051

Treatment means ± SEM

Growth throughout lactation

There was no significant difference in live body weight of progeny from gilts fed tallow, Salmate® or safflower oil during lactation (Figure 6). Progeny from the tallow treatment group were heavier at farrow, and at each time point during lactation compared to the Salmate® and safflower oil progeny. Progeny from all treatment groups were significantly heavier at wean when compared to their farrow body weight. Progeny from the tallow group were heavier at the time of wean whereas the Salmate® treatment group had the lowest body weight.

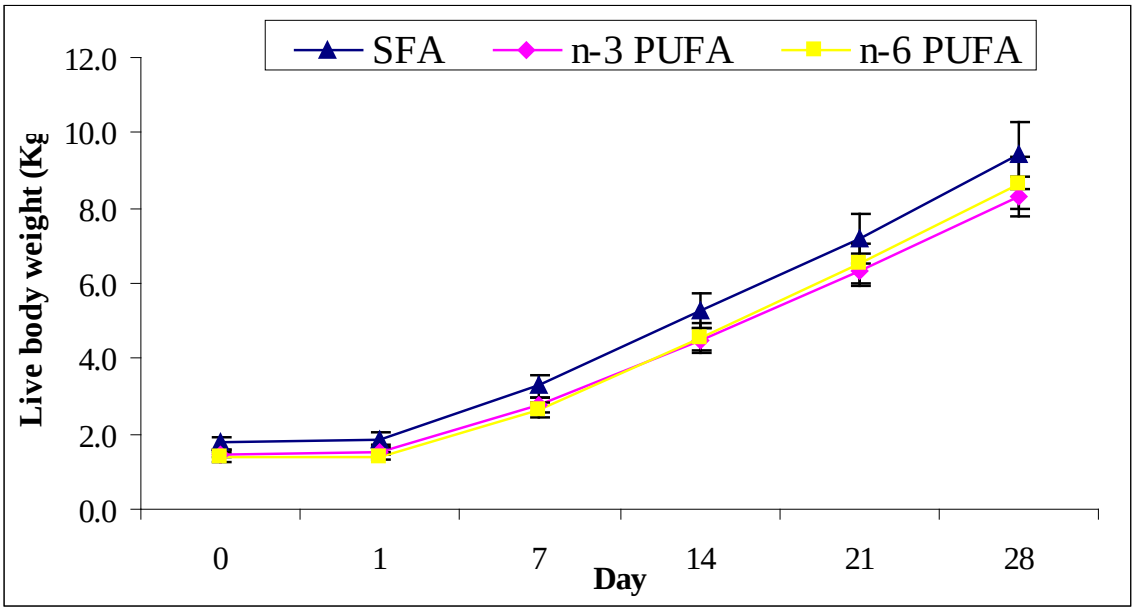


Figure 6 Treatment mean live body weight of progeny from gilts fed SFA, n-3 PUFA or n-6 PUFA during lactation.

Weaning Period Day 28 to Day 49

Stress response to weaning

Feeding different dietary fatty acid sources to gilts did not significantly affect salivary cortisol concentrations of the female progeny at the time of wean (T_0) (Table 9). Weaning significantly increased ($P<0.01$) salivary cortisol concentrations for all treatment groups. Although salivary cortisol concentrations for the n-3 PUFA fed progeny were reduced 90 min post-wean (T_{90}) compared to from the n-6 PUFA and saturated fat progeny this was not significant.

Table 9 Treatment mean saliva cortisol concentrations (units) from female pigs at wean and 90 min post-wean from gilts fed SFA, n-3 PUFA or n-6 PUFA.

Time	Tallow (SFA) n=9	Salmate® (n-3 PUFA) n=19	Safflower oil (n-6 PUFA) n=19
T_0	1.04 ± 0.30	0.71 ± 0.17	0.82 ± 0.20
T_{90}	6.40 ± 1.59	3.83 ± 0.77	5.21 ± 1.07

Treatment means ± SEM.

Feed intake

Weekly mean voluntary feed intakes for pigs during the weaner phase are shown in Figure 7. Due to increased contamination of feed residues with faeces and urine, accurate records of voluntary feed intake data were only possible for the first three weeks of the four week experiment. Voluntary feed intakes of weaner pigs from the n-6 PUFA treatment group was significantly lower ($P < 0.001$) than for the SFA and n-3 PUFA treatment groups for each week of the experiment. Feed consumption of the n-6 PUFA treatment group during the first week represented 36% and 54% of the feed consumed by the SFA and n-3 PUFA treatment groups respectively. These values increased during the second week to approximately 53% and 56% and during the third week to 55% and 53% when compared to the SFA and n-3 PUFA treatment groups. Total voluntary feed intake of pigs in the n-6 PUFA treatment group was 54% and 57% of the total feed consumed by the SFA and n-3 PUFA treatment groups. Voluntary feed intake was greatest for the SFA treatment group during the first 2 weeks of the experiment however; the n-3 PUFA treatment group consumed the greater amount of feed during the 3rd week of sampling.

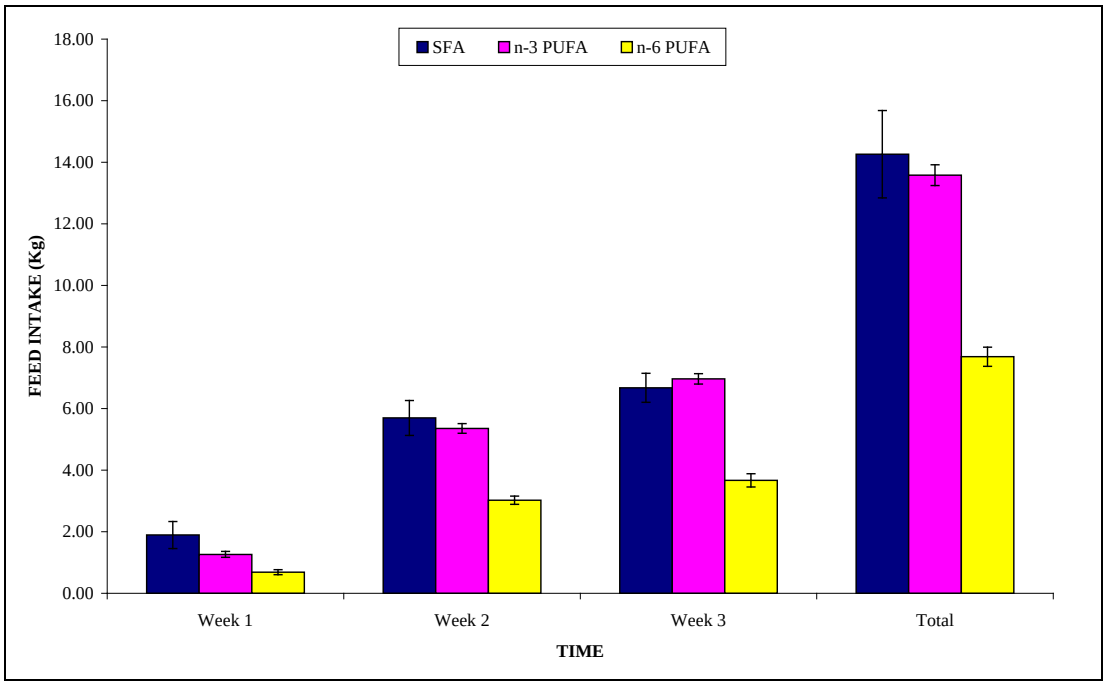


Figure 7 Treatment mean voluntary feed intake of female weaner pigs fed SFA, n-3 PUFA or n-6 PUFA diets.

Live body weight

Results for mean live body weight are shown in Figure 8. There was no significant difference for live body weight for the treatment groups at wean and 7 days post-wean. However, fourteen days post-wean, pigs from the n-6 PUFA treatment group were significantly lighter ($P < 0.001$) than those from either the SFA and n-3 PUFA treatment groups. This body weight pattern continued for the remainder of the experiment. No significant differences in live body weight were found between the SFA and n-3 PUFA treatment groups for the duration of the weaner phase.

Feed to gain

There were no significant differences in feed: gain for the three treatment groups (Figure 9). Feed: gain values for the n-6 PUFA treatment group reflected the depressed feed intake and subsequent reduced growth in live body weight gain, resulting in a similar feed: gain to that from the SFA and n-3 PUFA treatment groups.

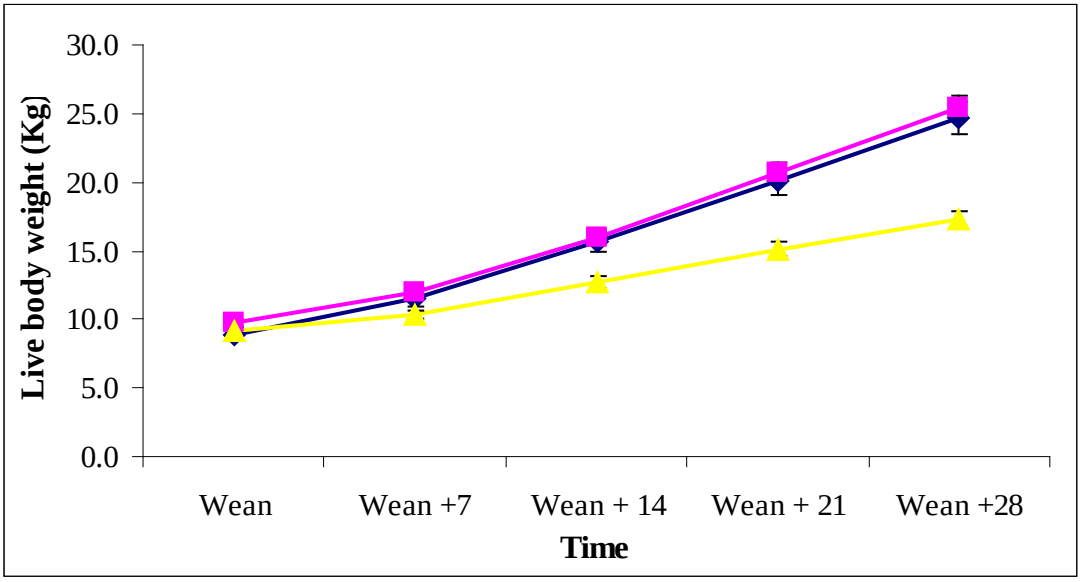


Figure 8 Treatment mean live body weight during the weaner phase for pigs fed saturated fatty acids, n-3 PUFA or N-6 PUFA.

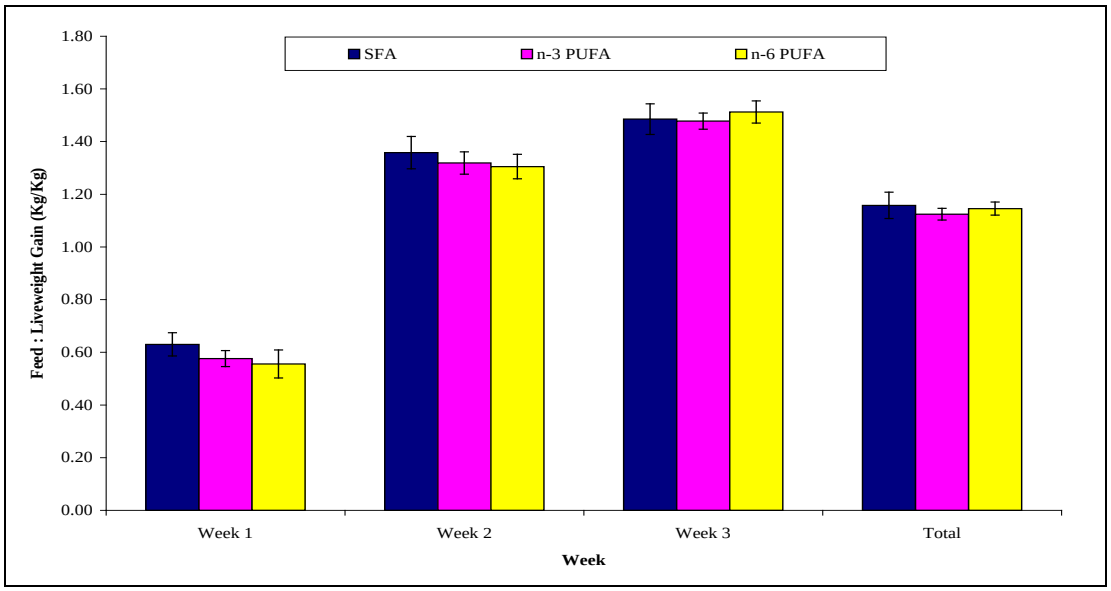


Figure 9 Weaner treatment mean feed consumed (Kg): live body weight gain (Kg) of pigs fed SFA, n-3 PUFA or n-6 PUFA.

Fatty Acid and Dietary Composition of the Weaner Phase Experimental Diets
The fatty acid composition of the weaner diets is shown in Table 10 and dietary composition is shown in Table 11. The tallow diet contained greater proportion of saturated (palmitic acid16:0; stearic acid 18:0) and monounsaturated (oleic acid 18:1) fatty acids compared to either the safflower oil or Salmate® diets. The safflower oil diet contained a greater proportion of linoleic acid 18:2n-6 compared to either the Salmate® or tallow diets, whereas, the Salmate® diet contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6

Table 10 Determined fatty acid composition (g/100g) of the weaner diets

Fatty acid	3% Tallow	3% Salmate®	3% Safflower oil
C14:0	1.39	1.44	0.94
C16:0	20.20	18.09	17.19
C16:1	1.31	2.39	1.08
C18:0	9.57	6.32	5.95
C18:1	37.85	36.47	33.73
C18:2(n-6)	26.73	28.44	38.65
C18:3(n-3)	1.75	1.84	1.67
C20:1	0.78	1.36	0.79
C20:2		0.38	
C20:5(n-3)		0.90	
C22:1		0.70	
C24:0		0.90	
C22:6(n-3)		0.79	
Σ Sat	31.17	26.75	24.09
Σ Monounsat	39.95	40.91	35.61
Σ Poly n-6	26.73	28.82	38.65
Σ Poly n-3	1.75	3.52	1.67
n-6:n-3	15.27	8.19	23.14
*P/S	0.91	1.21	1.67
PUFA Balance %	7.1	10.9	4.1

Table 11 Composition of Weaner diets (g/Kg)

Ingredient	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)
Wheat	374.3	374.3	374.3
Groats 10.5%	200.0	200.0	200.0
Lupin Kernels	72.0	72.0	72.0
Soyabean meal 48%	60.0	60.0	60.0
Meat meal	86.0	86.0	86.0
Blood meal	23.0	23.0	23.0
Soycomil	25.0	25.0	25.0
Whey powder 11%	100.0	100.0	100.0
Water	10.0	10.0	10.0
Natuphos 5000	0.1	0.1	0.1
Tallow mixer	30.0		
Salmate		30.0	
Safflower (Linoleic)			30.0
Salt	2.0	2.0	2.0
Limestone H/A	2.5	2.5	2.5
Lysine HCl	3.8	3.8	3.8
DL Methionine	1.3	1.3	1.3
Threonine	1.2	1.2	1.2
Isoleucine H/A	0.3	0.3	0.3
Tryptophan H/A	0.2	0.2	0.2
Zinc Oxide	2.8	2.8	2.8
QAF Creep Premix	2.0	2.0	2.0
Endox	0.2	0.2	0.2
Red Micro Grits	1.0		
Blue Micro Grits		1.0	
Green Micro Grits			1.0
Ronozyme	0.3	0.3	0.3
Biomin acid blend	3.0	3.0	3.0

Grower Period (Day 49-Day92)

Fatty Acid and Dietary Composition of the Grower Phase Experimental Diets
The fatty acid and dietary composition for the grower diet is shown in Tables 12 and 13 respectively. The fatty acid profiles for the 3 experimental diets were similar to the weaner diets with the tallow diets

containing a greater proportion of saturated fatty acids (palmitic acid 16:0; stearic acid 18:0) and monounsaturated fatty acids (oleic acid 18:1) compared to either the safflower oil or Salmate® diets. The Safflower oil diets contained a greater proportion of the n-6 PUFA 18:2n-6 (linoleic acid) and the Salmate® diets contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6.

Table 12 Determined fatty acid composition (g/100g) of the grower diets

Fatty acid	3% Tallow	3% Salmate®	3% Safflower oil
C14:0	1.37	1.54	
C16:0	21.15	17.47	16.32
C16:1	1.35	2.95	0.69
C18:0	10.25	4.28	4.98
C18:1	31.35	29.01	22.22
C18:2(n-6)	29.91	34.73	52.39
C18:3(n-3)	2.71	2.95	2.75
C20:1	0.63	1.75	
C20:2		0.53	
C20:5(n-3)		1.51	
C22:1		1.09	
C24:0		0.83	
C22:6(n-3)		1.35	
Σ Sat	32.78	24.12	21.31
Σ Monounsat	33.33	34.81	22.92
Σ Poly n-6	29.91	35.26	52.39
Σ Poly n-3	2.71	5.81	2.75
n-6:n-3	11.04	6.07	19.05
*P/S	1.00	1.70	2.62
PUFA Balance %	8.3	14.1	4.9

Table 13 Composition of Grower Diets (g/Kg)

Ingredient	Tallow (SFA)	Salmate (n-3 PUFA)	Safflower (n-6 PUFA)
Wheat	562.9	562.9	562.9
Barley	150.0	150.0	150.0
Mill mix	50.0	50.0	50.0
Canola meal (36%)	50.0	50.0	50.0
Soyabean meal (48%)	63.0	63.0	63.0
Meat meal	60.0	60.0	60.0
Water	10.0	10.0	10.0
Natuphos 5000	0.1	0.1	0.1
Porzyme 9310	0.2	0.2	0.2
Tallow-Mixer	30.0		
Salmate		30.0	
Safflower (Linoleic)			30.0
Salt	2.0	2.0	2.0
Limestone	15.0	15.0	15.0
Lysine-HCl	3.7	3.7	3.7
DL-Methionine	0.4	0.4	0.4
Threonine	1.0	1.0	1.0
Copper proteinate micro	1.0	1.0	1.0
QAF Grower Premix	0.7	0.7	0.7
Red Micro Grits	1.0		
Blue Micro Grits		1.0	
Green Micro Grits			1.0

Live Body Weight Gain

Body weight increased significantly ($P<0.001$) for each treatment group over the experimental period (Figure 10). However, body weight was significantly lower ($P < 0.01$) at week 5 of treatment for the n-6 PUFA treatment group compared to the SFA and n-3 PUFA groups. This reduction in body weight for the n-6 PUFA treatment group was maintained for the duration of the experiment. The difference in relative bodyweight for the n-6 PUFA group compared to the SFA and n-3 PUFA groups decreased over time from 30% (SFA) and 32% (n-3 PUFA) at week 5 to 18% and 19% of the SFA and n-3 PUFA treatment groups respectively at the completion of the grower phase (week 11). Pigs from the n-6 PUFA treatment group were approximately 24% and 26% lighter in bodyweight compared to pigs from the SFA and n-3 PUFA treatment groups respectively over the experimental period.

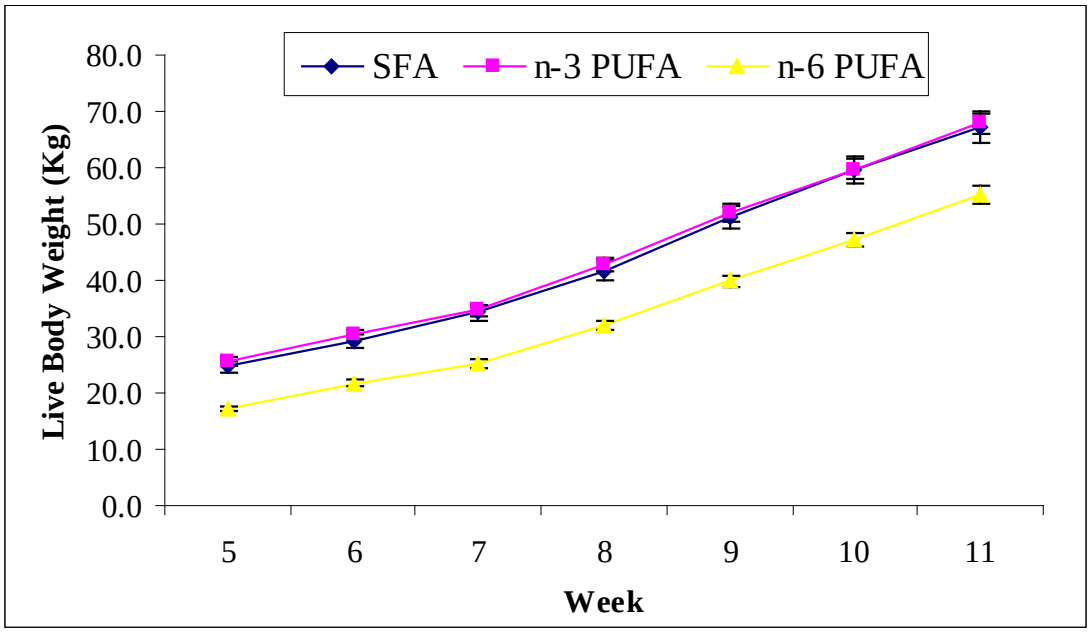


Figure 10 Treatment mean live body weight of pigs fed SFA, n-3 PUFA or n-6 PUFA housed in individual pens during the grower phase

Voluntary Feed Intake and Feed to Gain

Feed intakes, ADG and feed: gain for pigs fed tallow, n-3 PUFA, or n-6 PUFA for the grower period are shown in Table 14. During weeks 6 and 7 pigs from the tallow treatment group and pigs from the n-3 PUFA treatment group during weeks 6-8 consumed significantly more ($P< 0.001$) feed than pigs from the n-6 PUFA treatment group (Figure 11). From week 9 to the end of the grower phase there were no significant differences in feed intakes between the three treatment groups. There was no significant difference in voluntary feed intakes for the tallow and the n-3 PUFA treatment groups. Feed intakes increased significantly ($P<0.001$) for all treatment groups during weeks 8-11 when compared to weeks 5 and 6 of the experimental period. Daily voluntary feed intake for the SFA, n-3 PUFA and n-6 PUFA treatment groups during weeks 6 and 7 of the experiment represented 50, 51 and 45% respectively of the daily feed intake during weeks 8-11. Pigs fed tallow and n-3 PUFA had significantly higher ($P=0.004$) average daily gain (Table 14) compared to those pigs fed n-6 PUFA. There were no significant differences in feed: gain between the treatment groups for the grower phase (Table 14) although the tallow group consumed less feed per unit of live weight gain than both the n-3 and n-6 PUFA treatment groups.

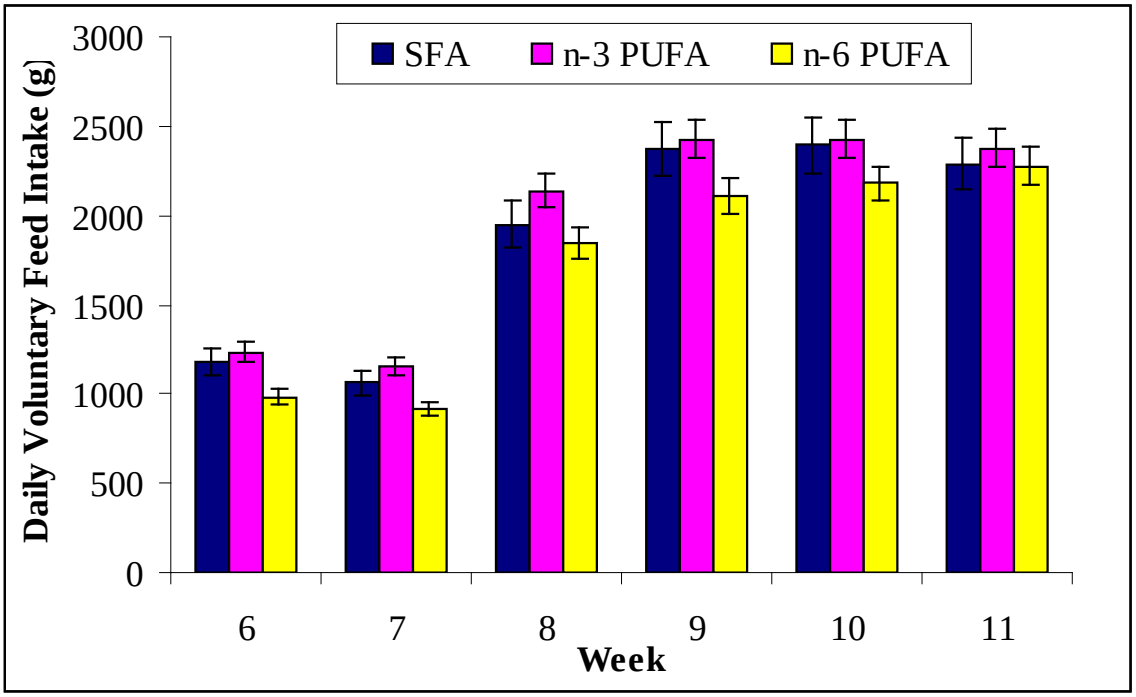


Figure 11 Treatment mean daily voluntary feed intake of individually housed grower pigs fed SFA, n-3 PUFA or n-6 PUFA experimental diets.

Table 14 Treatment mean voluntary feed intake, live body weight gain and feed to gain for the grower period in pigs fed SFA, n-3 PUFA or n-6 PUFA.

	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)	P-value
Voluntary Feed Intake (g/day)	2264 ± 95.10^{aa}	2373± 73.57^{aa}	2080 ± 64.47^{bb}	0.010
Body weight at start of grower period (Kg)	24.63 ± 1.00^{aaa}	25.48 ± 0.74^{aaa}	17.27 ± 0.50^{bbb}	0.001
Body weight at end of grower phase (Kg)	67.22 ± 2.69^{aaa}	67.97 ± 1.90^{aaa}	55.31 ± 1.55^{bbb}	0.001
Average Daily Gain (g/day)	1013 ± 35.47^{aa}	1009 ± 24.22^{aa}	904 ± 21.70^{bb}	0.004
Feed: gain	2.18 ± 0.08	2.27 ± 0.06	2.26 ± 0.06	0.64

Treatment means ± SEM. Values within rows without common superscripts are statistically different; ^{aa} P<0.01, ^{aaa} P<0.001.

Computed Tomography

Carcass composition determined at the commencement of the grower phase for pigs fed tallow, n-3 PUFA and n-6 PUFA are shown in Table 15. Body weight for pigs fed tallow and n-3 PUFA were significantly heavier (P<0.001) than pigs fed n-6 PUFA. The total fat percent for the n-3 PUFA group was significantly greater (P=0.03) when compared to tallow and n-6 PUFA fed groups pigs. Additionally, pigs from the n-3 PUFA treatment group had significantly (P=0.01) lower carcass bone composition than pigs from the SFA and n-6 PUFA treatment groups. No significant differences were found for the proportion of lean tissue mass or water content between treatment groups.

Table 15 Treatment mean carcass composition (%) of grower phase pigs fed SFA, n-3 PUFA or n-6 PUFA as determined by CT

Component	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)	P-value
Live body weight (Kg)	40.2 ± 1.7^{aaa}	41.1 ± 1.2^{aaa}	31.4 ± 1.0^{bbb}	0.001
Fat (%)	11.8 ± 0.5^{a}	13.5 ± 0.4^{b}	12.6 ± 0.4^{a}	0.03
Lean tissue (%)	64.9 ± 0.8	63.3 ± 0.5	63.2 ± 0.5	0.15
Bone (%)	9.4 ± 0.2^{aa}	8.7 ± 0.2^{bb}	9.3 ± 0.2^{aa}	0.01
Water (%)	7.3 ± 0.1	7.7 ± 0.1	7.7 ± 0.1	0.10

Treatment means ± SEM. Values within rows without common superscripts are statistically different; ^{a}P<0.05, ^{aa} P<0.01, ^{aaa} P<0.001.

Finisher Period (Day 49-Day92)

Fatty Acid and Dietary Composition of the Finisher Phase Experimental Diets

The fatty acid and dietary composition for the finisher phase diets are shown in Tables 16 and 17 respectively. The fatty acid profiles for the 3 experimental diets were similar to the weaner diets with tallow containing a greater proportion of saturated fatty acids (palmitic acid 16:0; stearic acid 18:0) and monounsaturated fatty acids (oleic acid 18:1) compared to either the safflower oil or Salmate® diets. The Safflower oil diet contained a greater proportion of the n-6 PUFA 18:2n-6 (linoleic acid) and the Salmate® diet contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6. The PUFA balance for the three diets was also similar for the weaner diets with the PUFA balance for the Salmate® diet greater than the safflower oil diet.

Weekly live body weight of finisher pigs

Weekly live body weight for the three treatment groups is shown in Figure 12. Live body weight significantly ($P<0.01$) increased for all treatment groups over the finisher period. Feeding n-6 PUFA continued to affect growth rate in a similar pattern as was shown for the grower phase with the body weight for these pigs significantly reduced ($P<0.01$) when compared to pigs fed n-3 PUFA or tallow. At the completion of the finisher period, pigs from the n-6 PUFA treatment group obtained approximately 88% and 87% of the body weights of pigs from the tallow and n-3 PUFA treatment groups respectively. There were no significant differences in live body weight between the tallow and n-3 PUFA treatment groups.

Table 16 Determined fatty acid composition (g/100g) for the finisher diets

Fatty acid	3% Tallow (SFA)	3% Salmate® (n-3 PUFA)	3% Safflower oil (n-6 PUFA)
C14:0	1.14	1.33	
C16:0	20.84	17.03	14.74
C16:1	1.20	2.76	
C18:0	9.39	3.48	2.45
C18:1	30.31	27.54	18.04
C18:2(n-6)	33.02	37.37	60.83
C18:3(n-3)	2.85	3.19	2.80
C20:1	0.63	1.72	0.61
C20:2		0.50	
C20:5(n-3)		1.54	
C22:1		1.08	
C24:0		0.89	
C22:6(n-3)		1.38	
Σ Sat	32.00	22.74	17.18
Σ Monounsat	32.13	33.29	18.65
Σ Poly n-6	33.02	37.86	60.83
Σ Poly n-3	2.85	6.11	2.80
n-6:n-3	11.59	6.20	21.73
P/S	1.00	1.93	3.74
PUFA Balance %	7.9	13.9	4.4

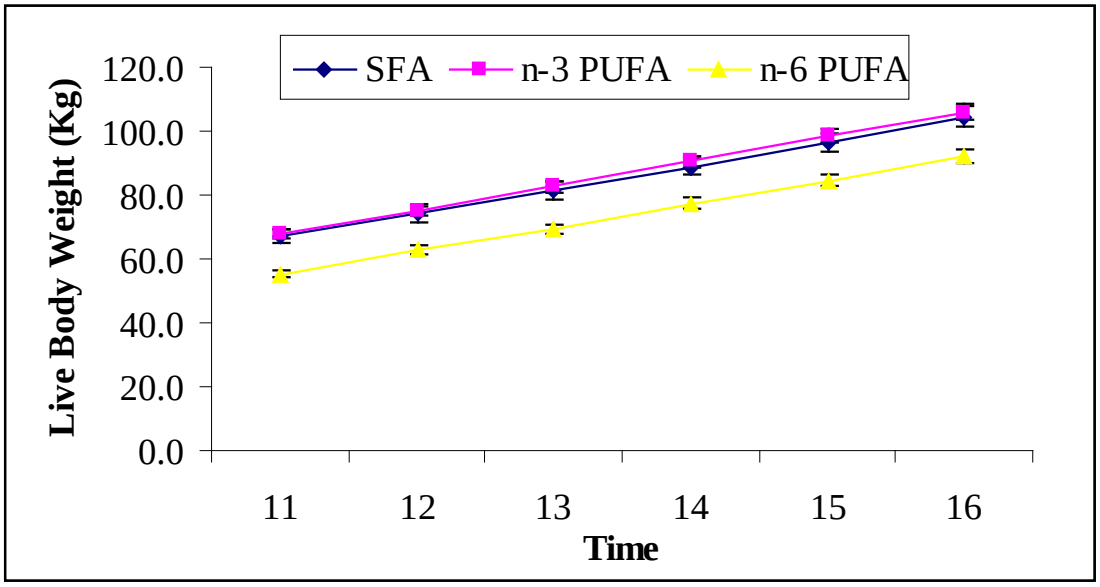


Figure 12 Treatment mean live body weight of individually housed finisher pigs fed diets containing SFA, n-3 PUFA or n-6 PUFA

Table 17 Composition of Finisher Diets (g/Kg)

Ingredient	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)
Wheat	643.4	643.4	643.4
Barley	100.0	100.0	100.0
Mill mix	150.0	150.0	150.0
Canola meal (36%)	35.3	35.3	35.3
Water	10.0	10.0	10.0
Natuphos 5000	0.1	0.1	0.1
Tallow-Mixer	30.0		
Salmate		30.0	
Safflower (Linoleic)			30.0
Salt	2.0	2.0	2.0
Limestone	18.3	18.7	18.7
Palphos	5.0	5.0	5.0
Lysine-HCl	3.3	3.3	3.3
Threonine	0.8	0.8	0.8
Copper proteinate micro	1.0	1.0	1.0
QAF Finisher 2Kg	0.7	0.7	0.7
Red Micro Grits	1.0		
Blue Micro Grits		1.0	
Green Micro Grits			1.0

Voluntary Feed Intake and Feed to Gain of Finisher Pigs

Data for daily voluntary feed intake during the finisher phase is shown in Figure 13. There was no significant difference in voluntary feed intake between treatment groups during the finisher phase. Feed intake within each treatment group increased during the finisher period however this was not significant.

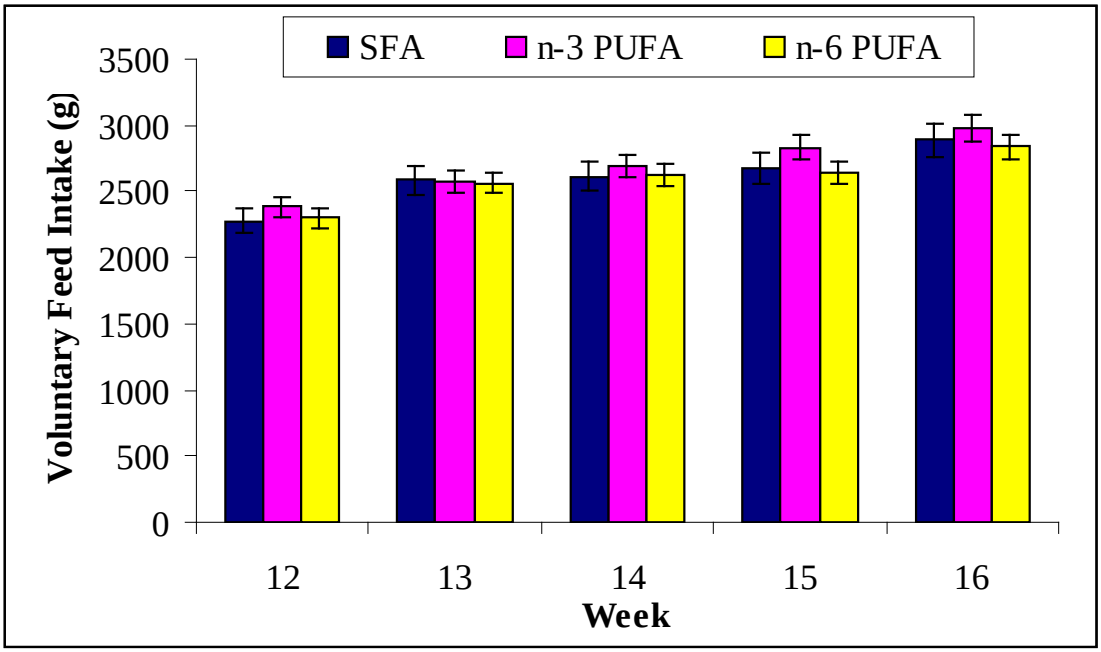


Figure 13 Treatment mean daily voluntary feed intake of individually housed finisher pigs fed SFA, n-3 PUFA or n-6 PUFA experimental diets.

Production data for the finisher period is shown in Table 18. There was no significant difference in overall voluntary daily feed intake, average daily gain and feed: gain between treatment groups. However, body weight at the commencement and at the end of the finisher period was significantly reduced ($P < 0.001$) for the n-6 PUFA pigs when compared to either the n-3 PUFA or tallow groups.

Table18 Treatment mean voluntary feed intake, live body weight gain and feed to gain for the finisher period in pigs fed SFA, n-3 PUFA or n-6 PUFA.

	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)	P-value
Voluntary Feed Intake (g/day)	2607 ± 114.71	2697 ± 83.62	2628 ± 84.10	0.566
Body weight at start of finisher period (Kg)	67.22 ± 2.69^{aaa}	67.97 ± 1.90^{aaa}	55.31 ± 1.55^{bbb}	0.001
Body weight at end	104.59 ±	105.95 ±	92 30 ±	0.001

of finisher phase (Kg)	3.2^{aaa}	2.33^{aaa}	2.03^{bbb}	
Average Daily Gain (g/day)	1062 ± 43.55	1077 ± 33.39	1027 ± 31.86	0.443
Feed: gain	2.51 ± 0.06	2.51 ± 0.04	2.59 ± 0.04	0.377

Treatment means ± SEM. Values within rows without common superscripts are statistically different; ^{aa} P<0.01, ^{aaa} P<0.001.

Computed Tomography (CT) Determined Carcass Composition of Finisher Pigs

CT determined carcass composition of finisher pigs are presented in Table 19. Pigs from the n-6 PUFA treatment group were significantly lighter (P<0.001) in body weight when compared to pigs from both the SFA and n-3 PUFA treatment groups. Feeding different fatty acid sources to finisher pigs had no significant effect on the proportion of individual carcass components; bone, lean tissue, adipose tissue or water.

Table19 Treatment mean finisher phase carcass composition (%) of pigs fed SFA, n-3 PUFA or n-6 PUFA as determined by CT

Component	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)	P-value
Live body weight (Kg)	92.8 ± 3.4^{aaa}	96.4 ± 2.8^{aaa}	82.8 ± 2.5^{bbb}	0.001
Fat (%)	18.1 ± 0.9	19.1 ± 0.7	18.6 ± 0.7	0.57
Lean tissue (%)	59.0 ± 1.1	58.7 ± 0.9	59.0 ± 0.9	0.90
Bone (%)	10.0 ± 0.4	9.7 ± 0.3	9.1 ± 0.3	0.13
Water (%)	8.4 ± 0.2	8.4 ± 0.1	8.3 ± 0.1	0.90

Treatment means ± SEM. Values within rows without common superscripts are statistically different; ^{aaa} P<0.001.

12 h Endocrine Profiles of Finisher Pigs: Plasma Non Esterified Fatty Acids (NEFA), Insulin, Glucose and Leptin

There were no significant differences in plasma NEFA (Figure 3), insulin (Figure 4) or glucose concentrations (Figure 5) for the 3 dietary groups over the 12h sampling period. Although there was no significant differences in plasma insulin concentrations for the 3 dietary groups, plasma insulin

concentrations for the pigs fed the safflower oil diet were consistently lower for the 12h profile when compared to feeding tallow or Salmate®. Circulating plasma concentrations over a 12 h period for glucose, insulin, NEFA and leptin are shown in figures 14, 15, 17 and 17 respectively. There were no significant differences in plasma glucose, insulin, NEFA or leptin for the treatment groups, however there was evidence of a time effect on circulating plasma concentrations of NEFA and leptin.

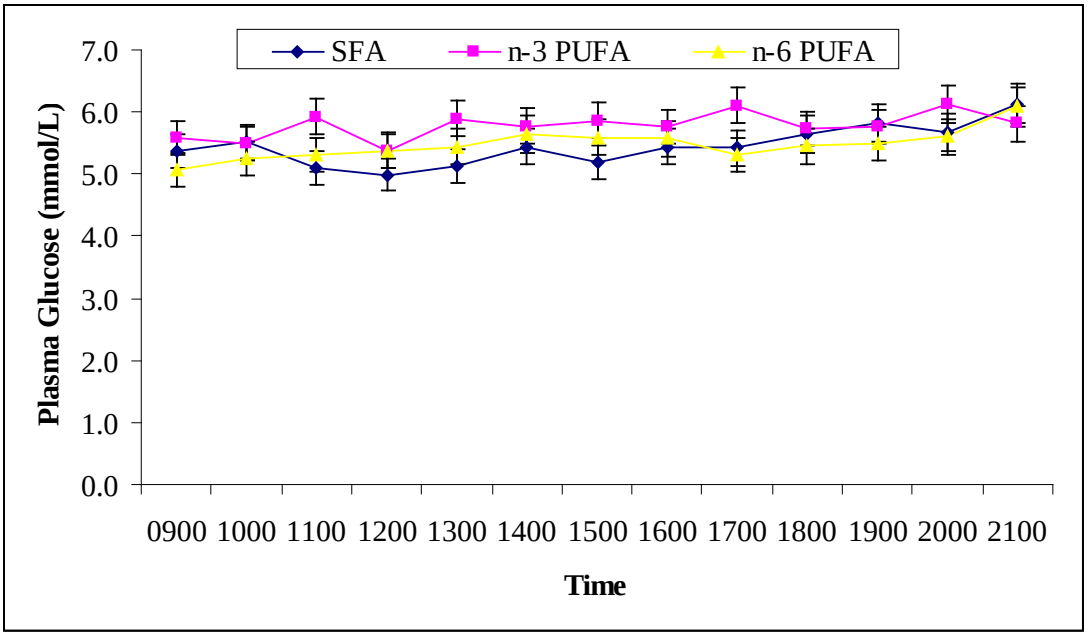


Figure 14 12 h profile of plasma glucose concentrations from finisher pigs fed SFA, n-3 PUFA or n-6 PUFA.

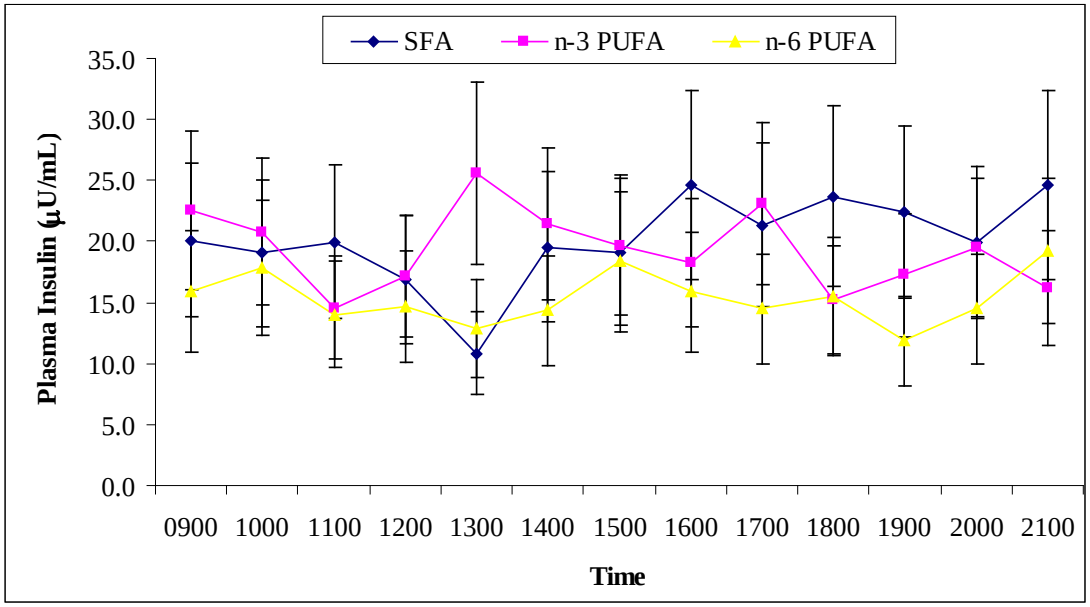


Figure 15 12 h circulating plasma insulin concentration from finisher pigs fed SFA, n-3 PUFA or n-6 PUFA.

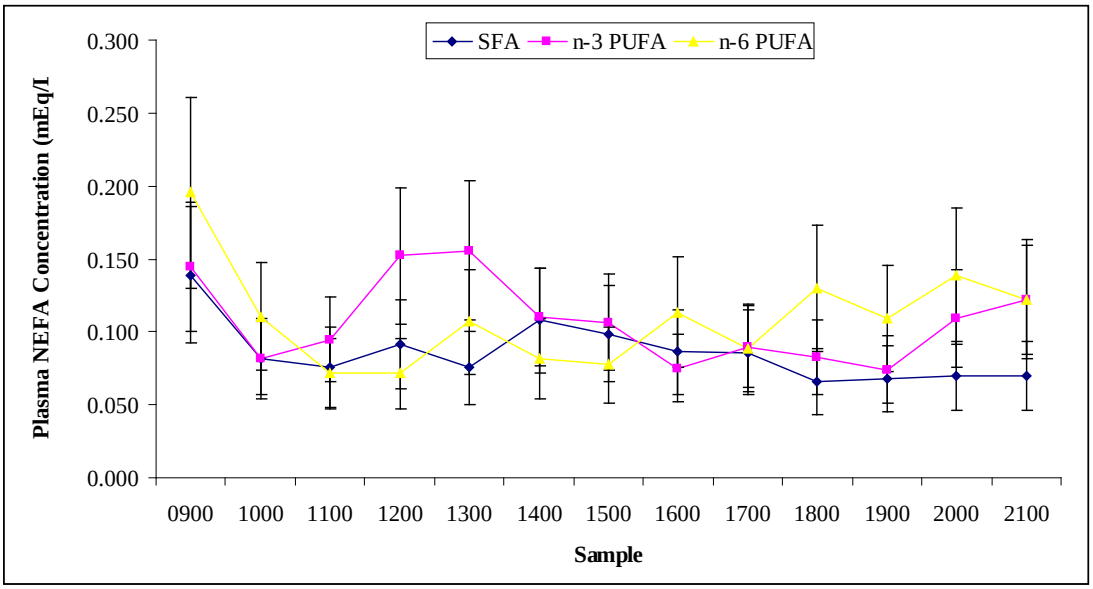


Figure16 Treatment mean 12 h profile for NEFA plasma concentration of finisher pigs fed either SFA, n-3 PUFA or n-6 PUFA

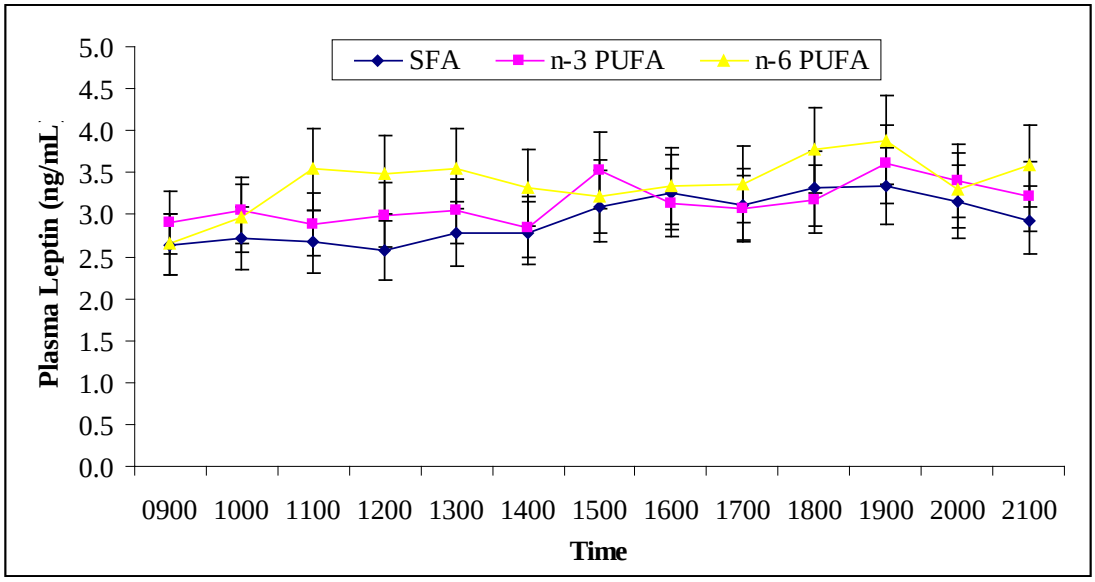


Figure 17 12 h circulating plasma leptin concentration from finisher pigs fed SFA, n-3 PUFA or n-6 PUFA.

Abattoir results

The abattoir results for the 3 dietary groups are shown in Table 20. The dress weight for pigs fed the Salmate® diet was significantly heavier when compared to pigs fed safflower oil and greater compared to pigs fed tallow. Although there was no significant differences in P2 measurement for the 3 dietary groups the P2 for the pigs fed safflower oil was greater when compared to pigs fed tallow or Salmate® diets.

Table 20 Treatment mean carcass values of pigs fed tallow, Salmate® or Safflower oil

	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)	P-value
Dress weight (Kg)	85.9 ± 5.63	91.1 ± 5.42	87.3 ± 5.42	0.51

P2 (mm)	14.7 ± 1.4	15.1 ± 1.3	17.3 ± 1.5	0.41

Treatment means ± SEM. Values within rows without common superscripts are statistically different.

Fatty acid profiles of subcutaneous adipose tissue and muscle samples

Data for subcutaneous back fat samples from finisher pigs fed either SFA, n-3 PUFA or n-6 PUFA are provided in Table 21. No significant difference in the total amount of SFA was found between treatment groups. Levels of MUFA were greatest in pigs fed SFA and were significantly greater than those found in pigs from the n-6 PUFA treatment group. Pigs from the n-3 PUFA treatment group were intermediary with no significant differences compared to both the SFA and n-6 PUFA treatment groups. Feeding n-3 PUFA to finisher pigs resulted in a significant increase ($P < 0.001$) in the total amount of n-3 PUFA as well as the individual n-3 PUFAs; ALA (18:3n-3), EPA (20:5n-3) and DHA (22:6n-3). Adipose tissue samples from SFA fed pigs also contained significantly more ALA (18:3n-3) in comparison to samples from n-6 PUFA fed pigs. Similarly, feeding n-6 PUFA to finisher pigs significantly increased ($P < 0.001$) the proportion of LA (18:2n-6) in addition to the total amount of n-6 PUFA incorporated into adipose tissues compared to both the SFA and n-3 PUFA treatment groups. Levels of LA (18:2n-6) were also significantly greater in the n-3 PUFA treatment group compared to tissues from the SFA group. The polyunsaturated to saturated fatty acid ratio was significantly affected with the addition of n-3 PUFA and n-6 PUFA into diets with both groups having significantly more PUFA in adipose tissue compared to the SFA treatment group. Furthermore, subcutaneous adipose tissue from the n-6 PUFA treatment group contained significantly more PUFA than the n-3 PUFA treatment group. Pigs from the n-3 PUFA treatment group had significantly higher ($P < 0.001$) PUFA balance than both the SFA and n-6 PUFA treatment groups. Additionally, pigs from the SFA treatment group had significantly higher ($P<0.001$) PUFA balance than pigs from the n-6 PUFA treatment group.

Table 21 Determined fatty acid profiles (g/100g) of finisher phase pig subcutaneous adipose tissue samples

Fatty acid	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)
14:0	1.35 ± 0.10^{ab}	1.51 ± 0.08^{a}	1.25 ± 0.07^{b}
16:0	23.95 ± 1.72	24.63 ± 1.35	23.50 ± 1.39
16:1	2.54 ± 0.18^{a}	2.54 ± 0.14^{a}	1.68 ± 0.10^{b}
18:0	12.30 ± 0.89	14.48 ± 0.80	14.14 ± 0.83
18:1	47.85 ± 3.44^{a}	41.22 ± 2.27^{ab}	36.63 ± 2.16^{b}

18:2n-6	8.89 ± 0.64[a]	11.85 ± 0.65[b]	20.03 ± 1.18[c]
18:3n-3	0.73 ± 0.06[a]	0.88 ± 0.05[b]	0.64 ± 0.04[a]
20:1	1.02 ± 0.07[a]	1.08 ± 0.06[a]	0.78 ± 0.05[b]
20:2	0.53 ± 0.04[a]	0.54 ± 0.03[a]	0.94 ± 0.06[b]
20:5n-3	ND	0.41 ± 0.03	ND
22:6n-3	ND	0.55 ± 0.03	ND
24:0	ND	0.65 ± 0.04	ND
∑SFA	37.64 ± 2.71	41.22 ± 2.27	38.90 ± 2.30
∑MUFA	51.42 ± 3.70[a]	44.88 ± 2.47[ab]	39.10 ± 2.31[b]
∑PUFA (n-3)	0.73 ± 0.06[a]	1.54 ± 0.08[b]	0.64 ± 0.04[a]
∑PUFA (n-6)	9.23 ± 0.66[a]	12.40 ± 0.68[b]	20.97 ± 1.24[c]
P/S	0.26 ± 0.02[a]	0.34 ± 0.02[b]	0.55 ± 0.03[c]
PUFA BAL	6.18 ± 0.51[a]	11.08 ± 0.61[b]	2.94 ± 0.17[c]

Treatment means ± SEM. Values within rows without common superscripts are statistically different ($P < 0.001$).

Determined fatty acid profiles of renal adipose tissue from finisher pigs fed either SFA, n-3 PUFA or n-6 PUFA are presented in Table 22. No significant differences were found between treatment groups for the total amount of SFA and MUFA contained within renal adipose tissue samples. Pigs fed n-6 PUFA had significantly less 16:1 and 20:1 than pigs from the n-3 PUFA treatment group. Feeding n-3 PUFA to pigs resulted in a significant increase in the proportion of ALA (18:3n-3) and total n-3 PUFA being incorporated into renal adipose tissue when compared to pigs from both the SFA and n-6 PUFA treatment groups. A concomitant increase in PUFA balance for the n-3 PUFA treatment group relative to both the SFA and n-6 PUFA treatment groups was also observed. Likewise, pigs from the SFA treatment group had significantly higher PUFA balance in renal adipose tissue than pigs from the SFA treatment group. Providing n-6 PUFA diets to finisher pigs resulted in an increase in the amount of LA (18:2n-6) and total n-6 PUFA recovered from renal adipose tissues as to pigs from the SFA and n-3 PUFA treatment groups. The amount of PUFA contained within renal adipose tissue significantly increased with the addition of dietary n-3 PUFA or n-6 PUFA with respect to SFA-fed pigs and n-6 PUFA fed pigs also containing significantly more PUFA than pigs from the n-3 PUFA.

Table 22 Determined fatty acid profiles (g/100g) of renal adipose tissue from finisher pigs fed SFA, n-3 PUFA and n-6 PUFA

Fatty acid	Tallow (SFA)	Salmate® n-3 PUFA	Safflower oil n-6 PUFA
14:0	1.42 ± 0.16	1.49 ± 0.13	1.34 ± 0.13
16:0	27.28 ± 3.16	27.06 ± 2.41	26.13 ± 2.48

16:1	1.99 ± 0.23[ab]	2.29 ± 0.20[b]	1.58 ± 0.15[a]
18:0	18.75 ± 2.17	16.83 ± 1.50	17.36 ± 1.65
18:1	40.33 ± 4.68	38.59 ± 3.43	33.55 ± 3.19
18:2n-6	8.57 ± 0.99[a]	10.23 ± 0.91[a]	16.61 ± 1.58[b]
18:3n-3	0.64 ± 0.07	0.58 ± 0.05	0.61 ± 0.06
20:0	0.19 ± 0.03	0.21 ± 0.02	0.19 ± 0.02
20:1	0.74 ± 0.09[ab]	0.98 ± 0.09[a]	0.64 ± 0.06[b]
20:2	0.31 ± 0.05[a]	0.40 ± 0.04[a]	0.62 ± 0.06[b]
20:4n-6	0.19 ± 0.03	0.19 ± 0.03	0.18 ± 0.02
20:5n-3	0.23 ± 0.05	0.26 ± 0.03	ND
22:1	ND	0.17 ± 0.03	ND
22:6n-3	ND	0.42 ± 0.04	ND
24:0	0.40 ± 0.09[a]	0.53 ± 0.05[a]	0.10 ± 0.02[b]
24:1	ND	1.11 ± 0.18	ND
∑SFA	47.66 ± 5.53	45.97 ± 4.09	45.06 ± 4.28
∑MUFA	43.03 ± 4.99	42.31 ± 3.77	35.80 ± 3.40
∑PUFA (n-3)	0.69 ± 0.08[a]	1.17 ± 0.10[b]	0.61 ± 0.06[a]
∑PUFA (n-6)	8.80 ± 1.02[a]	10.64 ± 0.95[a]	17.37 ± 1.65[b]
P/S	0.20 ± 0.02[a]	0.26 ± 0.02[a]	0.40 ± 0.04[b]
PUFA BAL	7.32 ± 0.85[a]	10.00 ± 0.89[b]	3.41 ± 0.32[c]

Treatment means ± SEM. Values within rows without common superscripts are statistically different ($P < 0.001$).

Table 23 Fatty acid profiles (g/100g) for muscle tissue from finisher pigs fed SFA, n-3 PUFA or n-6 PUFA

Fatty acid	Tallow (SFA)	Salmate® (n-3 PUFA)	Safflower oil (n-6 PUFA)
14:0	1.04 ± 0.11	1.09 ± 0.12	0.96 ± 0.09

16:0	21.20 ± 2.25	21.89 ± 2.32	21.82 ± 2.11
16:1	2.92 ± 0.31	2.64 ± 0.28	2.36 ± 0.23
18:0	11.06 ± 1.17	12.04 ± 1.28	12.06 ± 1.17
18:1	41.47 ± 4.40	38.36 ± 4.07	32.75 ± 3.18
18:2n-6	12.17 ± 1.29[a]	13.11 ± 1.39[a]	18.03 ± 1.75[b]
18:3n-3	0.41 ± 0.04[a]	0.49 ± 0.05[a]	0.28 ± 0.04[b]
20:1	0.70 ± 0.07	0.82 ± 0.09	0.61 ± 0.07
20:2	0.52 ± 0.05	0.52 ± 0.05	0.62 ± 0.07
20:4n-6	3.25 ± 0.34[a]	2.14 ± 0.23[b]	3.87 ± 0.38[a]
20:5n-3	ND	1.31 ± 0.14	ND
22:4	0.38 ± 0.04	ND	0.50 ± 0.05
22:5	ND	0.96 ± 0.13[a]	0.28 ± 0.05[b]
22:6n-3	0.30 ± 0.04[a]	0.86 ± 0.09[b]	0.19 ± 0.04[c]
24:0	0.47 ± 0.05[a]	0.85 ± 0.14[b]	0.51 ± 0.06[a]
∑SFA	33.85 ± 3.59	35.37 ± 3.75	35.30 ± 3.42
∑MUFA	45.11 ± 4.78	41.85 ± 4.44	35.52 ± 3.45
∑PUFA (n-3)	0.59 ± 0.16[a]	2.67 ± 0.28[b]	0.33 ± 0.04[c]
∑PUFA (n-6)	16.35 ± 1.73[a]	16.40 ± 1.74[a]	22.99 ± 2.23[b]
P/S	0.50 ± 0.05	0.54 ± 0.06	0.66 ± 0.06
PUFA BAL	3.50 ± 0.37[a]	14.01 ± 1.49[b]	1.43 ± 0.20[c]

Treatment means ± SEM. Values within rows without common superscripts are statistically different ($P < 0.001$).

Fatty acid profiles for muscle tissue from pigs fed either SFA, n-3 PUFA or n-6 PUFA are presented in Table 23. Feeding different types of fatty acids to finisher pigs did not affect the total amount of SFA and MUFA incorporated into muscle tissue as well as the polyunsaturated to saturated ratio between treatment groups. Pigs from the n-6 PUFA treatment group had significantly greater proportions of LA (18:2n-6) and total n-6 PUFA incorporated in muscle tissue compared to pigs from both the SFA and n-3 PUFA treatment groups. Additionally, feeding n-6 PUFA to finisher pigs significantly decreased total n-3 PUFA contained in muscle as well as the PUFA balance compared to both the SFA and n-3 fed treatment groups. Pigs from the SFA and n-3 PUFA treatment groups contained significantly more ALA (18:3n-3) and DHA (20:6n-3) than muscle from the n-6 PUFA treatment group. Further differences between the SFA and n-3 PUFA treatment group were also reported for PUFA balance and total n-3 PUFA with the SFA treatment groups being intermediary between the highest (n-3 PUFA) and lowest (n-6 PUFA) treatment groups. Muscle from pigs from the n-3 PUFA treatment group were the only samples where EPA (20:5n-3) was detected and furthermore

contained significantly greater amounts of 24:0 than both the SFA and n-6 PUFA treatment groups.

Experiment 2

Fatty Acid Composition of the Gestation Diets

The fatty acid composition for the experimental diets fed during gestation is given in Tables 1 and 2. The dietary fatty acid profile for the gestation diets was similar to those for Experiment 1. The tallow diet contained a greater proportion of saturated (16:0 and 18:0) and monounsaturated fatty acids (18:1) compared to the safflower oil (n-6 PUFA) or Optigen® (n-3 PUFA) diets. The safflower oil diets contained a greater proportion of LA (18:2n-6) when compared to either Optigen® or tallow whereas, the Optigen® diets contained the long-chain n-3 PUFA's EPA (20:5n-3) and DHA (22:6n-3) the concentrations of both EPA (20:5n-3) and DHA (22:6n-3) were slightly greater than that for the diets used in Experiment 1. The n-3 PUFA source used for Experiment 1 was Salmate®. Increasing the concentration of the dietary fats from 3% to 5% increased the concentration of saturated fatty acid (14:0; 16:0; 18:0) for the tallow diet, the n-6 PUFA (18:2n-6) for the safflower oil diet and the n-3PUFA (20:5n-3; 22:6n-3) for the Optigen® diet. The PUFA balance for the 3% was less for the tallow and Optigen® diets and less for the safflower oil diet when compared to the PUFA balance for 5% inclusion.

Table 1 Determined fatty acid composition (g/100g) of the 1st and 2nd trimester gestational diets

Fatty acid	3% Tallow (SFA)	3% Optigen® (n-3 PUFA)	3% Safflower oil (n-6 PUFA)
C14:0	1.25	2.46	
C16:0	20.23	20.29	19.06
C16:1	1.43	2.69	
C18:0	8.05	4.93	4.97
C18:1	32.88	29.86	20.23
C18:2(n-6)	33.69	29.91	52.82
C18:3(n-3)	2.48	2.86	2.92
C20:0		2.38	
C20:5(n-3)		1.72	
C22:0		1.57	
C22:6(n-3)		1.34	
Σ Sat	29.53	31.63	24.03
Σ Monounsat	34.31	32.55	20.23
Σ Poly n-6	33.69	29.91	52.82
Σ Poly n-3	2.48	5.92	2.92
n3:n6 (n-6:n-3)	0.074 (13.58)	0.198 (5.05)	0.055 (18.09)
P/S	1.22	1.13	2.32
PUFA Balance %	6.9	16.5	5.2

Table 2 Determined fatty acid composition (g/100g) of the 3rd trimester gestational diet

Fatty acid	5% Tallow (SFA)	5% Optigen® (n-3 PUFA)	5% Safflower oil (n-6 PUFA
C14:0	1.69	2.75	
C16:0	23.02	18.22	15.85
C16:1	1.42	3.14	
C18:0	11.93	3.99	3.97
C18:1	31.62	27.99	18.89
C18:2(n-6)	27.91	28.06	59.25
C18:3(n-3)	2.41	3.17	2.05
C20:0		2.66	
C20:5(n-3)		2.95	
C22:0		2.19	
C22:4		1.06	
C24:0		1.39	
C22:6(n-3)		2.44	
Σ Sat	36.64	31.20	19.82
Σ Monounsat	33.04	31.13	18.89
Σ Poly n-6	27.91	28.06	59.25
Σ Poly n-3	2.41	8.56	2.05
n3:n6 (n-6:n-3)	0.086 (11.58)	0.305 (3.28)	0.035 (28.90)
P/S	0.82	1.17	3.09
PUFA Balance %	7.9	23.4	3.3

Farrow Data

Litter Characteristics

Gestational length and birth weight was unaffected by fatty acid source. However, there was a differential effect of fatty acid source on litter characteristics (Table 3). Feeding n-3 PUFA and saturated fat during gestation significantly increased ($P < 0.05$) the number of piglets born alive compared to gilts fed n-6 PUFA. In addition, the number of mummified foetuses were significantly lower ($P < 0.01$) in litters of n-3 PUFA and saturated fat fed gilts compared to those gilts fed n-6 PUFA. The safflower oil diet contained a greater proportion of n-6 PUFA compared to the tuna oil or tallow diets whereas the tuna oil diet contained a greater proportion of n-3PUFA compared to safflower oil or tallow diets (Table 3).

Table 3 Litter characteristics from gilts fed tuna oil (n-3 PUFA), safflower oil (n-6 PUFA) or tallow (saturated fatty acids) and total levels of n-3 and n-6 PUFA for 3% and 5% fat enriched diets.

Treatment	Born alive/ litter	Still born/ litter	Mummified Foetus/litter	Total born/ litter	n-3 PUFA (3% & 5%)	n-6 PUFA (3% & 5%)
n-3 PUFA	11.2[a]	0.70	0.12[a]	11.88	5.9 & 8.9	9.9 & 28.1[2]
n-6 PUFA	9.19[b]	1.53	1.05[b]	10.77	2.9 & 2.1	52.8 & 59.3
Saturated	11.0[ab]	1.14	0.21[a]	12.16	2.5 & 2.4	33.7 & 27.9
SEM	0.48	0.20	0.14	0.57		
P-value	0.054	0.203	0.002	0.331		

Means within columns with different superscripts differ significantly

Fatty Acid Composition of the Lactation Diets

The fatty acid composition of the lactation diets is given in Table 4. The fatty acid profile for the 3 experimental diets was similar of that for the gestation diets. The tallow diet contained a greater proportion of saturated (16:0 and 18:0) and monounsaturated fatty acids (18:1) compared to the safflower oil (n-6 PUFA) or Optigen® (n-3 PUFA) diets. The safflower oil diets contained a greater proportion of linoleic acid (18:2n-6) when compared to either Optigen® or tallow whereas, the Optigen® diets contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6

Table 4 Determined fatty acid composition (g/100g) of the lactation diet

Fatty acid	4% Tallow (SFA)	4% Optigen® (n-3 PUFA)	4% Safflower oil (n-6 PUFA)
C14:0	1.87	3.07	
C16:0	20.86	18.01	16.77
C16:1	1.76	3.53	
C18:0	10.32	4.00	3.94
C18:1	32.09	25.26	16.69
C18:2(n-6)	29.03	27.76	56.69
C18:3(n-3)	2.69	3.82	3.22
C20:0		2.72	
C20:5(n-3)		3.50	
C22:0		2.17	
C24:0		1.74	
C22:6(n-3)		2.47	
Σ Sat	33.05	31.71	20.71
Σ Monounsat	33.85	28.79	16.69
Σ Poly n-6	29.03	27.76	56.69
Σ Poly n-3	2.69	9.79	3.22
n-6:n-3	10.79	2.84	17.61
P/S	0.96	1.18	2.89
PUFA Balance %	2.69	9.79	3.22

Table 5 Body weight (Kg) of progeny fed n-3, n-6 PUFA or saturated fatty acids during lactation

Treatment	Farrow	Day 1	Day 7	Day 14	Day 21	Wean
Optigen® (n-3 PUFA)	1.32 ± 0.03	1.42 ± 0.03	2.38 ± 0.06	3.40 ± 0.11	4.61 ± 0.15	5.00 ± 0.15[a]
Safflower oil (n-6 PUFA)	1.37 ± 0.05	1.51 ± 0.04	2.39 ± 0.07	3.55 ± 0.09	4.97 ± 0.13	5.47 ± 0.14 [b]
Tallow (SFA)	1.36 ± 0.04	1.50 ± 0.05	2.37 ± 0.09	3.63 ± 0.16	5.16 ± 0.20	5.62 ± 0.21 [b]

Means within columns with different superscripts differ significantly

Body weight for progeny fed the three fatty acid sources during the period of lactation is given in Table 5. There was no significant difference for body weight of pigs from gilts fed the 3 dietary fatty acid sources at the time of farrow. However, the body weight of progeny for gilts fed n-3 PUFA was lower at days 14 and 21 and was significantly reduced ($P<0.05$) at wean when compared to progeny from gilts fed n-6 PUFA or saturated fatty acids. This result suggests that the feeding of n-3 PUFA to gilts throughout gestation and lactation may negatively impact on body weight of progeny at the time of wean.

Table 6 P2 measurement (mm) from gilts fed n-3, n-6 PUFA or saturated fatty acids during lactation

Treatment	Farrow	Day 7	Day 14	Day 21	Wean	% Δ Farrow to wean
Optigen® (n-3 PUFA)	18.2 ± 0.5	18.1 ± 0.5	18.1 ± 0.5	17.9 ± 0.4	17.4 ± 0.4	4.4%
Safflower oil (n-6 PUFA)	17.0 ± 0.6	16.5 ± 0.6	16.7 ± 0.5	15.8 ± 0.6	16.1 ± 0.7	5.3%
Tallow (SFA)	16.6 ± 0.6	16.4 ± 0.8	16.8 ± 0.6	15.8 ± 0.7	15.9 ± 0.6	4.2%

The P2 measurement for gilts fed the 3 dietary sources of fatty acids over the period of lactation is shown in Table 6. The percent change in P2 from the time of farrow to wean was similar for gilts fed n-3 PUFA or saturated

fatty acids (4.4% and 4.2% respectively), whereas the percent change in P2 for gilts fed n-6 PUFA was approximately 1% greater (5.3%) when compared to gilts fed either n-3 PUFA or saturated fatty acids. This result suggests that gilts fed n-6 PUFA mobilize a greater proportion of fat during the period of lactation when compared to gilts fed either n-3 PUFA or saturated fatty acids.

Fatty Acid Composition of the Weaner Diets

The fatty acid composition of the weaner diets is given in Table 7. The fatty acid profile for the 3 experimental diets was similar of that for the gestation /lactation diets. The tallow diet contained a greater proportion of saturated (16:0 and 18:0) and monounsaturated fatty acids (18:1) compared to the safflower oil (n-6 PUFA) or Optigen® (n-3 PUFA) diets. The safflower oil diets contained a greater proportion of linoleic acid (18:2n-6) when compared to either Optigen® or tallow whereas, the Optigen® diets contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6. The n-3:n-6 ratio and the PUFA balance was greater for the Optigen® diet and lowest for the Safflower oil diet while intermediary for the tallow diet.

Table 7 Determined fatty acid composition (g/100g) of the weaner diets

Fatty acid	3% Tallow (SFA)	3% Optigen® (n-3 PUFA)	3% Safflower oil (n-6 PUFA)
C14:0	1.82	2.99	
C16:0	21.89	21.20	20.49
C16:1	1.67	3.01	
C18:0	12.75	8.97	9.66
C18:1	32.99	27.52	23.61
C18:2(n-6)	24.37	23.71	40.74
C18:3(n-3)	2.73	2.97	2.93
C20:0		2.23	
C20:5(n-3)		3.09	
C22:0		1.66	2.52
C22:6(n-3)		2.66	
Σ Sat	36.46	37.05	32.67
Σ Monounsat	34.66	30.53	23.61
Σ Poly n-6	24.37	23.71	40.74
Σ Poly n-3	2.73	8.72	2.93
n-6:n-3	8.93	2.72	13.90
P/S	0.74	0.88	1.34
PUFA Balance %	9.2	26.89	6.7

Body Weight throughout Weaning

Body weight for progeny fed the three fatty acid sources during the period of weaning is given in Table 8. The rate of gain from the day of wean until the move to grower pens was greater for pigs consuming the n-3 or n-3/tallow diets (13.2 and 13.7 kg respectively) with the ADG being similar for pigs fed the saturated fatty acid diet (12.9 kg). However, the rate of gain for pigs fed the n-6/tallow diet was reduced (11.8 kg) and

substantially reduced for pigs fed the n-6 PUFA diet when compared to pigs fed the n-3 PUFA, n-3/tallow or saturated fatty acid diets.

Table 8 Body weight (kg) of progeny fed n-3, n-6 PUFA or saturated fatty acids throughout weaning

Treatment	Wean +7 days	Wean +14 days	Wean +21 days	Wean +28 days	Move to group pens	Gain Wean to Move
n-3 PUFA	5.49 ± 0.14	7.58 ± 0.25	10.36 ± 0.36	14.74 ± 0.39	18.20 ± 0.45	13.2 kg
n-3/Tallow	5.69 ± 0.20	7.73 ± 0.33	11.43 ± 0.39	15.85 ± 0.47	18.74 0.61	13.7 kg
n-6 PUFA	5.50 ± 0.05	7.37 ± 0.30	9.93 ± 0.36	12.87 ± 0.43	14.54 ± 0.57	9.1 kg
n-6/Tallow	5.90 ± 0.29	8.35 ± 0.41	10.49 ± 0.60	13.99 ± 0.72	17.24 ± 0.84	11.8 kg
Saturated (Tallow)	5.74 ± 0.25	7.63 ± 0.33	11.00 ± 0.41	15.52 ± 0.43	18.54 ± 0.52	12.9

Fatty Acid Composition of the Pancreas (Day 28 post-wean)

The fatty acid composition of the pancreas at Day 28 post-wean is shown in Table 9. The effect of feeding the saturated diet for 28 days to pigs fed either n-6 PUFA or n-3 PUFA altered the fatty acid profile when compared to the pancreas of their n-6 PUFA or n-3 PUFA counterparts who were maintained on the PUFA diets. The proportion of the n-6 PUFA LA (18:2n-6) and AA (20:4n-6) were substantially reduced in the pancreas of the n-6 PUFA pigs fed the tallow diet when compared to pigs maintained on the n-6 PUFA diet. Similarly, the n-3 PUFAs EPA (20:5n-3) and DHA (22:6n-3) were considerably reduced in pigs fed the saturated fatty acid diet at wean when compared to their n-3 PUFA counterparts.

Table 9 Determined fatty acid composition (g/100g) of the pancreas (Day 28 post-wean)

	SFA	n-3 PUFA	n-3 PUFA / SFA	n-6 PUFA	n-6 PUFA / SFA
14:0	0.76 ± 0.1	0.89 ± 0.1	0.93 ± 0.1	0.98 ± 0.1	0.88 ± 0.1
16:0	18.10 ± 2.2	18.10 ± 1.7	18.23 ± 1.9	16.89 ± 2.1	18.95 ± 2.3
16:1	5.72 ± 0.70[b]	3.00 ± 0.28[a]	4.14 ± 0.45[ab]	3.61 ± 0.44[ab]	4.30 ± 0.5[b]
17:0	0.84 ± 0.1	0.75 ± 0.1	0.83 ± 0.1	0.70 ± 0.1	0.66 ± 0.1
18:0	11.06 ± 1.4	11.62 ± 1.1	10.87 ± 1.2	11.93 ± 1.5	11.03 ± 1.4
18:1	30.72 ± 3.7	29.40 ± 2.7	32.79 ± 3.6	23.69 ± 2.8	31.88 ± 3.8
18:2	15.69 ± 1.9[a]	17.53 ± 1.6[a]	15.06 ± 1.6 [a]	25.79 ± 3.1[b]	17.29 ± 2.1[a]
18:3	1.24 ± 0.1	1.25 ± 0.1	1.17 ± 0.1	1.22 ± 0.1	1.15 ± 0.1
20:0	0.50 ± 0.1	0.69 ± 0.1	0.88 ± 0.1	0.53 ± 0.0	0.47 ± 0.1

20:1	0.50 ± 0.1	0.79 ± 0.10		0.74 ± 0.1	0.69 ± 0.1
20:2	0.61 ± 0.1	0.59 ± 0.1	0.58 ± 0.1	0.86 ± 0.1	0.61 ± 0.1
20:3			0.40 ± 0.1	0.70 ± 0.1	0.73 ± 0.2
20:4	4.48± 0.6	2.36 ± 0.2	2.68 ± 0.3	5.56 ± 0.7	4.37 ± 0.5
20:5		3.37 ± 0.3	0.82 ± 0.1		
22:4				0.55 ± 0.1	0.55 ± 0.1
22:6	0.56 ± 0.1	1.36 ± 0.1	0.86 ± 0.1	0.89 ± 0.2	
24:0	0.65 ± 0.1	1.31 ± 0.1	0.87 ± 0.1	0.58 ± 0.1	0.57 ± 0.1
24:1			0.55 ± 0.1		
∑SFA	31.69 ± 3.9	32.92 ± 3.0	32.23 ± 3.5	31.06 ± 3.8	31.82 ± 3.9
∑MUFA	36.71 ± 4.4	33.18 ± 3.1	38.02 ± 4.1	27.94 ± 3.4	36.60 ± 4.5
∑PUFA (n-3)	1.81 ± 0.2	6.17 ± 0.7	2.88 ± 0.3	1.36 ± 0.2	1.15 ± 0.1
∑PUFA (n-6)	20.80 ± 2.5	20.47 ± 1.9	18.16 ± 1.9	32.85 ± 4.0	22.42 ± 2.7
n-6:n-3	11.51 ± 1.4	3.32 ± 0.3	6.30 ± 0.7	24.12 ± 2.9	19.49 ± 2.4
P/S	0.71 ± 0.1	0.81 ± 0.1	0.65 ± 0.1	1.11 ± 0.1	0.74 ± 0.1
PUFA BAL%	7.99 ± 0.9	22.99 ± 2.1	13.69 ± 1.5	3.96 ± 0.5	4.88 ± 0.6

Data within columns without common superscripts are significantly different P< 0.001

Fatty Acid Composition of the Grower/Finisher Diets

The fatty acid composition of the grower and finisher diets is given in Tables 10 and 11 respectively. The fatty acid profile for the experimental diets was similar to the weaner diets. The tallow diet contained a greater proportion of saturated (16:0 and 18:0) and monounsaturated fatty acids (18:1) compared to the safflower oil (n-6 PUFA) or Optigen® (n-3 PUFA) diets. The safflower oil diets contained a greater proportion of linoleic acid (18:2n-6) when compared to either Optigen® or tallow whereas, the Optigen® diets contained the long-chain n-3 PUFA's EPA 20:5 and DHA 22:6.

Table 10 Determined fatty acid composition (g/100g) of the grower diets

Fatty acid	3% Tallow (SFA)	3% Optigen® (n-3 PUFA)	3% Safflower oil (n-6 PUFA)
C14:0	1.74	2.36	
C16:0	22.67	18.11	15.22
C16:1	1.42	2.58	
C18:0	12.47	3.83	3.46
C18:1	30.92	23.94	18.18
C18:2(n-6)	25.80	33.65	59.56
C18:3(n-3)	2.54	3.53	2.92
C20:0		2.08	
C20:5(n-3)		2.71	
C22:0		0.59	
C22:1		1.74	
C24:0		1.42	

C22:6(n-3)		2.53	
Σ Sat	36.88	37.05	18.68
Σ Monounsat	32.34	30.53	18.18
Σ Poly n-6	25.80	23.71	59.56
Σ Poly n-3	2.54	8.72	2.92
n-6:n-3	10.16	2.72	20.40
P/S	0.77	0.88	3.34
PUFA Balance %	9.0	20.7	4.7

Table 11 Determined fatty acid composition (g/100g) of the finisher diets

Fatty acid	3% Tallow (SFA)	3% Optigen® (n-3 PUFA)	3% Safflower oil (n-6 PUFA)
C14:0	1.79	2.69	
C16:0	23.01	18.31	15.39
C16:1	1.44	3.08	
C18:0	12.42	3.77	3.56
C18:1	31.61	25.62	19.95
C18:2(n-6)	26.14	31.45	58.93
C18:3(n-3)	2.19	3.09	2.34
C20:0		2.55	
C20:5(n-3)		3.18	
C22:1		1.85	
C24:0		1.27	
C22:6(n-3)		3.14	
Σ Sat	37.22	28.59	18.95
Σ Monounsat	33.05	30.55	19.95
Σ Poly n-6	26.14	31.45	58.93
Σ Poly n-3	2.19	9.41	2.34
n-6:n-3	11.94	3.34	25.18
P/S	0.76	1.43	3.23
PUFA Balance %	7.7	23.0	3.8

Voluntary Feed Intake of Finisher Pigs

Results for treatment mean average daily feed intakes for the finisher experimental period are shown in Table 12. Pigs fed n-6 PUFA consumed significantly (P = 0.009) less feed during days 0-14 of the recording period than all other treatment groups. Pigs from the n-3 PUFA treatment group consumed significantly less feed throughout the second recording period (14-27) than pigs from both the n-3PUFA/SFA and SFA treatment groups. Additionally, pigs from the n-6 PUFA treatment groups consumed less feed than all other treatment groups for this same period.

Table 12 Feed intake (Kg/day) of finisher pigs fed diets containing either SFA, n-3 PUFA or n-6 PUFA fat sources.

Period	SFA	n-3 PUFA	n-3 PUFA/ SFA	n-6 PUFA	n-6 PUFA/ SFA
0-14	2.77 ± 0.15^{a}	3.01 ± 0.15^{a}	2.70 ± 0.16^{a}	2.11 ± 0.27^{b}	2.72 ± 0.17^{a}
14-27	3.15 ± 0.15^{a}	2.45 ± 0.15^{b}	3.04 ± 0.16^{a}	1.96 ± 0.27^{c}	2.72 ± 0.17^{ab}

0-27	2.91 ± 0.14^{a}	2.66 ± 0.13^{a}	2.76 ± 0.14^{a}	2.03 ± 0.16^{b}	2.67 ± 0.14^{a}

Data are presented as treatment means ± SEM. Means within rows without common superscripts are significantly different P = 0.009.

Feed to Gain of Finisher Pigs

Treatment mean feed to gain results for the finisher period are presented in Table 13. No significant differences between treatment groups were found for the first recording period (0-14 days). During the second recording period (14-27 days), feeding dietary n-3 PUFA to pigs resulted in a significantly reduced feed to gain compared to SFA, n-3 PUFA/SFA and n-6 PUFA treatment groups. Additionally, pigs from the n-6 PUFA/SFA treatment group consumed significantly ($P < 0.05$) less feed per unit gain in live bodyweight than their littermates from the n-6 PUFA fed group.

Table 13 Treatment mean feed to gain (Kg:Kg) for finisher stage pigs fed dietary SFA, n-3 PUFA or n-6 PUFA.

Period	SFA	n-3 PUFA	n-3 PUFA/ SFA	n-6 PUFA	n-6 PUFA/ SFA
0-14	2.42 ± 0.32	2.52 ± 0.32	2.55 ± 0.33	2.80 ± 0.48	2.49 ± 0.33
14-27	3.12 ± 0.40^{ac}	2.23 ± 0.29^{b}	3.16 ± 0.42^{ac}	3.89 ± 0.69^{a}	2.64 ± 0.35^{bc}
0-27	2.86 ± 0.21^{a}	2.52 ± 0.19^{a}	2.82 ± 0.21^{a}	3.55 ± 0.34^{b}	2.60 ± 0.20^{a}

Data are presented as treatment means ± SEM. Means within rows without common superscripts are significantly different $P < 0.05$.

Live body weight

Results for treatment mean live body weight during the finisher phase are listed in Table 14. All treatment groups showed significant ($P < 0.001$) growth throughout the experimental period. The n-6 PUFA treatment group commenced the experimental period significantly lighter than the other treatment groups, a relationship that did not change at the two successive time points. The n-3 PUFA treatment group was also significantly lighter when compared to the SFA treatment group at the commencement of the experiment; however this difference did not persist with time. No other significant differences between treatment groups were found.

Table 14 Treatment mean live body weight (Kg) of finisher stage piglets fed dietary SFA, n-3 PUFA or n-6 PUFA.

Day	SFA	n-3 PUFA	n-3 PUFA/ SFA	n-6 PUFA	n-6 PUFA/ SFA
0	67.32 ± 3.74^{a}	61.28 ± 3.72^{b}	62.82 ± 3.79^{ab}	47.86 ± 4.31^{c}	63.26 ± 3.81^{ab}
14	82.53 ± 3.74^{a}	77.66 ± 3.72^{a}	77.88 ± 3.79^{a}	59.35 ± 4.36^{b}	78.84 ± 3.81^{a}
27	95.39 ± 3.74^{a}	89.99 ± 3.72^{a}	89.69 ± 3.79^{a}	64.55 ± 4.36^{b}	91.49 ± 3.81^{a}

Data are presented as treatment means ± SEM. Means within rows without common superscripts are significantly different $P < 0.001$.

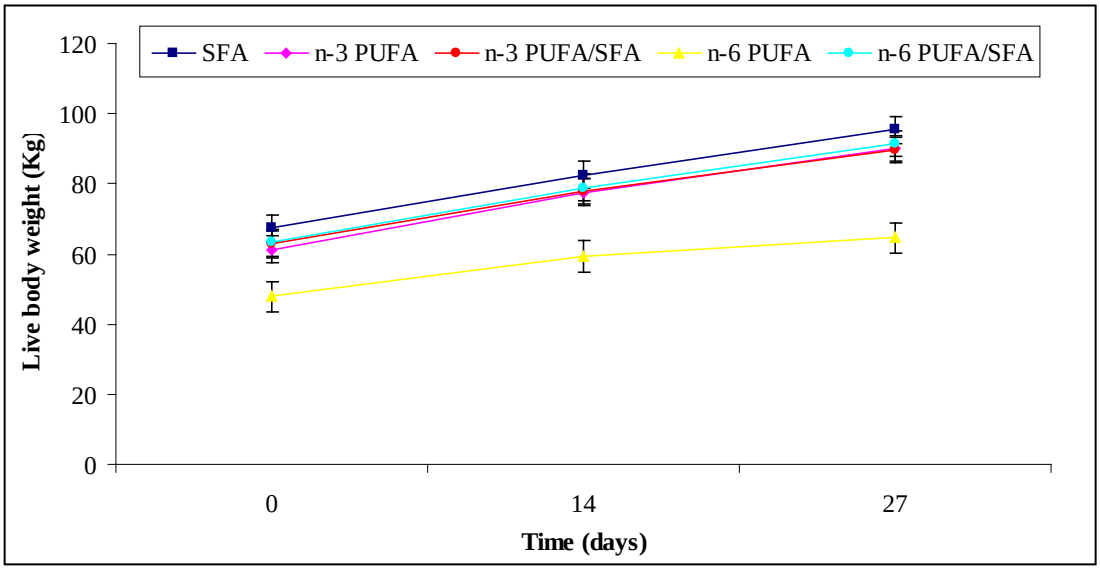


Figure 1 Live body weight of finisher pigs fed SFA, n-3 PUFA or n-6 PUFA for 27 days

Average Daily Gain

The results for average daily gain during the finisher phase are presented in Table 15. Pigs from the n-6 PUFA treatment group, on average, grew significantly ($P < 0.001$) less than pigs from all other treatment groups during all three time points (0-14, 14-27 and 0-27 days). No other significant differences between treatment groups were reported.

Table 15 Treatment mean average daily gain (Kg/day) for finisher stage pigs fed dietary SFA, n-3 PUFA or n-6 PUFA.

Period	SFA	n-3 PUFA	n-3 PUFA/ SFA	n-6 PUFA	n-6 PUFA/ SFA
0-14	1.14 ± 0.08^{a}	1.17 ± 0.08^{a}	1.04 ± 0.08^{a}	0.76 ± 0.08^{b}	1.08 ± 0.08^{a}
14-27	0.97 ± 0.07^{a}	0.93 ± 0.07^{a}	0.98 ± 0.07^{a}	0.53 ± 0.07^{b}	0.95 ± 0.07^{a}
0-27	1.04 ± 0.05^{a}	1.07 ± 0.05^{a}	1.00 ± 0.05^{a}	0.61 ± 0.07^{b}	1.04 ± 0.05^{a}

Data are presented as treatment means ± SEM. Means within rows without common superscripts are significantly different $P < 0.001$.

Carcass measurements

The results for P2 back fat measured at the cessation of the finisher phase experiment are presented in Table 16. The n-3 PUFA treatment group had significantly ($P < 0.001$) greater back fat depth at the P2 site than both the n-3 PUFA/SFA and n-6 PUFA/SFA treatment groups. The n-6 PUFA treatment group had significantly ($P < 0.001$) less back fat than all other treatment groups. Feeding n-6 PUFA to finisher pigs resulted in leg fat being significantly ($P < 0.001$) reduced when compared to all the other treatment groups. In addition, pigs from

the SFA and n-3 PUFA treatment groups had significantly ($P < 0.001$) greater amounts of leg fat than pigs from the n-6 PUFA/SFA group.

Table 16 Carcass composition values for pigs at the completion of the finisher phase fed dietary SFA, n-3 PUFA or n-6 PUFA.

Treatment	P2 Back fat (mm)	Leg Fat (mm)
SFA	9.57 ± 0.39^{ab}	12.49 ± 0.65^{a}
n-3 PUFA	10.76 ± 0.43^{a}	13.05 ± 0.65^{a}
n-3 PUFA/SFA	9.34 ± 0.40^{b}	12.15 ± 0.66^{ac}
n-6 PUFA	6.43 ± 0.46^{c}	7.33 ± 0.65^{b}
n-6 PUFA/SFA	8.65 ± 0.38^{b}	10.38 ± 0.58^{c}

Data are presented as treatment means ± SEM. Means within columns without common superscripts are significantly different $P < 0.001$.

Carcass composition

Data from processing at the abattoir are presented in Table 17. Pigs fed n-6 PUFA had significantly lower ($P < 0.001$) HSCW and dress weight percentage ($P = 0.006$) than pigs from all other treatment groups. Depth of loin muscle was significantly ($P < 0.001$) lower for the n-6 PUFA treatment group and all other treatment groups as well as in pigs fed n-3 PUFA when compared to pigs from the SFA treatment group. Determination of back fat depth at the P2 site revealed that pigs from the n-6 PUFA treatment group had significantly ($P < 0.001$)less back fat than all other treatment groups. Additionally, significant differences were found between the n-6 PUFA/SFA and both the n-3 PUFA and n-3 PUFA/SFA treatment groups.

Table 17 Carcass composition values for finisher pigs fed dietary SFA, n-3 PUFA or n-6 PUFA during the finisher phase

Treatment	HSCW (Kg)	Dress Weight (%)	Loin depth (mm)	P2 Back fat (mm)
SFA	71.81 ± 3.30^{a}	75.79 ± 0.53^{a}	51.52 ± 1.34^{a}	9.48 ± 0.51^{ab}
n-3 PUFA	67.22 ± 3.02^{a}	74.89 ± 0.52^{a}	46.99 ± 1.17^{b}	10.72 ± 0.57^{ab}
n-3 PUFA/SFA	66.82 ± 3.07^{a}	74.74 ± 0.60^{a}	49.45 ± 1.34^{ab}	10.14 ± 0.58^{ab}
n-6 PUFA	47.13 ± 2.69^{b}	72.60 ± 0.80^{b}	41.43 ± 1.82^{c}	5.44 ± 0.51^{c}
n-6 PUFA/SFA	67.90 ± 3.19^{a}	75.19 ± 0.60^{a}	49.50 ± 1.39^{ab}	8.41 ± 0.49^{a}
P-value	< 0.001	0.006	< 0.001	< 0.001

Data are presented as treatment means ± SEM. Means within columns without common superscripts are significantly different.

Mortality and "Off Trial" Pigs

Frequency of mortalities and animals removed off trial are presented in Table 18. There was no significant difference in the incidence of animals removed off trial between treatment groups however, animals from the n-6 PUFA treatment group were 13 times more likely ($P = 0.003$) to die than pigs fed SFA and 12.5 times more

likely than pigs from the n-3 PUFA group. No mortalities were reported for the n-6PUFA/SFA treatment group.

Table 18 Total pig mortality and pigs taken "off trial" from weaning to end of finisher period

Item	SFA	n-3 PUFA	n-3 PUFA/ SFA	n-6 PUFA	n-6 PUFA/ SFA
Off trial	2	1	0	4	2
Mortalities	1	1	2	6	0
Survived	23	20	11	20	24

Application of Research

PHASE 1 Interval Feeding

Summary of Results

A significant observation from this study has been the substantial reduction in feed intake but similar body weight resulting in an improved feed to gain for pigs fed for two hourly periods, one in the morning and one in the afternoon compared to pigs fed *ad libitum*. We observed an 8% reduction in average daily feed intake and a 10% improvement in feed efficiency when pigs were fed twice daily compared to the *ad libitum* fed controls. This finding is consistent with recent studies by Scrimgeour *et al.* (2008) who reported pigs fed twice daily consumed 87 % of *ad libitum* intakes of individually housed animals. A second important finding has been the difference in energy partitioning for pigs on the two feeding regimens. Feeding pigs phasically significantly decreased the percentage of fat deposited in the carcass and significantly increased the percentage of muscle. These changes were associated with distinct differences in the plasma insulin secretory profile. Insulin secretion for the phasic fed pigs resulted in a substantial spike in plasma insulin following the onset of each feeding period, whereas there was no significant difference in circulating insulin concentrations over the 24 h period for pigs fed *ad libitum.* The difference in the insulin secretory profile between the two treatment groups could modify insulin action and provide a link between feeding pattern and the way the pig partitions energy.

The results from this study suggest that bi-phasic feeding could significantly impact on the cost of production by improving herd feed efficiency through improved grower/finisher feed efficiency. The predicted adoption strategies have been calculated and are listed as follows:

- Benefit COP (c/kg) 0.20
- Chance of success 80%
- Ease of adoption 50%
- On farm problem 100%

Studies are currently being evaluated for commercialization of this feeding strategy into industry (Pork CRC Project 2G 108 – Biphasic feeding) at Rivalea, Corowa NSW. The project will be undertaken over a 12 month period and will involve three experiments two will involve the use of the electronic feeders to determine feeding behaviour, individual feed intakes, growth performance and feed efficiency. In addition, the repeatability of the results in group housed pigs will also be assessed. The 3rd experiment will involve pigs fed either twice daily or *ad libitum* and will be conducted in single pens to determine feed efficiency. In addition, a subsample will be selected for serial blood collection to determine differences in glucose/insulin metabolism and growth hormone status.

PHASE 2 Dietary Fatty Acids

Summary of Results

Two major studies were performed using dietary fatty acids to modulate production. These experiments were conducted at NSW Department of Primary Industries, EMAI and at Rivalea Australia, Corowa. In these studies, dietary fatty acids from the n-3 and n-6 PUFA series were given to gilts prior to mating and then continued throughout the period of gestation. These same fatty acid diets were then fed to the female progeny from these gilts. We observed selectivity for fatty acid incorporation into tissues that was dietary dependent. On the whole, tissues (brain, fat, muscle and pancreas) from pigs fed the n-3 PUFA diet contained a high proportion of n-3 PUFA specifically EPA (20:5n-3) and DHA (22:6n-3) whereas tissues from pigs fed the n-6 PUFA diet contained a high proportion of n-6 PUFAs LA (18:2n-6) and AA (20:4n-6) with tissues from pigs fed the more saturated diet contained a greater proportion of saturated fatty acids. The changes in fatty acid profile induced by the type of dietary fat are consistent with previous studies conducted in chickens (Newman *et al*. 2002) and pigs (Enser *et al*. 2000; Lauridsen *et a*l. 2007).

The results from both studies show that dietary fatty acids are readily incorporated into the tissues of the pig and have developmental and metabolic roles that are over and above their influence on energy density of the diet. Our studies show that n-3 and n-6 PUFA are important in the control of growth and development for both the fetus and the growing piglet particularly when fed in a commercial environment. These studies have shown differential effects of fatty acid source with major effects on reproduction, cognitive development, energy utilization, adaptation to weaning, gastrointestinal microflora distribution and the modulation of production performance throughout the grower/finisher phases. On the whole, diets containing a higher proportion of n-6 PUFA were shown to have a detrimental effect on growth and development while diets containing a higher proportion of n-3 PUFA had a more positive role.

The data from both experiments show that diets containing n-3 PUFA had a high PUFA balance and a low n-6PUFA:n-3 PUFA ratio whereas, diets containing n-6 PUFA had a considerably lower PUFA balance and a high n-6 PUFA:n-3 PUFA ratio while diets containing tallow were intermediate. Recent studies conducted at Wollongong University by Abbott and co workers (2009) have shown a dietary requirement for a PUFA balance of 10% for “normal” biological functioning. They suggested that a dietary PUFA balance <10% will result in the PUFA content of membranes behaving like a “perfect conformer” to the diet. This work also demonstrated that it

was the PUFA balance that was critical to this function and not the individual fatty acid subtypes. Our recent studies also suggest that this requirement for a PUFA balance of 10% may also be necessary for "normal" biological functioning for the pig. This is indicated by a dramatic increase in n-6 PUFA and a subsequent decrease in n-3 PUFA and may explain why pigs fed the n-6 PUFA diet from gestation through to the end of the finisher period displayed pronounced mortalities. The PUFA balance of the n-6 PUFA diet was considerably lower than 10% indicating a severe imbalance in the essential fatty acids required for normal function. Our results showed no significant differences for most of the biological variables that we measured for the tallow and n-3 PUFA fed pigs. The PUFA balance for the tallow diet was in the order of 10% and the PUFA balance for the n-3 PUFA diet was well in excess of this value. Although our data suggest that a PUFA balance of 10% may provide optimal performance we do not have conclusive evidence of the performance of animals between 5 and 10% PUFA balance and as such consider this area of research to be of high importance.

The importance of supplying specific dietary fatty acids during gestation has been demonstrated in our first study conducted at EMAI where we have shown that the fetus has a high requirement for specific fatty acid subtypes from both n-3 and n-6 PUFA series. The two principal fatty acids we have identified as being of significant importance are docasahexaenoic acid (DHA 22:6n-3) and arachidonic acid (AA 20:4-n6) with both having an incorporation rate of approximately 10%. These two fatty acid subtypes were identified from the brains of day old piglets and were both significantly incorporated into brains of all piglets fed all 3 dietary treatments, n-3 PUFA, n-6 PUFA and saturated fat diets and this was regardless of dietary treatment. The rate of incorporation of these two fatty acids was dietary dependent with the highest incorporation of DHA (22:6n-3) found in piglets fed the n-3 PUFA diet and this was at the expense of AA (20:4-n6). These findings concur with those of Rooke *et al*. (1998) (2000) who showed significant increases in the incorporation of long chain n-3 PUFA (EPA 20:5n-3 and DHA 22:6n-3) in piglet tissues when n-3 PUFA were provided in diets of gestating sows. These data show that firstly the developing fetus has a high requirement for DHA (22:6n-3) and AA (20:4n-6). This selectivity for specific fatty acids to the fetus has been observed in other studies. Haggarty *et al* (1999) found a selective preferential transport for DHA (22:6n-3) with the following order of preference to the fetal site DHA > AA > ALA > LA. Secondly, our data also show that the synthesis of long chain n-3 PUFA subtypes maybe met by supplying dietary short chain n-3 PUFA sources such as linseed and canola oil. This finding is consistent with studies by Enser *et al*.(2000) and Kralik *et al*. (2006) who have shown in pigs that the longer chain n-3 PUFA, EPA (20:5n-3) and DHA (22:6n-3) can be synthesized from the short-chain linolenic acid (18:3n-3). Our own studies also show the production of the longer chain n-3 PUFA, specifically DHA (22:6n-3) from its short chain precursor 18:3n-3 in muscle tissue. Thus, it does appear that the gilt and or fetus in addition to the growing pig has

the capacity to synthesise the longer chain n-3 PUFAs from their shorter chain precursors.

Our data also show that the deleterious effects induced by the n-6 PUFA can be ameliorated if pigs are fed another fatty acid source at the point of wean. Pigs exposed to n-6 PUFA throughout gestation and lactation and then fed tallow at wean resulted in animals at the end of the finisher with significantly improved production characteristics compared to their n-6 PUFA fed counterparts. This dietary change in fatty acid source also produced a pig with an improved feed to gain when compared to saturated fatty acids or n-6 PUFA, a reduced P2 when compared to saturated fatty acids or n-3 PUFA and a lower mortality rate when compared to pigs fed saturated fatty acids or n-6 PUFA. The improved production performance of pigs fed the n-6 PUFA prior to weaning then fed a more saturated fatty acid diet at wean was associated with significant alterations in the fatty acid profile of the pancreas. The alteration of the fatty acid profile of the pancreas from one containing a high proportion of n-6 PUFA to one where the n-6 PUFA content was diluted to a profile resembling a more saturated one was in the order of 28 days. Our data also suggest that the timing for a change in the dietary fatty acid source to affect homeostasis appears to be critical as there is a threshold at which point a change in fatty source does not improve production characteristics. It should also be noted that the negative effects of n-6 PUFA at the time of farrow would also need to be considered particularly as this fatty acid type resulted in significantly reduced ($P<0.05$) number of piglets born alive, significantly increased mummified foetus's ($P<0.002$) as well as an increase in the number of still borns.

The growth set back for pigs fed n-6 PUFA during the period of wean we suggest to be related to the differences in the development of the gastrointestinal tract (GIT) and possibly to a heightened inflammatory response as a consequence of the consumption of a pelleted feed. The morphology of the GIT from pigs fed the three dietary fatty acid sources showed distinct differences at the time of wean. The weight of the GIT for piglets fed n-6 PUFA was significantly ($P< 0.05$) greater when compared to GIT from piglets fed either n-3 PUFA or saturated diets. In addition, the abundance of intestinal micro flora for the ileum, caecum and colon was greater for piglets fed n-6 PUFA when compared to n-3 PUFA or saturated fat fed piglets (data from undergraduate project-Heffernan 2009). The pro inflammatory cytokines such as IL-1, IL-6 and IL-8 may have also have been up-regulated in pigs fed the n-6 PUFA as a response to the change in feed from a liquid during lactation to a pellet at the point of wean. These cytokines play important roles in the up- and down-regulation of acute inflammation (Arend *et al*. 1998) and have roles in appetite regulation buy reducing feed intake (Plata-Salamán, 1993). The significant reduction in feed intake for the n-6 PUFA fed pigs may be the consequence of a greater synthesis of these cytokines as the n-6 PUFA are the pre cursors for the pro-inflammatory bioactive molecules whereas the n-3 PUFA are the precursors for the less inflammatory cytokines. Our studies have shown that pigs fed

the n-6 PUFA diet had significantly greater (P<0.001) incorporation of n-6 PUFA 18:2n-6 and 20:4n-6 into muscle when compared to muscle from either n-3 PUFA or saturated fed pigs and significantly reduced n-3 PUFA 18:3n-3 and 20:5n-3. A heightened inflammatory state for pigs fed the n-6 PUFA may have compromised these animals during the weaning period and that this pro inflammatory response may have been maintained throughout the grower/finisher phases. Our data show a significantly greater mortality (P=0.003) and a higher morbidity for pigs fed the n-6 PUFA diet when compared to either the n-3 PUFA or saturated fed pigs and that this may be indicative of a compromised immune system.

Conclusion

PHASE 1 Interval Feeding

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 improvements in feed to gain and carcass composition. The results from this experiment suggest that a phasic feeding pattern would impact favourably on commercial piggeries. However, the practicalities of the implementation of such a feeding regimen in a commercial environment will need to be explored and warrants further investigation.

PHASE 2 Dietary Fatty Acids

Dietary PUFA supplementation influences the tissue fatty acid profiles of gilts and her progeny. Supplementation with either n-3 or n-6 PUFA during gestation and lactation has differential effects on many production parameters. These fatty acids have the potential to manipulate reproductive performance and can impart negative or positive outcomes in production responses for the progeny. Our data suggest that it is the proportion of these two dietary fatty acid sources that is important rather than the individual fatty acids *per se*. The dietary n-6:n-3 ratio or the PUFA balance is critical for growth and development of the pig. A high n-6:n-3 ratio or low PUFA balance negatively impacts on reproductive performance and growth while diets with a low n-6:n-3 ratio or high PUFA balance has a positive impact. These findings highlight the practical importance of diet formulation in providing an adequate supply and balance of n-3 and n-6 PUFA during gestation, lactation and development. Feeding the correct balance of fatty acids particularly PUFA may improve reproductive performance and subsequent growth of the progeny particularly in respect to health and disease. Furthermore, the incorporation of the correct balance of essential fatty acids into the tissues of pigs may have a positive impact on the health of animals and consumers. These findings highlight the practical importance of an adequate supply and balance of n-3 and n-6 PUFA during gestation, lactation, growth and development. Dietary manipulation has considerable potential for improving the reproductive

performance of gilts and sows, and the survival, growth and development of her progeny. Thus, diet formulation using the correct combination of n-3 PUFA and n-6 PUFA should be considered as an important component for the pig industry.

Limitations/Risks

PHASE 1 Interval Feeding
The effectiveness of this feeding strategy will be determined by the feeding environment. Our initial phasic feeding experiment was carried out using single pens and as such we are unable to determine the potential of this approach in a group-housed situation. We do not envisage any risks associated with this feeding system.

PHASE 2 Dietary Fatty Acids
A possible limitation of formulating diets containing n-3 PUFA may be the cost and availability of marine sources of this fatty acid subtype. However, our studies also suggest that short chain sources of n-3 PUFA rather than long chain n-3 PUFA sources may be as equally as effective in decreasing the n-6:n-3 PUFA ratio. We do not envisage any risks using diets containing reduced n-6 PUFA and elevated n-3 PUFA sources.

Recommendations

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

- Conduct commercial trials using the phasic feeding strategy with group-housed pigs.
- Conduct experiments to determine the optimum PUFA balance for commercial production. Suggest that diets use a PUFA balance of between 5 and 10%. The proportion of n-6 PUFA should be reduced and the proportion of n-3 PUFA increased
- Recommend a higher PUFA balance for gestation diets as there is a requirement for the placenta and the developing foetus for an adequate supply of n-3 PUFA, specifically DHA 22:6n-3.
- Consider using short chain n-3 PUFA sources such as linseed or canola oil rather than long-chain n-3 PUFA sources such as tuna oil.

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Appendices

Appendix 1:

Publications Arising from this Project

SJ Wilkinson, JA Downing, K Scrimgeour, PC Thomson, LR Giles, PC Wynn and RE Newman (2007) The effect of feeding level on growth, plasma non-esterified fatty acids and urea levels in finisher pigs. *Manipulating Pig Production XI*: 197

Wilkinson SJ, Hunter R, Thomson P, Wynn PC, Downing JA and Newman RE (2008) Dietary fatty acid subtype effects cognitive development in gilt progeny. *Proceedings of the 13th Asian-Australian Association of Animal Production Societies, Hanoi, Vietnam. 22-26 September, 2008*

RE Newman, JA Downing, PC Wynn, R Taylor, PC Thomson and SJ Wilkinson (2008) Insulin secretion and body composition are influenced by the feeding pattern. *Asia Pacific Journal of Clinical Nutrition* 17: (Suppl 3): S46.

RE Newman, KR Yeung, CG Grupen, PC Thomson, JA Downing D Broek, SJ Wilkinson (2009) Dietary n-6 PUFA and n-3 PUFA have a differential effect on gilt litter characteristics. *Manipulating Pig Production XII*: (Accepted for publication)

CG Grupen, SJ Wilkinson, JA Downing, RE Newman (2009) Effects of dietary fatty acids on the secretion of metabolic hormones and ovarian activity in prepubertal pigs. *Manipulating Pig Production XII*: (Accepted for publication)

SJ Wilkinson, RD Taylor, JA Downing, PC Thomson RE Newman (2009) The effects of fatty acid subtype on performance and carcass composition in finisher pigs. *Manipulating Pig Production XII*: (Accepted for publication)

SJ Wilkinson, W Buttemer, JA Downing, PC Thomson RE Newman (2009) The effects of fatty acid subtype on performance and respiratory quotient in suckling/weaner pigs. *Manipulating Pig Production XII*: (Accepted for publication)

Appendix 2:

Dietary Crossover used in Fatty Acid Experiment 2