The effect of phase-feeding on the growth performance, carcass characteristics and nitrogen balance of growing and finishing pigs

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A completely randomised design experiment was conducted to determine if group-housed grower-finisher pigs (43.9 to 95 kg) show differences in performance and nitrogen utilisation when provided with a single high lysine diet (11 g/kg) or with a mean lysine concentration of 9.5 g/kg, either as a single diet or as a series of two or four diets. Four hundred and forty pigs were assigned to four dietary treatments. The experimental treatments were (total lysine) (1) 11 g lysine/kg from day 0 to slaughter (SHD) (2) 10.5 g/kg lysine from day 0 to day 28 and 8.5 g/kg lysine from day 29 to slaughter (DFD) (3) 9.5 g/kg lysine from day 0 to slaughter (RFD) and (4) 11 g/kg lysine from day 0 to day 14, 10 g/kg lysine from day 14 to day 28, 9.0 g/kg lysine from day 28 to day 42 and 8.0 g/kg lysine from day 42 to slaughter (PFD). The estimated lysine concentration required for treatments RFD, DFD and PFD was 9.5 g/kg for group-housed pigs. All diets were pelleted and formulated to have a net energy concentration of 9.8 MJ/kg. The pigs were group fed in mixed-sex pens using single space feeders (11 pigs/feeder, 6 boars and 5 gilts). Daily feed intake was lower ($P < 0.05$) in treatment SHD in comparison to RFD and DFD during the overall grower-finisher period (2.08 vs 2.18 and 2.23 kg/day, respectively). Lysine conversion ratio was poorer for pigs on treatment SHD compared with DFD ($P < 0.01$), RFD ($P < 0.01$) or PFD ($P < 0.001$), while food conversion ratio was better for pigs on treatment SHD compared with treatments DFD ($P < 0.01$) and PFD ($P < 0.001$) during the grower-finisher period (2.31 vs 2.43 and 2.48 kg/kg, respectively). N intake and excretion were higher ($P < 0.001$) for pigs offered SHD compared to all other treatments (3.93 vs 3.51, 3.42, 3.40 kg and 2.56 vs 2.14, 2.03, 2.10 kg for SHD vs DFD RFD and PFD for intake and excretion, respectively). N utilisation

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coefficient was lower for pigs on treatment SHD than pigs on treatments DFD ($P < 0.01$), RFD ($P < 0.001$) or PFD ($P < 0.01$). In conclusion, phase feeding did not result in any benefit to pig performance, N excretion, N utilisation or carcass characteristics when compared with a single diet that was formulated to match the animal's requirement for lysine (treatment RFD).

Keywords: excretion; nitrogen; phase feeding; pigs

Introduction

In recent times, minimising N output from pig facilities has become an important objective of legislators, producers and nutritionists. Dietary manipulation provides the opportunity to reduce the environmental impact of pig production (Jongbloed and Lenis, 1992) and this is especially true for protein sources, where the average retention of dietary N in pigs has been reported to be less than 50% (Kornegay and Verstegen, 2001).

Some producers tend to oversupply nutrients (e.g. protein and lysine) to finishing pigs (Han *et al.,* 1998) by feeding a single or perhaps two diets throughout the growing-finishing period (Lenis, 1989). Not only does protein oversupply result in increased N excretion but it can also reduce food efficiency (Tokach *et al.,* 1999). Therefore, accurate estimates of nutritional requirements are essential to optimize dietary nutrient balance and to minimize emissions. Obtaining these estimates is difficult because nutritional requirements are influenced by many factors, including genetic growth characteristics, management, and physiological status (Ferket *et al.,* 2002).

Phase feeding programs match the animal's nutrient requirements as they change with age or size and reduce the time animals are fed a deficient or excessive amount of nutrients. Boisen, Fernandez and Madsen (1991) demonstrated that N excretion could be reduced by 5 to 8% simply by increasing the number of feed phases from two to four.

The use of two diets in comparison to phase feeding has advantages in that less feed storage and management is required. In order for this strategy to be successful, accurate knowledge of the requirements of the pigs is required and more intensive management may have to be applied in order to match supply to requirement. The nutritional requirements of swine (NRC, 1998) have been defined under laboratory-type conditions where animals are well cared for and the environmental conditions are maintained as close to optimum as possible. However, these requirement data may not be applicable under field conditions where animals are housed in groups and exposed to various environmental and disease challenges.

The objectives of this experiment were: (1) to determine if group-housed pigs show differences in performance when provided with the same mean lysine concentration either as a single diet or as a series of two or four diets, (2) to compare the performance of pigs offered a single high lysine diet (11 g/kg), as is typical in Ireland, to pigs offered diets containing a lower mean lysine concentration (9.5 g/kg) either as a single diet or as a series of two or four diets, (3) to determine the effect of these feeding strategies on estimated N excretion and retention and (4) to determine the effects of these feeding strategies on carcass characteristics.

It is hypothesised that pig performance will be unaffected by feeding strategy, while lysine conversion ratio will be improved by using both a phase feeding strategy and a diet formulated to match the lysine requirements of the animal compared with a single high lysine diet. Furthermore, it is hypothesised that N excretion could be reduced by phase feeding or by matching lysine concentrations to the pig's needs.

Materials and Methods

Experimental diets

The experiment was designed as a completely randomised design comprising four dietary treatments. The experimental treatments were designed to supply (total lysine): (1) 11 g lysine/kg from day 0 to slaughter (SHD) (2) 10.5 g/kg lysine from day 0 to day 28 and 8.5 g/kg lysine from day 29 to slaughter (DFD) (3) 9.5 g/kg lysine from day 0 to slaughter (RFD) and (4) 11 g/kg lysine from day 0 to day 14, 10 g/kg lysine from day 14 to day 28, 9 g/kg lysine from day 28 to day 42 and 8 g/kg lysine from day 42 to slaughter (PFD). The estimated total lysine concentration required for treatments RFD, DFD and PFD was 9.5 g/kg lysine for group-housed pigs between 44 kg and 95 kg, based on a daily feed intake of 2.2 kg and a growth rate of 890 g/day (Reynolds and O' Doherty, 2006) using pigs of similar genotype at this Institute. The diets were formulated using standard feeding values for the ingredients to have a net energy concentration of 9.8 MJ/kg (Noblet *et al.,* 1994). All amino acid requirements were met relative to lysine (Close, 1994). All diets were pelleted (4.5 mm pellets) and delivered in individually identified 25 kg paper bags. Diet composition and nutrient analysis are presented in Table 1.

Animals and management

Four hundred and forty pigs (progeny of Landrace × Large White sows by Meatline boars) (initial weight 43.9 (s.d. ± 2.1) kg) were blocked on the basis of live weight and within each block assigned to one of four dietary treatments. The pigs were penned in mixed gender groups of 11 (6 boars and 5 females) and were stocked at 0.95 m^2 per pig with 10 pens per treatment. Mixed gender groups were used to reflect the commercial situation in Ireland. Prior to the experiment, the pigs had received standard commercial feeding and management. The house was mechanically ventilated to provide an ambient temperature of 18 °C. Each pen had a solid floor lying area with access to slats at the rear. Individual single-space feeders with water nipples were present in all pens providing an *ad libitum* supply of both food and water. Animals were individually weighed at the start of the experiment and subsequently on days 14, 28, 42 and on the morning of slaughter. Feed intake was measured by recording the feed disappearance from the feeder. Dietary transitions occurred after weighing on day 14, 28 and 42.

Carcass analysis

All the pigs were slaughtered in one batch on day 57 of the experiment. Mean slaughter weight was 95.2 kg (s.e. 1.07). Following slaughter, pigs were identified by means of an individual slap number thus allowing assignment of carcass data on an individual basis. Hot carcass weight (HCW) were measured approximately 1 h post mortem. Eye muscle depth and subcutaneous backfat were obtained by probing the right hand side of the carcass using a Hennessy Grading Probe (Hennessy and Chong, Auckland, New Zealand) at 6.5 cm from the mid-line of the split back between the 3rd and 4th last ribs. The lean meat

Table 1. Composition and nutrient analysis of experimental diets (g/kg)

Item	Diet (g/kg) lysine						
	11.0	10.5	10.0	9.5	9.0	8.5	8.0
Ingredient (kg/tonne)							
Wheat	259.7	288.6	310.6	339.2	361.4	384	411.6
Barley	300	300	300	300	300	300	300
Soyabean meal	268	242	222	196	176	156	130.7
Beetpulp	100	100	100	100	100	100	100
Soyabean oil	47.6	44.5	42.2	39	36.7	34	31.2
Dicalcium phosphate	8.8	9.1	9.4	9.8	10	10.2	10.6
Limestone	7.5	7.4	7.3	7.3	7.2	7.1	7
Salt	5	5	5	5	5	5	5
Lysine	0.7	0.7	0.9	1.2	1.2	1.2	1.4
DL-methionine	0.2	0.2	0.1	0	0	0	0
Vitamins & minerals[†]	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Analysis (g/kg)							
Crude protein	206.3	191.8	190.3	171.2	168.9	157.7	139.0
Dry matter	892.2	894.4	887.5	886.4	888.2	888.6	887.5
Ether extract	58.4	55.8	51.5	51.0	44.2	47.6	47.4
Crude ash	52.5	51.8	49.4	49.8	49.8	46.8	51.7
Neutral detergent fibre	151.8	137.7	164.9	126.5	150.9	115.8	112.9
Lysine	11	10.4	9.9	9.4	9.1	8.4	8.0
Methionine & cysteine	6.6	6.3	6.0	5.7	5.4	5.1	4.8
Threonine	7.2	6.8	6.5	6.2	5.8	5.5	5.2
Tryptophan	2.0	1.9	1.8	1.7	1.6	1.5	1.4
Calcium[a]	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Phosphorus[a]	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Net energy (MJ/kg)	9.8	9.8	9.8	9.8	9.8	9.8	9.8
DE (MJ/kg)	14.4	14.4	14.1	14.1	14.0	13.9	13.9

[†] The premix gave the following dietary concentrations: Vitamin A 10,000 iu.kg^{-1}, Vitamin D_3 2,000 iu.kg^{-1}, Vitamin E (as α-tocoperol) 60 iu.kg^{-1}, Cu as $CuSO_4$ 90 mg/kg, Fe (as $FeSO_4$) 100 mg/kg, Zn (as ZnO_4) 100 mg/kg, Se (as NaSe) 0.3 mg/kg, Mn (as MnO) 25 mg/kg and I (as $Ca(IO_3)_2$) 0.2 mg/kg on a $CaSO_4/CaCO_3$ carrier.

[a] Calculated from proximate analysis (Ministry of Agriculture, Fisheries and Food, 1991).

concentration was estimated according to the following formula (Department of Agriculture and Food, (Ireland), 1994):

Estimated lean meat (g/kg) = 534.1 – 7.86x + 2.66y,

where x = fat depth (mm) and y = muscle depth (mm).

Maximum protein deposition rate (Pd_{max} kg/day) was determined using the method of Moughan (1995). Further carcass data were calculated by application of the following equations:

Carcass weight (CW) (kg) = HCW × 0.98

Kill-out proportion (g/kg) = CW/Live weight × 100

Carcass daily gain (kg/day) = ((CW–(initial live weight × 0.65))/days to slaughter

Carcass FCR = total feed intake/total carcass gain

Carcass nitrogen analysis

Nitrogen balance analysis was based on the comparative slaughter technique. N intake was calculated by multiplying overall crude protein intake by 0.16. Lean meat N gain was calculated as the difference in estimated final meat N content [Carcass weight × lean meat proportion × 0.22 (22% protein in lean, (Whittemore, 1998)) × 0.16 minus initial lean meat nitrogen content [initial lean × 0.22 × 0.16]. Initial carcass lean meat content was estimated by multiplying initial weight by 0.675 and 0.65 to adjust to carcass weight and to estimate lean meat content of the carcass (Bikker *et al.,* 1996). Lean meat N gain represents 0.57 of body N content (NRC, 1998), thus dividing lean meat N by 0.57 gives body N gain. Daily N retention was estimated by dividing body N gain by the number of days to slaughter. Daily protein deposition was calculated by multiplying daily N deposition by 6.25. N excretion was estimated by subtracting overall body N content from overall N intake.

Laboratory analysis of samples

The dry matter of the feed was determined following drying for 72 h at 55 °C according to the Association of Analytical Chemists (1995). The dried concentrates were milled through a 1 mm screen (Christy and Norris hammer mill) and analysed for ash after ignition of a known weight of concentrate in a muffle furnace (Nabertherm, Bremen, Germany) at 500 °C for 4 h. Dietary crude protein concentration was determined as Kjeldahl N × 6.25 using the LECO FP 528 instrument (Leco Instruments, UK Ltd., Cheshire). Neutral detergent fibre was determined by the method of Van Soest, Robertson and Lewis (1991). Ether extract (EE) was determined using the 1043 Soxtec System HT6 as derived from the Soxhlet method. The gross energy (GE) was determined using an adiabatic bomb calorimeter (Parr, Illinois, USA). Dietary amino acid concentrations were determined using the method of Iwaki *et al*. (1987). Analysis of all samples was performed in duplicate.

Statistical analysis

Performance and carcass data were analysed as a completely randomised design using Proc GLM of SAS (1985). Individual pen means represented the experimental unit. Initial live weight was included as a covariate in the analysis of the growth data and slaughter weight was used as a covariate in the analysis of carcass data. Data from the experiment are presented as least squares means. Performance data were analysed for the following periods; days 0 to 14 (early-grower), 14 to 28 (late-grower), 28 to 42 (early-finisher), 42 to slaughter (late-finisher) and day 0-slaughter (grower-finisher). Contrasts statements were used to compare the effects of SHD versus DFD, RFD and PFD. The difference between RFD and PFD was also evaluated. In all tables, the probability level, which denotes significance for a given comparison, is given for each contrast. The coefficient of variation was 1.83% and 2.5% for initial live weight and final (slaughter) weight, respectively.

Results

Performance

The effects of dietary treatment on average daily feed intake (ADFI), average daily gain (ADG), food conversion ratio (FCR), average daily lysine intake (ADLI) and lysine conversion ratio (LCR) are presented in Table 2.

Pigs offered the SHD treatment had a lower ADFI than pigs offered treatments DFD ($P < 0.05$) or RFD ($P < 0.01$) during the early-grower period. Pigs offered the PFD treatment had a lower ($P < 0.05$) ADFI than pigs offered treatment RFD during this period. During the late-finisher period, pigs offered SHD had a lower feed intake than pigs offered treatment DFD ($P < 0.01$), RFD ($P < 0.05$) or PFD ($P < 0.05$). During the overall grower-finisher period, pigs offered SHD had a lower ($P < 0.05$) feed intake than pigs offered DFD.

Table 2. Dietary lysine concentrations for each treatment and least squares means for treatments, by growth phase, for food intake, growth rate and conversion ratios along with significance (P values) of contrasts among treatment means

Growth phase[1]	Treatment[2]				s.e.	Contrasts			
	SHD	DFD	RFD	PFD		C1	C2	C3	C4
				Lysine g/kg					
Early-grower	11.0	10.5	9.5	11.0	-	-	-	-	-
Late-grower	11.0	10.5	9.5	10.0	-	-	-	-	-
Early-finisher	11.0	8.5	9.5	9.0	-	-	-	-	-
Late-finisher	11.0	8.5	9.5	8.0	-	-	-	-	-
				Food intake (kg/day)					
Early-grower	1.69	1.82	1.85	1.73	0.035	0.012	<0.01	0.46	0.03
Late-grower	1.87	1.92	1.90	1.96	0.084	0.66	0.82	0.45	0.60
Early-finisher	2.23	2.39	2.30	2.28	0.068	0.12	0.42	0.57	0.91
Late-finisher	2.51	2.77	2.67	2.70	0.053	<0.01	0.05	0.03	0.67
Overall	2.08	2.23	2.18	2.17	0.042	0.02	0.11	0.14	0.89
				Daily gain (kg/day)					
Early-grower	0.909	0.950	0.903	0.915	0.033	0.40	0.90	0.89	0.80
Late-grower	0.878	0.863	0.870	0.779	0.052	0.84	0.92	0.20	0.24
Early-finisher	0.909	0.830	0.909	0.897	0.029	0.05	0.99	0.79	0.80
Late-finisher	0.903	1.04	0.967	0.909	0.035	0.01	0.21	0.89	0.26
Overall	0.900	0.921	0.912	0.875	0.018	0.44	0.64	0.40	0.19
				Food conversion ratio (kg/kg)					
Early-grower	1.87	1.92	2.05	1.89	0.055	0.51	0.04	0.76	0.05
Late-grower	2.13	2.24	2.21	2.54	0.101	0.43	0.56	0.01	0.04
Early-finisher	2.45	2.89	2.53	2.54	0.096	<0.01	0.57	0.51	0.92
Late-finisher	2.78	2.67	2.78	2.97	0.087	0.37	0.96	0.16	0.15
Overall	2.31	2.43	2.39	2.48	0.032	0.02	0.08	<0.01	0.05
				Daily lysine intake (g/day)					
Early-grower	18.64	19.21	17.59	19.06	0.385	0.32	0.04	0.45	0.02
Late-grower	20.62	20.24	18.08	19.67	0.849	0.75	0.05	0.44	0.21
Early-finisher	24.59	20.38	21.86	20.60	0.624	<0.01	<0.01	<0.001	0.17
Late-finisher	27.75	23.59	25.39	21.63	0.472	<0.001	<0.01	<0.001	<0.001
Overall	22.90	20.85	20.73	20.24	0.416	<0.01	<0.01	<0.001	0.49
				Lysine conversion ratio (g/kg)					
Early-grower	20.60	20.22	19.51	20.87	0.572	0.64	0.20	0.74	0.11
Late-grower	23.46	23.61	21.09	25.40	1.024	0.92	0.12	0.20	<0.01
Early-finisher	27.04	24.63	24.08	22.93	0.868	0.05	0.03	<0.01	0.37
Late-finisher	30.68	22.74	26.44	23.76	0.798	<0.01	<0.01	<0.001	0.03
Overall	23.22	22.63	22.73	20.24	0.814	0.91	0.16	0.27	0.36

[1] Early-grower = days 0 to 14, late-grower = days 14 to 28, early-finisher = days 28 to 42, late-finisher = days 42 to slaughter.
[2] Defined by lysine concentration pattern.
[3] Contrast C1= SHD vs. DFD, C2 = SHD vs. RFD, C3 = SHD vs. PFD, C4 = RFD vs. PFD.

Pigs offered the SHD ($P < 0.05$) and PFD ($P < 0.01$) treatments had a higher ADLI than pigs offered RFD during the early-grower period. Pigs offered treatment SHD had a higher ($P < 0.001$) ADLI than pigs offered treatments DFD, RFD and PFD during the early finisher, late-finisher and during the overall grower-finisher period.

Pigs offered SHD had a higher ($P < 0.05$) ADG than pigs offered treatment DFD during the early-finisher period, however during the late-finisher period, pigs offered treatment DFD had a higher ($P < 0.01$) ADG than pigs offered SHD.

Pigs offered the SHD and PFD treatments had a better ($P < 0.05$) FCR than pigs offered RFD during the early-grower period. Pigs offered SHD had a better ($P < 0.01$) FCR than pigs offered PFD during the late-grower period. Also, pigs offered treatment RFD had a better ($P < 0.05$) FCR that pigs offered PFD during this period. Pigs offered SHD had a better FCR than pigs offered DFD during the early-finisher ($P < 0.01$) and during the overall grower-finisher period ($P < 0.05$). Pigs offered the SHD treatment had a better ($P < 0.001$) FCR than pigs offered PFD during the overall grower-finisher period. Pigs offered the treatment RFD had a better ($P < 0.05$) FCR than pigs offered PFD during the overall grower-finisher period.

Pigs on RFD had a better ($P < 0.01$) LCR than pigs offered PFD during the late-grower period. Pigs offered treatment RFD had a better LCR than pigs offered treatment SHD during the early-finisher ($P < 0.05$) and late-finisher periods ($P < 0.01$). Pigs offered PFD had a better ($P < 0.05$) LCR than pigs offered RFD during the late-finisher period. Pigs offered treatment PFD had better FCR than those offered SHD during early finisher ($P < 0.01$) and later-finisher ($P < 0.001$) periods.

Pigs offered SHD had a poorer ($P < 0.01$) LCR than pigs offered the RFD and DFD treatments during the late-finisher period. Pigs offered SHD had a poorer ($P < 0.001$) LCR than pigs offered treatment PFD during the early finisher ($P < 0.01$), late-finisher ($P < 0.001$) and overall grower-finisher periods ($P < 0.01$).

Carcass traits

The effects of treatment on carcass traits are presented in Table 3. There were no significant treatment effects on slaughter weight, kill-out proportion, carcass weight, lean meat content, backfat, eye muscle depth, carcass ADG or Pd_{max}. Pigs on SHD had a better carcass FCR than pigs offered treatments DFD ($P < 0.05$) and PFD ($P < 0.01$). Pigs offered RFD had a better ($P < 0.05$) carcass FCR than pigs

Table 3. Least squares means, by dietary treatment, for live weight at slaughter (SW), carcass weight (CW), kill-out and lean meat proportions, maximum protein deposition rate (Pd_{max}), eye muscle depth (EMD), carcass daily gain (CADG), carcass food conversion ratio (CFCR), and carcass lysine conversion ratio (CLCR) along with significance (P value) of contrasts among treatment means

Carcass traits	Treatments[1]				s.e.	Contrasts[2]			
	SHD	DFD	RFD	PFD		C1	C2	C3	C4
Live weight at slaughter (kg)	95.2	96.5	96.0	93.8	1.075	0.40	0.62	0.31	0.20
Carcass weight (kg)	71.6	71.8	71.3	70.6	3.143	0.98	0.94	0.82	0.88
Kill-out (g/kg)	745.2	749.1	747.9	747.7	3.489	0.44	0.59	0.62	0.97
Lean meat (g/kg)	582.0	573.0	582.0	576.0	51.30	0.22	0.96	0.40	0.42
Backfat depth (mm)	12.4	13.5	12.5	13.2	0.653	0.27	0.91	0.40	0.44
Pd_{max} (kg/day)	0.171	0.170	0.173	0.162	4.571	0.89	0.78	0.16	0.10
EMD (mm)	57.8	57.5	57.9	57.4	1.796	0.99	0.94	0.88	0.94
CADG (kg/day)	0.744	0.769	0.759	0.729	0.014	0.23	0.47	0.48	0.14
CFCR (kg/kg)	2.79	2.90	2.87	2.97	0.035	0.03	0.14	<0.01	0.03
CLCR (g/kg)	30.7	27.0	27.2	27.7	0.341	<0.001	<0.001	<0.001	0.37

[1] See footnotes for Table 2.

[2] See footnotes for Table 2.

offered PFD. Carcass lysine conversion ratio (CLCR) was higher (P < 0.001) in pigs offered SHD compared with all other treatments.

Nitrogen balance

The effects of treatment on N balance are presented in Table 4. Pigs offered SHD had a higher (P < 0.001) N intake and N excretion than pigs offered DFD, RFD and PFD throughout the grower-finisher period. Pigs offered SHD had a lower N utilisation value than pigs offered DFD (P < 0.01), PFD (P < 0.01) and RFD (P < 0.001) diets. Pigs offered RFD had a higher (P < 0.05) N utilization value than pigs on PFD.

Discussion

Nitrogen production as an environmental concern is now a real issue for pig producers. European Union legislation concerning N production by pig producers is primarily bound by two directives: the Integrated Pollution and Prevention Control (IPPC), Council Directive 96/61/EC and the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2006, S.I. No. 378 of 2006. It has been estimated that the grower-finisher pig utilizes a mere 0.33 of the feed N in commonly available diets, the remainder (accounting for 0.71 of the total N excreted from pig production systems) being excreted (Dourmad *et al*., 1999). More than a quarter of these losses may be attributed to the failure to maximise production and to optimise efficiency by the correct matching of dietary protein quantity and quality to that required by the pig as it grows (Whittemore, Green and Knap, 2001). Ensuring adequate amino acid supplies at all times according to the growth potential and physiological status of the animal (Lewis, 2001) is one approach to improving the efficiency of utilization of N by pigs. Another is to improve the dietary amino acid balance and consequently reduce the protein concentration of the diet (Dourmad *et al.,* 1999). In the current experiment, grower-finisher pigs were offered a single high lysine diet or a number of diets with the same mean lysine content as either a single diet or as a series of two or four diets.

When providing a single diet throughout the growing-finishing period, the lysine concentration is either adequate initially and then excessive, as lysine requirement declines with increasing live weight, (Campbell, Taverner and Curic, 1988), or it is below initial requirements, with the expectation that pigs will be able to compensate in later stages for the initial

Table 4. Least squares means for effect of dietary treatment on nitrogen balance variables and significance (P value) of contrasts

Variable	Treatment[1]				s.e.	Contrasts[2]			
	SHD	DFD	RFD	PFD		C1	C2	C3	C4
N intake (kg)	3.93	3.51	3.42	3.40	0.070	<0.001	<0.001	<0.001	0.89
N gain (kg)	1.36	1.36	1.38	1.30	0.035	0.94	0.64	0.27	0.10
N excretion (kg)	2.56	2.14	2.03	2.10	0.052	<0.001	<0.001	<0.001	0.35
N retention (g/day)	23.9	24.0	24.3	22.9	0.600	0.94	0.64	0.27	0.13
N utilisation (g/g)	0.347	0.390	0.407	0.383	0.007	<0.01	<0.001	<0.01	0.04
PD[3] (g/day)	149.0	150.0	152.0	143.0	3.877	0.94	0.65	0.27	0.13

[1] See footnote for Table 2.

[2] See footnote for Table 2.

[3] PD = Protein deposition.

effects of dietary restriction (Reynolds and O' Doherty, 2006). Pigs offered the 11 g/kg diet (SHD) had a better ADG than the 8.5 g/kg lysine diet (DFD) during the early-finisher period indicating that the lysine supply to DFD pigs was deficient during this period. However, during the late-finisher period, pigs offered 8.5 g/kg lysine diet had a better daily gain than pigs offered SHD. The increase in daily gain of pigs offered DFD can firstly be attributed to an increase in feed intake compared with pigs offered SHD during the late-finisher period (2.77 vs 2.51 kg/day). Secondly, it would appear that pigs offered treatment DFD exhibited compensatory growth following a period of dietary restriction during the early-finisher period (Reynolds and O'Doherty, 2006). Thirdly, the SHD treatment may have restricted growth during the late-finisher period due to an over-supply of protein. This would lead to a deterioration in FCR and growth because the excess protein would have to be deaminated and excreted (Gill, 1998).

Pigs offered the 11 g/kg lysine diet (SHD) had a lower feed intake than the pigs offered 10.5 g/kg and 9.5 g/kg lysine diets during the early-grower period and had a lower feed intake than the pigs offered 9.5 g/kg and 8.5 g/kg lysine diets during the late-finisher period. This was probably due to two reasons. Firstly, the increased heat increment resulting from the deamination of excess amino acids in higher protein diets can limit feed intake if heat dissipation becomes limiting (Forbes, 1995). Secondly the lower intake of pigs offered the SHD treatment may be due to the increase in the digestible energy (DE) concentration of the diet (Cole and Chadd, 1989). The estimated DE concentration of SHD (14.4 MJ/kg) was higher than that of RFD (14.0 MJ/kg) and DFD (13.95 MJ/kg) (Table 1).

In the current experiment, four-phase-feeding lead to a deterioration in FCR during the late-grower period compared with feeding the single high lysine diet or the RFD diet. This deterioration in FCR may have occurred due to the dietary transition involved with phase feeding. Pigs offered the single high lysine diet (SHD) had a better FCR than the pigs offered both the two phase and four phase diets during the overall grower-finisher period, while there was no effect on overall daily gain. Several researchers have reported that FCR is optimised at lysine levels greater than are needed to maximise live-weight gain (Van Lunen and Cole, 1996). Casserly (2005) reported that the optimum lysine concentration proposed for pigs of similar genotype and housed in similar conditions as at this Institute was 12 g/kg for minimum FCR while ADG was maximised at a lysine concentration of 11.4 g/kg.

Lysine conversion ratio is a function of lysine intake and daily gain. Pigs on treatment SHD had a poorer LCR during the late-finisher period compared with pigs offered treatments RFD, DFD or PFD who consumed less lysine per day but were more efficient in utilising and converting lysine into daily gain than SHD pigs. LCR deterioration occurs when protein deposition reaches a constant rate along with increased lysine intake (O'Connell, Lynch and O'Doherty, 2005). Langer and Fuller (1995) proposed that lower lysine intake may increase the efficiency of utilisation. Protein retention is linearly related to lysine intake when no other dietary factor is limiting (Susanbeth, 1995). Susanbeth (1995) suggested that when limitations are placed on energy intake or growth potential, but lysine intake increases, this causes a decline in efficiency of lysine utilization.

The carcass lysine conversion ratio was poorer for pigs on treatment SHD compared with all other treatments. O'Connell *et al*. (2005) reported similar findings when comparing phase feeding with a single high lysine diet. Feeding lysine to requirement (9.5 g/kg) as one diet (RFD) was more carcass efficient than phase feeding a mean total lysine of 9.5 g/kg, while being no poorer than SHD. It would appear that as the lysine level was reduced, carcass FCR deteriorated probably due to an increased ratio of fat:lean deposition.

Nitrogen excretion, which is a function of N intake and retention, was significantly different between treatments. Pigs on treatment SHD had the highest N excretion rates compared with treatments DFD, RFD and PFD. Pigs offered diets matched to their lysine requirements had the lowest excretion rates. Increased N excretion rates may have occurred due to oversupply of lysine leading to increased deamination resulting in increased urea excretion, with the ultimate effect being increased N excretion (O'Connell *et al.,* 2005). Pigs offered treatment SHD had 20%, 17% and 16% higher N excretion rates than pigs on treatments RFD, PFD and DFD, respectively. This equates to a reduction of about 6.7% in nitrogen excretion for every 10 g/kg reduction in crude protein when comparing pigs on SHD and pigs offered treatment RFD. Similar results have been reported by Kerr and Easter (1995) who reported a reduction of 8.4% in N excretion for every 10 g/kg reduction in dietary crude protein concentration.

The variation in N utilisation co-efficients in this study (0.347 to 0.406), is in agreement with results from O'Connell *et al.* (2005) who reported values ranging from 0.38 to 0.46. Whittemore, Hazzeldine and Close (2003) suggested that 0.66 of consumed N is excreted, implying that proportionately about 0.34 is retained. Matching lysine to the animal requirements gave the best utilisation of N, while pigs on treatment SHD had the poorest N utilisation.

Conclusion

The results from the current experiment indicate that in terms of pig performance, there are no benefits from a two or four phase feeding regime when the lysine concentration of the diet matches the requirements of the pig, as with treatment RFD. A single lysine diet (calculated based on requirements) throughout the grower-finisher period may offer producers the best option in terms of overall N utilisation and lower N excretion rates in comparison to a two or four phase feeding regime.

Despite having a better FCR than DFD or PFD treatments, the feeding of a single high lysine diet resulted in higher N excretion rates and lower N utilisation values in comparison to the other dietary treatments. In order for phase-feeding to be successful, all pigs must be of similar live weight as additional feed storage costs may occur, therefore phase-feeding may be most relevant in an all-in-all-out system of production. Feeding pigs to their lysine requirements, as with treatment RFD, appears to be the best strategy in minimising N emissions along with only requiring one feed storage bin for grower-finisher pigs.

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