Effects of Energy Intake and Dietary Protein Concentration on Energy Partition and Energetic Efficiency in Growing Pigs

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Abstract

The influence of energy intake and dietary protein concentration on the energy partition and the rates of energy expenditure in growing pigs were evaluated in a 2x2 factorial arrangement. The factors were two feeding levels and two dietary protein concentrations, each fed to separate 6 entire males. Energy and nitrogen balances and calorimetric measurements were recorded simultaneously in each animal when weighed 54.5 ± 3.7 kg. Energy retained as protein and fat increased with level of feeding. Increased protein intake resulted into increased rate of heat production and protein energy retention and low rate of fat energy retention. The energy requirement for maintenance was slightly lower in animals fed on the high compared with those on low-protein diets. The partial efficiency of ME utilisation for growth was poor in the animals fed on high dietary protein concentration (k_g 0.504 against 0.601). The net energetic efficiency for protein deposition was also lower (k_p 0.34 against 0.71) and fat deposition higher (k_f 0.80 against 0.66) in the animals fed on high relative to those on low protein diet. The results indicate that the energy cost of protein accretion increases with increasing dietary protein concentration.

Keywords: Protein, energy, intake, efficiency, pigs

Introduction

The rates of energy expenditure, that is, heat output per unit of protein deposited are shown to be positively related to the rates of protein accretion (Noblet *et al.*, 1999; Milgen *et al.*, 2000). The increased body protein content and higher rates of protein turnover, resulting from the higher rates of protein accretion have been attributed to the increased energy expenditure. Although this hypothesis has been advanced by several workers (Rao and McCracken, 1990; Campbell *et al.*, 1991; Quiniou *et al.*, 1996) it is doubtful whether the trend can be generalised for all changes in the rate of protein deposition regardless of the provoking factor.

Increasing dietary protein above maintenance levels, when the supply of energy is adequate, results in increased protein synthesis and degradation, the former being greater than the later and hence results in increased net protein accretion (Lobley, 1998). Inconsistent results on the energy costs of protein accretion have been reported in some studies, where dietary protein or amino acid contents have been used to manipulate body composition (Close *et al.*, 1983; Coyer *et al.*, 1987; MacLeod, 1990). Insignificant change in the energy expenditure per unit of protein accretion between low and high protein diets have been documented in fowl fed diets between 130 g and 230 g CP/kg (MacLeod, 1990) and in pigs fed diets between 153g and 258 g CP/kg (Close *et al.*, 1983). On the other hand, Coyer *et al.* (1987) observed a doubling of the energy cost per unit of protein deposition in rats fed diets containing 166 g as opposed to 68 g CP/kg. These studies suggested that changes in protein accretion be invariably linked to changes in

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whole-body protein turnover and heat production. The present experiment was therefore designed for further testing of the hypothesis that the rate of energy expenditure per unit of protein deposition increases with rate of protein accretion stimulated by increasing energy intake and dietary protein concentration.

Materials and Methods

Experimental design and treatments

A 2x2 factorial arrangement involving two feeding levels and two diets was employed. A total of 24 pigs were allocated to the four treatments, each with six pigs. The two diets were formulated and pelleted. The ingredients and chemical composition of the diets are presented in Table 1. The intended DE content was 15 MJ/kg dry matter, with crude protein contents of 150 and 250 g/kg as fed, for diets 1 and 2, respectively. Lysine and methionine plus cystine contents were made proportional to the protein content of the diet. The two diets were fed at two levels, based on the metabolic body weights ($W^{0.63}$) of the animals. The low-level (L) of feeding was 2.25 x ME_m and the high level (H), 3.2 x ME_m, where ME_m = 719 kJ/kg $W^{0.63}$ (ARC, 1981).

Table 1: Composition of the experimental diets (g/as fed)

	DIET (g CP/kg as fed)	
	150	250
Ingredient		
Barley	2110.0	163.0
Wheat	470.0	350.0
Soya bean meal	60.0	214.0
Fish meal	48.0	126.0
Fat (BP 50)	170.0	130.0
Lysine-HCL	3.0	1.0
Limestone	7.5	3.5
Dicalphosphate	18.0	
Mineral & Vitamin	12.5	12.5
Calculated chemical composition		
Crude Protein	152.0	251.8
Crude Fibre	48.0	42.8
Calcium	11.8	12.3
Phosphorus	8.8	9.1
Lysine	9.14	15.44
Methionine + Cystine	4.30	7.60
Degestible energy (DE,MJ/kg)	15.01	15.19

Experimental animals and management

Twenty-four entire male pigs were selected from the sows present at the Institute of Grassland and Environmental Research (IGER), Shinfield, Britain, after weaning at 21 days of age. They were raised until 35 ± 1.2 kg body weight, during which they were fed *ad libitum* on a diet designed to contain 13.4 MJ DE/kg, 190 g CP and 9.5 g lysine per kg as fed. The animals were then allocated to the experimental treatments and individually penned in a house maintained at a temperature of 20±1C. The pens were fitted with automatic water nipples, where drinking water was available throughout. Both food and water supply were at the same temperature as that of the building. Feeding of the experimental diets for each pig was adjusted weekly, following weighing. The daily allowances for all pigs were given in two equal meals at 0900 and 1600h. Refusals were collected each morning, dried and weighed. Drinking water supply was *ad libitum*.

Calorimetric, energy and nitrogen balance

Energy and nitrogen balances and calorimetric measurements were recorded simultaneously in each animal at a mean body weight of 54.5 ± 3.7kg. Animals were accustomed to the conditions within the calorimeters and to the experimental protocol for seven days before the measurements were taken. A direct calorimetry using calorimeters operated on a heat sink principal was used. Each animal's total heat output was recorded continuously for four days. Seven-day collection periods were allowed for energy and nitrogen balances, whereby the total faeces, urine (preserved using 25% H_2SO_4 w/v) and pen washings were collected daily and stored at 2°C. At the end of the balance period, thoroughly mixed sub-samples of the total 7-day output of faeces (3 x 250 g) or mixed urine and washings (2 x 500 ml) for each pig were taken and stored at - 20°C until required for analysis.

Chemical and data analyses

Dry matter, gross energy and nitrogen contents of the feed, faeces and urine samples were estimated using the procedures of A.O.A.C. (1990). Daily metabolisable energy (ME) and

Table 2: The main effects of feeding level (FL) and dierary protein concentration (Diet) on the intake and utilization of dietary energy and protein in t he pigs

Component	Feeding level		Significant	Diet(g CP/kg)		Significant	SED	Significant FlxDiet
	High	Low		150	250			
Energy intake(MJ/d)								
GE	34.360	23.420	***	28.429	29.381	NS	0.733	NS
DE	26.148	18.038	***	21.291	22.895	**	0.572	NS
ME	23.911	16.718	***	19.728	20.901	*	0.608	NS
Degestibility								
DE:GE	0.760	0.770	NS	0.750	0.781	***	0.013	NS
ME:DE	0.915	0.927	NS	0.929	0.913	*	0.0	NS
Nitrogen intake (g/d) and degestibility								
NI	63.580	43.670	***	40.996	66.260	***	1.44	***
IDN	51.140	36.190	***	31.853	55.470	***	1.41	***
IDN:NI	0.796	0.823	***	0.780	0.839	***	0.013	NS
Nitrogen: Energy								
NEGE	1.843	1.857	NS	1.444	2.256	***	0.018	NS
IDN: ME	2.122	2.154	NS	1.619	2.657	***	0.041	NS
IDN: DE	1.939	1.989	NS	1.503	2.425	***	0.037	NS
Nitrogen utilisation (NR)								
(g/d)	27.530	20.162	***	19.666	28.024	***	1.71	NS
NR:NI	0.440	0.467	NS	0.482	0.424	**	0.025	NS
NR:IDN	0.554	0.569	NS	0.617	0.506	***	0.029	NS

Table 3 : The average main effects of feeding level (FL) and dietary protein concetration (Diet) on the general performance of the pigs during the blance period

Comeponent	Feeding level		Significant	Diet (gCP/kg)		Significant	SED	Significat FLxDiet
	High	Low		150	250			
Liveweight (kg)								
	55.48	53.48	NS	52.94	56.03	*	2.647	NS
Food Intake								
(kg/d)	1.755	1.195	***	1.451	1.500	NS	0.037	NS
(Kg/kg $W^{0.61}$.d)								
	0.152	0.106	***	0.129	0.129	NS	0.0	NS
Weight gain (kg/d)								
	1.016	0.738	***	0.796	0.958	***	0.058	NS
Food:gain								
	1.769	1.638	NS	1.841	1.566	**	0.115	NS

digestible nitrogen (IDN) intake, nitrogen retention (NR), protein and fat energy retention were derived according to ARC (1981). The data were tested according to the factorial arrangement (Mead and Curnow, 1986).

Results

Nutritive value of the diets

The mean digestibility of energy that is digestible energy (DE) as a proportion of gross energy (GE) (DE:GE) was slightly higher in the low-fed animals, but the mean difference was not significant (Table 2). However, energy digestibility was significantly ($P<0.01$) poorer with the low protein diet (diet 1) than the high protein diet (diet 2). The average metabolisability of DE, that is ME:DE was significantly ($P<0.05$) higher with diet 1 (0.93) than diet 2 (0.91). Animals fed on diet 1 had significantly ($P<0.05$) lower DE and ME intakes than those on diet 2. The mean apparent digestibility of nitrogen (IDN:NI) was significantly improved with increased dietary protein concentration (Table 2). Increased feeding level was associated with increased amounts of nitrogen (NI) and digestible nitrogen (IDN) intake. These values were also higher for those animals fed on diet 2 than those on diet 1. Feeding level x diet interactions for NI and IDN were significant ($P<0.001$). High-fed animals retained more ($P<0.001$) nitrogen than the low-fed ones. Increased dietary protein concentration was associated with more ($P<0.001$) nitrogen being retained, though significantly ($P<0.01$) lowered the efficiency of nitrogen utilisation (NR:IDN).

Table 3 presents the mean main effects of feeding level and dietary protein concentration on food intake, weight gain and food conversion efficiency of the pigs during the balance period. Food intake was significantly ($P<0.001$) higher in the high-fed animals than the low-fed ones, but not significantly ($P>0.05$) different between the dietary treatments. Increased feeding level significantly ($P<0.001$) increased body weight gain. Although mean food conversion ratio increased with feeding level, the difference was not significant ($P>0.05$). Body weight gain similarly increased ($P<0.01$) with increasing dietary protein concentration of the diet and this was associated with significant ($P<0.01$) lower food conversion ratio. The interactions between feeding level and diet on the growth parameters of the pigs were not significant ($P>0.05$).

Tissue deposition and energetic efficiencies

Increased level of feeding significantly increased ME intake, heat loss and total energy retained (Table 4). Animals fed on diet 1 had lower ($P<0.05$) ME intakes than those on diet 2. Heat loss was proportionately 0.20 higher in the high- than in low-fed animals and it increased with dietary protein concentration. Total energy retained was proportionately 0.46 higher in the high-fed than in the low-fed pigs. However, the difference between the two diets was not significant ($P<0.05$). At similar levels of energy intake, increasing dietary protein concentration significantly increased the energy accreted as protein by 0.27 and reduced that retained as fat by 0.50.

Animals fed on the high dietary protein concentration had slightly poorer efficiency of energy utilisation for growth (k_g) and protein retention (k_p) relative to those on low protein concentration (Table 5). However, the net energetic efficiency for fat retention (k_f) increased with increased dietary protein concentration. The estimate of the energy requirement for maintenance (ME_m) for those animals fed on low protein diet was higher compared with those on high protein concentration.

Discussion

The observed differences in energy digestibility and metabolisability between the two diets resulted in unexpectedly higher intakes of DE and ME by the animals fed on high protein diet compared with those on low protein diet. Similar energy and protein interaction influences on metabolisability of diet and hence energy intake have been documented elsewhere (Campbell *et al.*, 1985; Rao and McCracken, 1990). The proportionate 0.20 higher heat loss in the animals on high feeding level relative to those on low feeding level is consistent with other reports (Close *et al.*, 1985; Coyer *et al.*, 1987; Rao and McCracken, 1990; Noblet *et al.*, 1999; Milgen *et al.*, 2000). This higher heat output is by definition the heat increment of feeding. Increased heat loss with increasing protein concentration may be associated with additional heat load due to disposal of excess dietary protein which

Table 4: The main effects of feeding level (FL) and dietary protein concentration (Diet) on the partion of ME intake into heat loss, energy retention and protein and fat energy

Component	Feeding level		Significant	Diet (gCP/kg)		Significant	SED	Significant
	High	Low		150	250			FlxDiet
ME								
(MJ/d)	23.911	16.718	***	19.728	20.901	*	0.608	NS
(MJ/kg $W^{0.61}$ d)	2.064	1.476	***	1.750	1.790	*	0.026	NS
Heat loss								
(MJ/d)	16.048	12.578	***	13.558	15.068	***	0.480	NS
(Mj/kg $W^{0.61}$ d)	1.385	1.110	***	1.204	1.292	**	0.034	NS
Energy retention								
(MJ/d)	7.863	4.140	***	6.170	5.833	NS	0.603	NS
(MJ/kg $W^{0.61}$.d)	0.679	0.365	***	0.546	0.499	NS	0.058	NS
Protein energy								
(MJ/d)	4.078	2.986	***	2.913	4.151	***	0.252	NS
(MJ kg $W^{0.61}$.d)	0.351	0.262	***	0.258	0.355	***	0.018	NS
Fat e energy								
(MJ/d)	3.785	1.153	***	3.257	1.682	**	0.554	NS
(MJ kg $W^{0.61}$.d)	0.328	0.103	***	0.288	0.144	***	0.058	NS
Energy efficiency								
ER:GE	0.229	0.177	**	0.212	0.194	NS	0.018	NS
ER:ME	0.329	0.247	***	0.304	0.272	NS	0.026	NS

Table 5: The maintence energy requirement (M_{em}, MJ ME/kg $W^{0.61}d^{-1}$) and energetic efficiencies of ME utilisation for growth (k_g) protein(k_p) and fat (k_f) deposition for animals fed the different diets

DIET	ME_m	k_g	k_p	k_f
1	0.842[1]	0.601		
	0.951[2]		0.709	0.662
2	0.801	0.504		
	0.572		0.341	0.806
Pooled	0.806	0.542		
	0.733		0.405	0.760

1 Simple linear regression model

2 Multiple linear regression model

could have been deaminated in the liver and eventually converted to urea. It is well known that one urea cycle consumes four high-energy phosphates (Mathews and van Holder (1990) contribute to the cost of excreting the excessive protein intake. The significantly higher heat loss in animals fed on high protein diet compared with those on low protein diet might have also been attributed to differences in the composition of gain. Since increasing protein intake was associated with a higher proportion of protein with respect to lipid (protein:fat ratio of 1.50 and 4.14 for animals on low and high protein concentration, respectively) being deposited, and given that the cost of protein deposition is higher (20 kJ/g) than that of fat deposition (14 kJ/g) (ARC, 1981), the observed differences in heat output was inevitable.

The proportionate 0.46 higher ER in the animals on high than low level of feeding was expected and accords with several other observations on growing pigs (Campbell *et al.*, 1985; Rao and McCracken, 1990). Surprisingly, the partial energetic efficiency of ME utilization for growth (k_g) for animals fed on high protein diet (0.504) was lower than those on low protein diet (0.601). This implies that. increased dietary protein intake was associated with a poor efficiency of ME utilization above maintenance and is possibly attributed to the increase in heat loss observed in these animals (Campbell *et al.*, 1985).

The overall mean value of the maintenance energy requirement (ME_m) obtained by simple linear regression model (0.806 MJ/kg $W^{0.61}d^{-1}$) compared well with other reported values (ARC, 1981; Campbell and Taverner, 1988). It is interesting to note that the mean ME_m value determined on the pigs fed on low protein diet was slightly higher than that for the pigs on high protein diet (0.842 compared with 0.801 MJ ME/kg $W^{0.61}d^{-1}$). This supports the results of Gurr *et al.* (1980) who observed increased metabolic rates and body temperature of rats given a low protein diet. However, given that animals fed on high protein diet deposited protein at a relatively higher rate and protein energy accounted for 0.71 of the total energy retained compared with 0.47 for those on low protein diet, their body protein content and protein turn-over rate are expected to be relatively high. Hence, these pigs were expected to have higher ME_m than that fed on low protein diet. The reasons for this discrepancy is not clearly known, though may possibly be linked to differences in the quality rather than quantity of the proteins, which was not evaluated in this study.

The higher estimates of k_p observed in animals fed low protein diet than those on high protein diet implies that the energy cost of depositing 1 kJ of protein in these animals is relatively low (1.41 vs 2.94 kJ). Values of ME_m followed a similar trend. The present results are, however, in contrast to the findings of Close *et al.* (1983), who reported higher estimates of k_p (0.66 vs 0.27) and ME_m (0.503 vs 0.356 MJ/kg $W^{0.75}d^{-1}$) for animals fed on high- compared with those on low-protein rations. The reason for this discrepancy is not known though the small ranges of energy and protein intake and hence in body composition between the groups employed in the present study and variations in the diet composition between experiments may explain the differences.

The estimated k_p value for low protein diet was higher (0.71) and that of high protein diet was lower (0.34) than the preferred value (0.54) of ARC (1981). The k_f value for low protein diet (0.66) was lower and for high protein diet (0.80) was higher than that of 0.74 calculated by ARC (1981). The estimated k_f value for high protein diet, however, is within the range calculated on theoretical grounds (Millward *et al.*, 1976). The multiple regression models gave greater and smaller estimates of ME_m for low protein diet (0.951 MJ/kg $W^{0.61}d^{-1}$) and high protein diet (0.572 MJ/kg $W^{0.61}d^{-1}$), respectively compared with those estimated by simple linear regression analysis. Values for simple linear regression analysis were 0.842 and 0.801 MJ/kg $W^{0.61}d^{-1}$ for low and high protein diets, respectively. It is well known that multiple regression models produce higher or similar values than simple regression procedures (Hofstetter and Wenk, 1985; Close *et al.*, 1983). It is therefore difficulty to explain the low ME_m value that computed by multiple regression equations for animals fed on high protein diet in the present study.

Conclusion

It can be concluded that increasing the rate of protein accretion by elevating dietary protein intake may increase energy expenditure without necessarily increasing the energy requirement for maintenance.

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