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The influence of protein nutrition in early life on growth and development of the pig

1. Effects on growth performance and body composition

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1. The effects of feeding either a high-protein (HP) diet or a low-protein (LP) diet between 1·8 and 15 kg live weight (LW) and a low-energy (LE) or a high-energy (HE) intake but at the same protein intake subsequent to 15 kg LW on the performance and body composition of pigs growing to 75 kg LW were investigated.

2. During the LW period 1·8–15 kg, pigs given the LP diet exhibited poorer growth performance ($P < 0.01$) and at 15 kg contained more fat ($P < 0.01$) in their empty bodies than pigs given the HP diet.

3. On the LE treatment subsequent to 15 kg LW, pigs previously given the LP diet deposited protein at a faster rate and exhibited more rapid and efficient growth to 60 kg LW than those given the HP diet before 15 kg. However, on the HE treatment, pigs previously given the LP diet deposited protein at a slower rate and exhibited poorer growth performance ($P < 0.05$) between 15 and 45 kg LW but grew at a faster rate between 45 and 60 kg LW than pigs previously given the HP diet.

4. On the LE treatment subsequent to 15 kg LW the differences in body composition between the two protein groups were no longer significant at 45 kg. However, on the HE treatment, pigs previously given the LP diet remained fatter ($P < 0.05$) to 60 kg LW than those previously given the HP diet.

5. The results suggested that restricting protein intake between 1·8 and 15 kg LW reduced, temporarily, the upper limit of protein retention and growth performance during subsequent development. This finding is discussed in relation to the effects of protein nutrition in early life on the hyperplasic development of muscle tissue.

Wyllie *et al.* (1969) and Zimmerman & Khajarern (1973) reported that pigs given protein-deficient diets between 5 and 20 kg live weight (LW) exhibited more rapid growth and deposited protein at a faster rate during subsequent development than pigs given protein-adequate diets before 20 kg LW. Wyllie *et al.* (1969) and Zimmerman & Khajarern (1973) also suggested that protein nutrition between 5 and 20 kg LW had little influence on body composition at 90–93 kg LW. However, there is less information on the effects of protein nutrition before 5 kg LW on subsequent growth and body composition. The results of previous research at this centre (Campbell & Dunkin, 1980) indicated that protein deprivation in early life reduced the upper limit for protein retention and growth performance during subsequent development. A similar effect was also suggested by the results of Sherry *et al.* (1978). However, in both the latter experiments the animals were killed at a relatively early stage of development and, therefore, they provide no information as to whether the depressed performance exhibited during subsequent growth is a permanent or transient effect.

Similarly, there is little information on the influence of nutrition in later life on the subsequent growth performance or body composition of pigs receiving different levels of dietary protein in early life. In rats, the results of Barnes *et al.* (1973) suggest that compensatory growth following a period of protein deprivation may be more evident if the rate of protein retention in the later period is limited by protein nutrition.

The experiment reported here was conducted to study the effects of feeding a low- or a high-protein diet from 1·8 to 15 kg LW and a low- or a high-energy intake subsequent to

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Table 1. *Composition of experimental diets given to pigs between 1·8 and 15 kg live weight (LW)*

Diet...	High-protein	Low-protein
(a) Liquid diets given between 1·8 and 10 kg LW*		
Ingredients (g/kg DM)		
Ultra-filtered skim-milk powder†	573	210
Glucose	215	401
Soya-bean oil	44	71
Butter fat	168	273
Mineral mix‡	—	45
Analysis		
Gross energy (MJ/kg DM)	25·4	26·4
Crude protein (N × 6·38) (g/kg DM)	392	152
(b) Dry diets given between 10 and 15 kg LW		
Ingredients (g/kg air dry diet)		
Wheat	500	500
Skim-milk powder	300	100
Fish meal	100	33
Soya-bean oil	20	30
Tapioca	60	299·5
Dicalcium phosphate	12·5	30
Salt	2·5	2·5
Vitamin–mineral premix§	5·0	5·0
Analysis		
Gross energy (MJ/kg)	17·6	18·0
Crude protein (N × 6·38) (g/kg)	251	140

DM, dry matter.
* Constituted with water to 200 g total solids/kg.
† Prepared by the continual circulation of raw skim milk in contact with a semi-permeable membrane for 3 h at 55° and by spray-drying.
‡ The following micronutrients added daily before feeding (mg/pig per d): cholecalciferol 0·12, D-α-tocopherol 31·0, retinol 0·85, menadione 0·06, thiamin 1·50, riboflavin 2·50, nicotinic acid 20·0, pantothenic acid 10·00, pyridoxine 2·50, cyanocobalamin 0·02, biotin 0·08, pteroylmonoglutamic acid 1·00, ascorbic acid 100·0, iron 20·0, zinc 10·0, manganese 4·0, copper 2·0.
§ Provided the following nutrients (mg/kg air-dry diet). Vitamins: retinol 6·4, cholecalciferol 8·3, menadione 660, riboflavin 3·3, D-α-tocopherol 22, nicotinic acid 16·5, pantothenic acid 5·5, pyridoxine 1·1, cyanocobalamin 17, biotin 56, choline 1100. Minerals: iron 88, zinc 55, manganese 22, copper 6·6, iodine 0·22, selenium 0·1.

15 kg LW on the growth performance and body composition of pigs grown to 75 kg LW. In order to investigate the persistence of the initial differences in body composition between the two protein groups, pigs were killed serially, at LW intervals of 15 kg, subsequent to 15 kg LW.

EXPERIMENTAL

Animals and design

Forty-two entire male piglets (Large White) were removed from their dams within 24–36 h of birth. As individual piglets reached 1·8 kg LW they were randomly allocated to either a high-protein (HP) or a low-protein (LP) treatment to 15 kg LW and, at the latter weight, three pigs from each treatment group were killed. The remainder were randomly allocated to either a high-energy (HE) treatment or a low-energy (LE) treatment. From each of these four treatment combinations, two pigs, chosen at random, were killed at each of four LW (30, 45, 60 and 75 kg).

Subsequent to the 15 kg LW stage, the results were analysed as a 2 × 2 × 4 factorial design

Table 2. *Composition of experimental diets given to pigs between 15 and 75 kg live weight*

Diet...	A	B
Ingredients (g/kg air-dry diet)		
Wheat	345	270·5
Barley	345	270·5
Fish meal	50	39·2
Soya-bean meal	150	116·5
Meat-and-bone meal	100	78·4
Tapioca	—	216·0
Dicalcium phosphate	5	3·9
Vitamin–mineral premix*	5	5·0
Analysis (determined)		
Digestible energy (MJ/kg)	15·4	15·5
Crude protein (N × 6·38) (g/kg)†	222	172

* Provided the following nutrients (mg/kg air-dry diet). Vitamins: retinol 6·4, cholecalciferol 8·3, menadione 660, riboflavin 3·3, D-α-tocopherol 22, nicotinic acid 16·5, pantothenic acid 5·5, pyridoxine 1·1, cyanocobalamin 17, biotin 56, choline 1100. Minerals: iron 88, zinc 55, manganese 22, copper 6·6, iodine 0·22, selenium 0·1.

with two replicates per treatment. The respective factors were protein nutrition to 15 kg (low and high), subsequent energy intake (low and high) and weight at slaughter 30, 45, 60 and 75 kg).

Diets and feeding

The ingredients and proximate composition and analyses of the diets given to pigs at 15 kg LW are presented in Table 1. Between 1·8 and 10 kg LW pigs were given liquid diets containing 200 g total solids/kg and with crude protein (nitrogen × 6·38; CP): gross energy (GE) values of 5·8 (LP) and 15·4 (HP) g/MJ. Both diets were fed according to a scale which provided 2·1 MJ GE/kg $LW^{0.75}$ per d. Between 10 and 15 kg LW the LP and HP liquid diets were replaced with dry diets containing approximately 18 MJ GE/kg and 140 and 250 g CP/kg respectively (Table 1). These diets were fed according to a scale which provided 2·0 MJ GE/kg $LW^{0.75}$ per d.

The ingredients and proximate composition of the two diets given subsequent to 15 kg LW are presented in Table 2. Diet A contained 15·4 MJ digestible energy (DE)/kg and 222 g CP/kg and was fed according to a scale which increased linearly from 657 g/pig per d at 15 kg to 2195 g/pig per d at 75 kg LW. This scale was similar to that published by the Agricultural Research Council (1967) and provided a DE intake of 1·29 MJ/kg $LW^{0.75}$ per d. This was designated the LE treatment. Diet B (Table 2) was formulated by dilution of diet A with tapioca (214 g/kg) to ensure both diets had the same amino acid balance. It was fed according to a scale which increased from 838 g/pig per d at 15 kg to 2866 g/pig per d at 75 kg LW. This scale was chosen to provide pigs with the same daily intake of CP as those on the LE treatment but with an energy intake of 1·6 MJ DE/kg $LW^{0.75}$ per d, and was designated the HE treatment.

The DE concentrations of the two diets given subsequent to 15 kg LW (diets A and B, Table 2) were determined in a metabolism trial involving eight entire male pigs averaging 45 (SE 3·4) kg LW. The pigs were kept in metabolism crates and the two diets were allocated equally among the eight animals. Each diet was fed for a period of 14 d at a rate equal to 25 g/kg LW at the commencement of the feeding period and the faeces from each pig were collected daily during the last 5 d of the period. The total faeces collected from each pig was weighed, mixed and subsampled for subsequent analysis. The dry matter (DM) and GE contents of the diets and faeces were determined by drying samples to constant weight in a forced draught oven at 105° and with an adiabatic bomb calorimeter respectively.

Housing and management

Between weaning and 10 kg LW the piglets were housed in individual wire-mesh cages (0·6 × 0·45 × 0·52 m high) located in an insulated room in which the temperature was kept at 30° for the first week of the experiment and at 25° thereafter. At 10 kg LW the pigs were moved to individual pens in an insulated building maintained at a temperature of 21°.

The homogenized liquid diets were fed twice daily at 08.00 and 16.00 hours. Formalin (1 ml/l) was added as a preservative immediately after homogenization and vitamins and trace minerals were added daily before feeding. The levels (see footnote to Table 1) were in accordance with the estimates of requirements published by the Agricultural Research Council (1967).

Before commencement of the experimental treatments at 1·8 kg LW, all pigs were given the same liquid diet at a level calculated to provide 1·5 MJ GE/kg $LW^{0.75}$ per d.

Pigs were weighed daily to 10 kg LW and twice weekly thereafter. Feeding subsequent to 10 kg was twice daily at 08.00 and 16.00 hours.

Post-slaughter procedures

Immediately after slaughter the contents of the gastrointestinal tract were removed. For pigs killed at 15 kg LW the eviscerated carcass, blood, internal organs and empty gut were weighed together and stored at −20°. The frozen material was ground to a fine paste with a commercial butcher's mincer, mixed and subsampled for chemical analyses. A similar procedure was adopted for pigs killed at heavier weights except that only the right side of the carcass was used for chemical analysis and this was prepared and analysed separately from the blood, internal organs and empty gut, which were bulked together.

Chemical analyses

Proximate analyses of dietary ingredients and of prepared diets were performed using the methods outlined by the Association of Official Agricultural Chemists (1965).

For carcass material, DM was determined by drying three samples (25–30 g) to constant weight in a forced draught oven at 105°. Ash was determined by burning the oven-dry samples at 600° in a muffle furnace. Protein (N × 6·25) was determined by Kjeldahl analysis (Association of Official Agricultural Chemists, 1965) and body fat by extracting freeze-dried samples in chloroform–methanol (2:1, v/v) for 8 h and drying the extract to constant weight (Braude & Newport, 1973).

RESULTS

Animal health

Two pigs from each of the initial treatments died before reaching 15 kg LW. On each occasion, death was preceded by a period of severe diarrhoea and a reduction in feed intake. Post-mortem examination revealed that the gastrointestinal contents of all four pigs contained a high concentration of a rotavirus. The values for these animals were not included in the statistical analysis. Accordingly, the performance results between 1·8 and 15 kg LW are based on the means of nineteen pigs per treatment and there were eight pigs allocated to each of the four treatment combinations subsequent to 15 kg LW.

Growth performance and body composition to 15 kg LW

The results of the LW period 1·8–15 kg are presented in Table 3. Pigs given the LP diet grew at a slower rate, had a higher food conversion ratio (FCR) and at 15 kg contained more fat ($P < 0.01$) but less protein ($P < 0.05$) and water ($P < 0.05$) than pigs given the HP diets.

Table 3. *Effects of dietary protein level on the performance and body composition of pigs growing from 1·8 to 15 kg live weight (LW)*

Dietary protein level†...	High (HP)	Low (LP)	SEM‡	Statistical significance of difference HP *v.* LP
Growth performance				
Daily LW gain (g)	309	218	3·30	**
FCR	1·00	1·44	0·02	**
Composition of empty body (g/kg)				
Water	702	587	2·9	**
Protein	171	154	2·10	**
Fat	89	223	2·7	**
Ash	38	36	2·2	NS

FCR, food conversion ratio (g feed intake: g LW gain). NS, not significant. ** $P < 0·01$.
† For details, see Table 1.
‡ Based on 36 df for growth performance and 4 df for body composition.

Table 4. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) and energy intake between 15 and 75 kg LW on pig performance subsequent to 15 kg LW*
(Mean values for all slaughter weights)

LW (kg)...	Dietary protein level† 1·8–15	Energy intake‡ 15–75	Performance: Daily LW gain (g)	Performance: FCR
	HP	LE	520	1·93
		HE	677	1·84
	LP	LE	567	1·72
		HE	644	1·91
Least significant difference ($P < 0·05$) between any two means			25·0	0·09
SEM (28 df)			8·2	0·03
Protein × energy interaction			*	*

FCR, food conversion ratio (g feed intake:g LW gain); HP, high-protein; LP, low-protein; LE, low-energy; HE, high-energy.
* $P < 0·05$.
† For details, see Table 1 and p. 607.
‡ For details, see Table 2 and p. 607.

Results subsequent to 15 kg

There were significant interactions between the effects of protein nutrition to 15 kg LW, subsequent energy intake and slaughter weight for most indices of growth performance and body composition.

Growth performance

The results, pooled for slaughter weight (Table 4) showed there was a significant ($P < 0·05$) interaction between the effects of protein nutrition before 15 kg LW and subsequent energy intake for growth rate and FCR. On the LE treatment, pigs previously given the LP diets exhibited more rapid and efficient growth than those given the HP diets before 15 kg LW. However, on the HE treatment subsequent to 15 kg LW these trends were reversed.

The results for the LW ranges 15–30, 15–45, 15–60 and 15–75 kg and for the intermediate ranges (30–45 and 45–60 kg) are presented in Tables 5 and 6 respectively. These results

Table 5. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) and subsequent energy intake on the performance of pigs growing from 15 to 30, 15 to 45, 15 to 60 and 15 to 75 kg LW*

(No. of pigs per treatment given in parentheses)

	Dietary protein level†	Energy intake‡	Daily gain (g)				FCR			
LW (kg)...	1·8–15	15–75	15–30 (8)	15–45 (6)	15–60 (4)	15–75 (2)	15–30 (8)	15–45 (6)	15–60 (4)	15–75 (2)
	HP	LE	438	515	551	612	1·76	1·80	1·95	1·96
		HE	565	650	712	740	1·62	1·77	1·95	2·1
	LP	LE	491	550	594	630	1·47	1·67	1·80	1·90
		HE	520	616	704	700	1·80	1·85	1·88	2·0
Least significant difference ($P < 0·05$) between any two means			28	31	40	62	0·10	0·11	0·12	0·18
SEM§			11·1	11·3	13·0	22·7	0·05	0·04	0·04	0·05
Protein × energy interaction			*	*	*	NS	*	*	*	NS

FCR, food conversion ratio (g feed intake: g LW gain); HP, high-protein; LP, low-protein; LE, low-energy, HE, high-energy.

NS, not significant. *$P < 0·05$.

† For details see Table 1 and p. 607.

‡ For details see Table 2 and p. 607.

§ SEM based on 28, 20, 12 and 4 df for LW phases 15–30, 15–45, 15–60 and 15–75 kg respectively.

Table 6. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) and subsequent energy intake on the performance of pigs growing from 30 to 45 and 45 to 60 kg LW*

(No. of pigs per treatment given in parentheses)

	Dietary-protein level†	Energy intake‡	Daily gain (g)		FCR	
LW (kg)...	1·8–15	15–75	30–45 (6)	45–60 (4)	30–45 (6)	45–60 (4)
	HP	LE	616	641	1·85	2·16
		HE	768	875	1·92	2·32
	LP	LE	642	705	1·80	2·02
		HE	762	972	1·90	1·90
Least significant difference ($P < 0·05$) between any two means			32	43	0·09	0·12
SEM§			12·0	12·6	0·05	0·05
Protein × energy interaction			NS	NS	NS	NS

NS, not significant.

FCR, food conversion ratio (g feed intake: g LW gain); HP, high-protein; LP, low-protein; LE, low-energy; HE, high-energy.

† For details, see Table 1 and p. 607.

‡ For details, see Table 2 and p. 607.

§ SEM based on 20 and 12 df for LW phases 30–45 and 45–60 kg respectively.

showed that on the LE treatment, pigs previously given the LP diets grew at a faster rate than those previously given the HP diets in all but the LW phases 30–45 and 15–75 kg. On the HE treatment, however, pigs given the LP diets before 15 kg grew at a slower rate to 45 kg and at a similar rate between 15 and 60 and 15 and 75 kg LW as those previously given the HP diets. The results for the intermediate periods (Table 6) showed that on the

Table 7. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) and subsequent energy intake on the time taken and feed required by pigs to reach 45 and 75 kg LW*

(No. of pigs per treatment shown in parentheses)

LW (kg)...	Dietary protein level† 1·8–15	Energy intake‡ 15–75	Time (days) 1·8–45 (6)	Time (days) 1·8–75 (2)	Feed (kg/pig) 1·8–45 (6)	Feed (kg/pig) 1·8–75 (2)
	HP	LE	104	142	66·1	129
		HE	89	123	66·3	135
	LP	LE	114	156	68·9	128
		HE	109	149	74·8	145
Least significant difference ($P < 0·05$) between any two means			5·0	6·2	4·2	5·2
SEM §			1·6	3·4	1·1	2·2
Protein × energy interaction			*	*	*	*

HP, high-protein; LP, low-protein; LE, low-energy; HE, high-energy.
* $P < 0·05$.
† For details, see Table 1 and p. 607.
‡ For details, see Table 2 and p. 607.
§ SEM based on 20 and 4 df for LW phases 1·8–45 and 1·8–75 kg respectively.

HE treatment pigs given the LP and HP diets before 15 kg LW grew at similar rates between 30 and 45 kg whereas, between 45 and 60 kg, pigs previously given the LP diets exhibited more rapid and efficient growth ($P < 0·05$) than those previously given the HP diets.

The interaction between the effects of protein nutrition to 15 kg and subsequent energy intake was also significant for the time taken and feed used for pigs to reach all LW studied. The results for the LW phases 1·8–45 kg and 1·8–75 kg are given in Table 7. During both periods, feeding the HP diets initially or the HE intake subsequent to 15 kg LW reduced age at slaughter. However, within the two energy treatments, pigs in the HP–HE group were younger than pigs on all other treatments; while pigs on the LP–HE treatment were only slightly younger ($P < 0·05$) at 45 kg than those on the LP–LE treatment and older at both LW than pigs on all other treatments. Feed utilization in both periods was also higher for HP–HE pigs than for pigs on the HP–LE and LP–HE treatments.

Body composition

Changes in the proportion of fat between 15 and 75 kg LW for the four treatment combinations are shown graphically in Fig. 1. There was a significant ($P < 0·05$) interaction between the effects of protein nutrition before 15 kg LW, subsequent energy intake and LW for body fat and body water (Table 8). The results showed that body fat increased with increasing LW and that the differences between the two initial treatment groups progressively diminished. However, the persistence of these differences was dependent on energy intake subsequent to 15 kg LW. At 30 kg LW pigs previously given the LP diets were fatter than those previously given the HP diets regardless of energy intake. However, on the LE treatment, body fat in pigs previously given the LP diets declined with increasing LW and at 45 kg was equal to that of pigs previously given the HP diets. On the HE treatment, body fat of pigs previously given the LP diets remained constant to 60 kg and at the latter LW was similar to that of pigs given the HP diets before 15 kg. Body water responded in a similar manner but in the opposite direction to body fat.

There was a significant ($P < 0·05$) interaction between the effects of protein nutrition

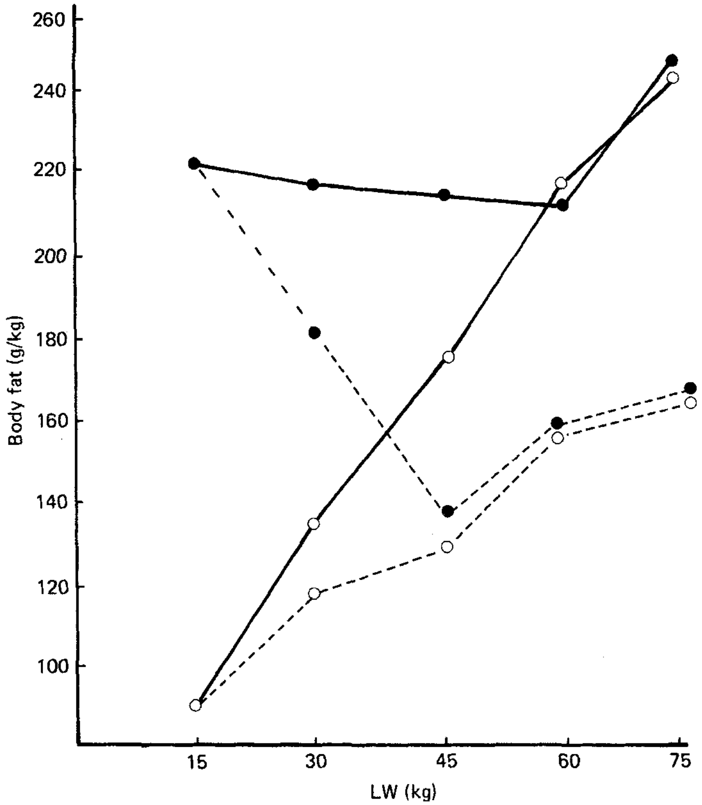

Fig. 1. Effects of feeding pigs a low-protein diet (●) or a high-protein diet (○) between 1·8 and 15 kg live weight (LW) and a high-energy intake (—) or a low-energy intake (---) subsequent to 15 kg LW on change in body fat content between 15 and 75 kg LW. For details of treatments, see Tables 1 and 2 and p. 607.

Table 8. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) subsequent energy intake and LW on the proportions of fat and water in the empty bodies of pigs killed at 30, 45, 60 and 75 kg LW (two pigs per treatment)*

LW (kg)...	Dietary protein level† 1·8–15	Energy intake‡ 15–75	Body fat (g/kg) 30	45	60	75	Body water (g/kg) 30	45	60	75
	HP	LE	119	126	155	160	651	647	614	609
		HE	134	170	214	240	656	624	577	550
	LP	LE	179	135	158	163	591	644	607	603
		HE	214	214	208	240	591	587	587	548
Protein × energy interaction			*	*	NS	NS	*	*	NS	NS

SEM (16 df): body fat, 3·7; body water, 5·2.
Least significant difference ($P < 0.05$) between treatment means: body fat, 13·0 g/kg; body water, 15·6 g/kg.
HP, high-protein; LP, low-protein; LE, low-energy; HE, high-energy.
NS, not significant. *$P < 0.05$.
† For details, see Table 1 and p. 607.
‡ For details, see Table 2 and p. 607.

Table 9. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) on the body protein content of pigs at 30, 45, 60 and 75 kg LW*

(Values averaged for pigs given low- and high-energy intakes subsequent to 15 kg LW)

LW (kg)	Dietary protein level† (1·8–15 kg LW)	Body protein (g/kg)
30	HP	181
	LP	163
45	HP	177
	LP	175
60	HP	180
	LP	177
75	HP	180
	LP	181
SEM (24 df)		2·9
Least significant difference ($P < 0·05$) between any two means		8·8
LW × protein interaction		*

HP, high-protein; LP, low-protein.
* $P < 0·05$.
† For details, see Table 1 and p. 607.

to 15 kg and LW for body protein. The results averaged for pigs on the LE and HE treatments after 15 kg LW (Table 9) showed that the difference in body protein at 15 kg LW between pigs given the HP and LP diets in early life progressively diminished as LW increased and was no longer significant at 45 kg LW. Body protein after 15 kg LW was also reduced in pigs on the HE treatment. Averaged over all LW subsequent to 15 kg the body protein contents of pigs on the LE and HE treatments were 187 and 167 g/kg respectively. The proportion of ash in the empty body subsequent to 15 kg LW was not significantly affected by either protein or energy nutrition.

Rates of deposition of fat and protein

The results for the deposition of fat and protein during the LW ranges 15–30, 15–45, 15–60 and 15–75 kg are given in Table 10. The values for the intermediate periods (30–45 and 45–60 kg) are presented in Table 11. On the LE treatment, pigs previously given the LP diets deposited protein at a faster rate at almost all stages subsequent to 15 kg than pigs previously given the HP diets. However, on the HE treatment pigs previously given the LP diets deposited protein at a slower rate to 45 kg LW and at a faster rate thereafter than pigs given the HP diets before 15 kg LW.

On the LE treatment pigs previously given the LP diets deposited fat at a slower rate and had a smaller fat: protein (FPR) in their daily gain to 45 kg LW than pigs given the HP diets before 15 kg LW (Tables 10 and 11). On the HE treatment, pigs previously given the LP diets deposited fat at a similar rate but had a higher FPR to 30 kg than pigs given the HP diets to 15 kg LW. However, between 45 and 60 kg these trends were reversed.

DISCUSSION

The results to 15 kg LW showed that feeding the protein-deficient diets produced a relatively slow-growing pig, which contained considerably more fat (150%) but less protein and water at the completion of the initial period than those given the protein-adequate diets. Similar effects of dietary protein level on growth and body composition have been reported for young pigs by a number of other authors (Zimmerman & Khajarern, 1973; Williams, 1976; Campbell & Biden, 1978; Newport, 1979; McCracken *et al.* 1980).

Table 10. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) subsequent energy intake and LW period on the rates of deposition of protein and fat and fat: protein of the gain in pigs subsequent to 15 kg LW (two pigs per treatment)*

	Dietary protein level†	Energy intake‡	Protein deposition (g/d)				Fat deposition (g/d)				Fat:protein of daily gain			
LW (kg)...	1·8–15	15–75	15–30	15–45	15–60	15–75	15–30	15–45	15–60	15–75	15–30	15–45	15–60	15–75
	HP	LE	75	95	102	116	62	65	92	101	0·82	0·70	0·90	0·90
		HE	101	108	127	125	104	133	176	202	1·02	1·25	1·40	1·60
	LP	LE	86	103	108	118	74	45	90	89	0·83	0·44	0·83	0·80
		HE	79	104	124	123	109	130	144	175	1·38	1·26	1·20	1·46

SEM (16 df): protein deposition, 2·3; fat deposition, 5·2; fat:protein of daily gain, 0·04.
Least significant difference ($P < 0·05$) between treatment means: protein deposition, 3·5 (g/d); fat deposition, 10·1 (g/d); fat:protein of daily gain, 0·14.
HP, high-protein; LP, low-protein; LE, low-energy; HE, high-energy.
† For details, see Table 1 and p. 607.
‡ For details, see Table 2 and p. 607.

Table 11. *Effects of dietary protein level between 1·8 and 15 kg live weight (LW) and subsequent energy intake on the rates of deposition of protein and fat and the fat:protein of the daily gain in pigs growing from 30 to 45 and 45 to 60 kg LW (two pigs per treatment)*

	Dietary protein level†	Energy intake‡	Protein deposition (g/d)		Fat deposition (g/d)		Fat:protein value daily gain	
LW (kg)...	1·8–15	15–75	30–45	45–60	30–45	45–60	30–45	45–60
	HP	LE	118	118	64	158	0·54	1·33
		HE	173	152	173	286	1·00	1·78
	LP	LE	138	134	12·5	153	0·09	1·13
		HE	151	201	160	189	1·06	0·94
SEM (4 df)			3·8	4·6	5·8	6·4	0·04	0·05
Least significant difference ($P < 0·05$) between any two means			7·5	9·6	15·4	17·4	0·16	0·18
Protein × energy interaction			*	*	*	*	*	*

HP, high-protein; LP, low-protein; LE, low-energy; HE, high-energy.
* $P < 0·05$.
† For details, see Table 1 and p. 607.
‡ For details, see Table 2 and p. 607.

The relative levels of protein retention and growth exhibited subsequent to 15 kg by pigs previously given the HP and LP diets were dependent on the level of energy intake offered during the later period. When given the LE intake the protein-deprived pigs deposited protein more rapidly and consequently grew at a faster rate than those previously given the HP diets. A similar compensatory growth response has been reported in grower-finisher pigs following the feeding of LP diets between weaning at 3–4 weeks of age and 20–25 kg LW (Wyllie *et al.* 1969; Zimmerman & Khajarern, 1973; Wyllie & Owen, 1978). However, when the pigs were provided with a higher energy intake subsequent to 15 kg LW, and thereby given more scope to express their potential for protein retention, those previously given the LP diets exhibited slower rates of protein deposition and growth to 45 kg LW than pigs previously given the HP diets.

The interaction between the effects of protein nutrition in early life and subsequent nutrition on growth performance in the later period that is demonstrated here is similar to that reported by Campbell & Dunkin (1980) for pigs grown to 45 kg LW and is in line with the results of Barnes *et al.* (1973) for growing rats. Taken in conjunction with the results for the cellularity of muscle tissue (Campbell & Dunkin, 1983) it appears that protein deprivation in early life reduces, at least temporarily, muscle DNA and, in turn, this may reduce the upper limit of protein deposition during subsequent development. Thus, if nutrition in the later period could support a potential rate of protein deposition which exceeds this upper limit, pigs previously given LP diets would accrete protein at a slower rate and exhibit poorer growth performance than those given HP diets initially. A similar association between the accretion of muscle DNA in early life and subsequent growth performance is indicated for poultry by the results of Moss (1968). In a comparison of genetically-lean and fat pigs, Buhlinger *et al.* (1978) also suggested that the slower rate of protein deposition observed in the fatter strain resulted from these animals containing fewer nuclei in muscle than the genetically-leaner animals. A close association between muscle DNA and protein deposition is further indicated by the results of the present experiment, since the marked improvement in the rate of protein deposition and growth performance exhibited between 45 and 60 kg LW by pigs on the LP-HE treatment was associated with a rapid increase in the rate of DNA accretion (Campbell & Dunkin, 1983). Although this improvement in growth performance subsequent to 45 kg LW resulted in the average daily gain of pigs on the LP-HE treatment being similar from 15 to 60 and 15 to 75 kg LW to those on the HP-HE treatment, the difference in age between the two groups at 60 kg LW was similar to that at 15 kg LW (mean difference 18·5 d and this difference was extended to 26 d at 75 kg LW). However, the reliability of the results between 15 and 75 kg LW is limited by the fact that they are based on only two pigs per treatment.

The results for growth performance and protein deposition on the LE treatment subsequent to 15 kg LW suggest that if the rate of protein deposition in the later period is limited by energy intake, pigs previously given LP diets are able to accrete protein at a faster rate and exhibit more rapid growth than those given HP diets in early life. Possibly an elevated level of growth hormone in protein-deprived pigs, as reported by Atinmo *et al.* (1978), is responsible for the latter effect. Nevertheless, the compensatory growth exhibited on the LE treatment by the protein-deprived pigs was only partial and at all LW these animals were considerably older than pigs given the HP diets before 15 kg LW. In practical terms our findings suggest that to maximize the efficiency of meat production, young pigs should be given protein-adequate diets. This conclusion is in apparent contrast with results of similar experiments reported by Wyllie *et al.* (1969) and Zimmerman & Khajarern (1973) for pigs weaned at 3–4 weeks of age, since both these groups of authors suggested that protein nutrition between 5 and 20–25 kg LW had little effect on the over-all performance of pigs grown to 90–93 kg LW. Nevertheless, in both the latter experiments the compensatory growth exhibited subsequent to 20–25 kg LW by pigs previously given LP diets was also only partial. Consequently this concept may require critical re-evaluation. This seems especially pertinent for commercial situations, where nutrition from 20 to 45–50 kg LW is generally designed to exploit the animal's maximum growth potential. The results of the present experiment suggest that it is precisely under these nutritional circumstances that the growth-depressant effects of early protein restriction will be most pronounced.

The results for body composition showed that the marked differences that existed between two protein groups at 15 kg LW had disappeared by 75 kg LW. However, the persistence of these differences, particularly that of body fat, was dependent on energy intake subsequent to 15 kg LW. On the LE treatment the initial differences in body composition had disappeared at 45 kg LW following a period in which lean growth predominated between 30 and 45 kg in the protein-deprived pigs. During this period the FPR of pigs previously given the LP diets was only 0·09 compared with 0·54 for pigs given the HP diets before 15 kg. However, on the HE treatment subsequent to 15 kg LW the protein-deprived pigs remained fatter to 60 kg LW. Furthermore, at 30 kg LW the difference in body fat between the two groups relative to that at 15 kg LW had increased. This was the result of the very slow rate of protein deposition exhibited between 15 and 30 kg LW by the protein-restricted pigs, whereas their concomitant rate of fat deposition was similar to that of pigs given the HP diets before 15 kg LW. Over-all, these results demonstrate the remarkable uniformity of body composition even after extreme changes induced by manipulation of protein intake in early life.

The results suggest that protein restriction in early life reduces, temporarily, the animal's subsequent potential for protein retention and LW gain although the extent of these effects appear to be influenced by energy intake in the later period. The results also suggest that there is no justification for feeding protein-deficient diets during the early stage of growth since, from the results presented, it seems that protein restriction in early life will increase the time and feed required by pigs to reach normal slaughter weights. Furthermore, in the case of pigs killed at light pork weights (45–50 kg) a protein restriction imposed during early development is likely to increase carcass fat percentage.

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