Utilization of ileal digestible amino acids by growing pigs: effect of dietary lysine concentration on efficiency of lysine retention

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Diets were formulated using sugar, soya-bean meal and free amino acids to contain 0·1–0·8 g lysine/MJ digestible energy (DE) and offered at three times maintenance to male and female pigs from 20 to 45 kg live weight. Growth responses and retentions of protein, fat, energy and lysine were assessed. Increasing the dietary lysine concentration resulted in significant ($P < 0·001$) linear and curvilinear increases in growth rates and decreases in food conversion ratios. There was only a small effect of lysine concentration on total energy retention, but a substantial effect on the partitioning of energy deposition, with increases in the rate of protein deposition and decreases in fat retention. There was no difference in the efficiency of protein deposition between male and female pigs but males responded more to higher lysine concentrations than females (estimated 0·93 and 0·74 g lysine/MJ DE for males and females respectively). Lysine concentration in the protein deposited by the pigs increased linearly and curvilinearly ($P < 0·01$) from 5·8 to 6·6 g lysine/16 g N with increasing dietary lysine concentration. There was a linear and quadratic response ($P < 0·001$) in retention of ileal digestible lysine, with the minimum retention of 0·16 occurring at 0·1 g lysine/MJ DE and increasing to a maximum retention of 0·73 at a dietary concentration of 0·47 g lysine/MJ DE. The efficiency of lysine retained/ileal digestible lysine intake was 0·86 and the endogenous lysine loss was estimated at 0·94 g/d.

Ileal digestible lysine: Lysine: Soya-bean meal: Pig

Amino acid availability is normally assessed using slope-ratio assays, where the response to graded levels of the test amino acid in a protein is compared with the response to graded levels of the standard amino acid (e.g. Batterham *et al.* 1984). Such assays are time-consuming and expensive to conduct, and there has been increasing interest in the potential of the ileal digestibility assay for assessing availability. With this assay, the digestibility of amino acids at the terminal ileum is assessed, normally by the use of a cannula inserted in the terminal ileum.

Leibholz (1985) reported that the retention of ileal digestible lysine from five diets ranged from 0·86 to 0·94 and suggested that the assay could be used to assess availability. The high retentions of ileal digestible lysine indicate that the technique has potential to assess availability and it would have the advantage that the availabilities of all nine essential amino acids could be assessed at the one time. However, the estimates of lysine retention reported by Leibholz (1985) are higher than other reports in the literature. For example, Zebrowska & Kotarbinska (1972) reported that only 50% of the dietary lysine was recovered in the carcasses of pigs given a barley–skim milk diet. Batterham *et al.* (1990) reported that only 53–63 % of the estimated ileal digestible lysine was retained in pigs given wheat–cottonseed meal or wheat–soya-bean meal diets. It is possible that the efficiency of lysine retention could be influenced by the degree of lysine deficiency in the diet and this may in part account for the variation in the previously mentioned estimates.

The present paper reports an experiment which was conducted to determine the efficiency

of lysine utilization in both male and female pigs as affected by dietary lysine concentration. The study forms part of a longer term project to evaluate the relative merits of the ileal digestibility assay for assessing amino acid availability.

EXPERIMENTAL

Diets

Soya-bean meal (Table 1) was used as the source of lysine and most amino acids in the diets (Table 2). Supplements of threonine, valine, methionine and histidine were added to maintain a minimum surplus of 20% of the other essential amino acids relative to lysine (Agricultural Research Council, 1981). The soya-bean meal was 'prepress' solvent extracted. It contained 14·9 (SE 0·45) MJ digestible energy (DE)/kg and the apparent ileal digestibilities of nitrogen and lysine were 0·85 (SE 0·017) and 0·89 (SE 0·019) respectively (determined with four pigs fitted with 'T'-piece cannulas at the terminal ileum and housed in metabolism crates). The DE contents of the other dietary components were estimated using results of previous determinations at this Institute. Dietary energy was maintained at 15·3 MJ DE/kg using raw sugar (sucrose) and soya-bean oil as non-protein energy sources.

Animals and procedures

The eight diets were arranged in a randomized block design. The pigs were blocked on 7-week weight, sex and position in the experimental facilities. There were four blocks, each containing eight males and eight females, all of the Large White breed. The pigs were penned individually and water supplied by 'nipple' drinkers.

Dietary treatments were introduced when the pigs reached 20 kg live weight. The diets were offered at three times maintenance energy requirements. The pigs were fed every 3 h, with an automatic frequent feeder to ensure the utilization of the added free amino acids (Batterham & Murison, 1981). The food was offered air-dry. Rations were adjusted after the weekly weighings of the pigs.

The pigs were slaughtered by electric stunning after reaching a minimum of 45 kg live weight. The blood was collected and the viscera washed to remove undigested material. The blood and washed viscera were then combined and frozen. The carcasses (with hair) were washed clean with water, split longitudinally down the middle of the vertebrae and the left-hand side stored at $-15°$, then ground, mixed, sampled and freeze-dried before chemical analyses. The blood and viscera were processed in a similar manner.

In order to determine nutrient retentions, four male and four female pigs were slaughtered at the commencement of the experiment (20 kg live weight) and the chemical composition of the blood plus washed viscera and whole carcasses determined as described for pigs slaughtered at 45 kg live weight.

Pig response was assessed in terms of daily live-weight gain; food conversion ratio (FCR); backfat thickness (P_2); empty body-weight:final live weight; gain/d and FCR on an empty body-weight basis; protein, fat and energy content in the empty body; protein, fat and energy deposition/d; protein, fat and energy deposition:DE intake; protein retention:ileal digestible protein intake; lysine retention:total lysine intake and lysine retention:apparent ileal digestible lysine intake.

The following factors were used in the previously mentioned calculations: 6·25 to convert N to protein (Agricultural Research Council, 1981); 0·93 and 0·92 to convert initial live weight to estimated empty-body-weight for males and females respectively; 8·4 and 9·4 to calculate the energy (MJ/kg) and 140 to calculate the protein (g/kg) in the empty bodies for males and females respectively at the commencement of the experiment (these factors were determined on the four males and four females slaughtered at 20 kg live weight). Fat

Table 1. *Composition (g/kg) of the soya-bean meal*

Crude protein (nitrogen × 6·25)	463
Dry matter	883
Light petroleum (b.p. 40–60°) extract	14
Neutral-detergent fibre	111
Ash	66
Gross energy (MJ/kg)	17·5
Digestible energy (MJ/kg)	14·9
Essential amino acids	
Threonine	19
Cystine	9
Valine	17
Methionine	7
Isoleucine	18
Leucine	35
Tyrosine	16
Phenylalanine	23
Histidine	14
Lysine	27
Tryptophan	6·8
Apparent ileal digestibility of lysine (proportion of total)	0·89

Table 2. *Composition (g/kg; air-dry basis) of the diets*

Diet no....	1	2	3	4	5	6	7	8
Components								
Sugar (sucrose)	891	831	771	711	651	591	531	471
Soya-bean meal	57	114	171	228	285	342	399	456
L-Threonine	0·11	0·23	0·34	0·46	0·57	0·68	0·80	0·91
L-Valine	0·33	0·66	0·99	1·32	1·65	1·98	2·31	2·64
DL-Methionine	0·48	0·97	1·45	1·94	2·42	2·91	3·39	3·88
L-Histidine	0·03	0·06	0·09	0·12	0·15	0·18	0·21	0·24
Minerals and vitamins*	5	5	5	5	5	5	5	5
Dicalcium phosphate	30	30	30	30	30	30	30	30
Soya-bean oil	16	18	20	22	24	26	28	30
Composition								
Digestible energy (DE) (MJ/kg)	15·3	15·3	15·3	15·3	15·3	15·3	15·3	15·3
Lysine (g/kg)	1·53	3·07	4·60	6·13	7·67	9·20	10·7	12·27
(g/MJ DE)	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8

* Contributed (mg/kg diet): iron 60, zinc 100, manganese 30, copper 5, iodine 2, sodium chloride 2·8 g, selenium 0·15, retinol equivalent 960 μg, cholecalciferol 12 μg, α-tocopherol 20, thiamin 1·5, riboflavin 3, nicotinic acid 14, pantothenic acid 10, pyridoxine 2·5, cyanocobalamin 15 μg, pteroylmonoglutamic acid 2, choline 500, ascorbic acid 10, biotin 0·1.

in the carcass was calculated as (carcass energy − protein energy): 39·6 (Burlacu *et al.* 1973). Energy stored as protein was calculated as carcass protein (kg) × 24·2 (Jordan & Brown, 1970). The amino acid compositions of composite samples of the blood plus viscera and the carcasses from the eight pigs for each diet, and for the eight pigs slaughtered at 20 kg live weight, were determined.

The results were analysed by analysis of variance and linear and quadratic functions were

Table 3. *Live-weight gain, food conversion ratio (FCR) and backfat thickness of male (M) and female (F) pigs given increasing concentrations of dietary lysine during the 20–45 kg growth phase*

Lysine (g/MJ DE)	Live-wt gain (g/d)			FCR			Backfat (mm)		
	M	F	Mean	M	F	Mean	M	F	Mean
0·1	205	147	176	5·08	6·23	5·65	19·8	15·3	17·5
0·2	385	399	392	3·24	3·20	3·22	20·8	22·5	21·6
0·3	480	483	481	2·68	2·68	2·68	19·0	20·3	19·6
0·4	557	564	561	2·34	2·32	2·33	17·5	19·0	18·3
0·5	669	646	658	1·92	2·00	1·96	14·3	15·3	14·8
0·6	691	686	688	1·87	1·93	1·90	14·8	11·3	13·0
0·7	745	715	730	1·75	1·85	1·80	12·3	15·3	13·8
0·8	759	694	727	1·72	1·87	1·79	13·3	16·0	14·6
Mean	561	542		2·58	2·76		16·4	16·9	
SEM (edf 44)	17·7			0·122			1·29		
Statistical significance									
Lysine (L)		***			***			***	
Sex (S)		*			**			NS	
L × S		NS			***			*	
L: Linear		***			***			***	
Quadratic		***			***			NS	
S × L: Linear		NS			*			NS	
Quadratic		*			**			NS	

NS, not significant ($P > 0·05$); DE, digestible energy.
* $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.

fitted to describe the nature of the responses and to predict maximum values. The regression equations relating FCR on an empty-body-weight basis, protein retention:ileal digestible protein intake and lysine retention:ileal digestible lysine intake to dietary lysine concentration were improved by deleting the responses at 0·1 g lysine/MJ DE from the calculations and only the latter equations are reported in Table 10 and Fig. 2 (pp. 91 and 92). The relationships between protein retention to ileal digestible protein intake and lysine retention to ileal digestible lysine intake were analysed by a bent stick model for non-linear regression.

Chemical analyses

The techniques used were the methods of the Association of Official Analytical Chemists (1984) except that N and gross energy in the carcass samples were determined by near infra-red reflectance spectrophotometry using previously established regression equations (George *et al.* 1987). The concentrations of N and gross energy in the samples from pigs given diets 1 and 2 were outside the range of values used to develop the prediction equations, and these values were determined by Kjeldahl N and adiabatic bomb calorimetry. Amino acids (except proline, hydroxyproline and tryptophan) were determined by high-performance liquid chromatography (HPLC; Hughes & Wilson, 1982). A two-buffer gradient-elution system with a Benson DX8·25 8 μm ion exchange column was used. Detection was by post-column derivatization with *o*-phthaldialdehyde–mercaptopropionic acid using u.v. absorption at 336 nm. The amino acid profiles were adjusted to an estimated 0·95 recovery of Kjeldhal N (Association of Official Analytical Chemists, 1984). For the determination of methionine in the soya-bean meal, performic acid oxidation was used before acid hydrolysis (Gehrke *et al.* 1987). Tryptophan was determined by HPLC following alkaline-hydrolysis using lithium hydroxide (Degussa AG, 1986).

Table 4. *Empty-body weight: live weight, empty-body-weight gain/d and food conversion ratio (FCR) on an empty-body-weight basis of male (M) and female (F) pigs given increasing concentrations of dietary lysine during the 20–45 kg growth phase*

Lysine (g/MJ DE)	Empty-body-wt: live wt (kg:kg)			Empty-body-wt gain (g/d)			FCR (empty-body-wt basis)		
	M	F	Mean	M	F	Mean	M	F	Mean
0·1	0·98	0·97	0·97	215	157	186	4·83	5·80	5·31
0·2	0·96	0·96	0·96	382	393	387	3·26	3·25	3·26
0·3	0·95	0·95	0·95	461	470	465	2·79	2·75	2·77
0·4	0·95	0·96	0·96	537	562	549	2·43	2·33	2·38
0·5	0·94	0·94	0·94	632	616	624	2·03	2·10	2·06
0·6	0·94	0·94	0·94	652	654	653	1·98	2·01	2·00
0·7	0·94	0·92	0·93	705	660	683	1·85	2·01	1·93
0·8	0·95	0·93	0·94	733	652	693	1·78	1·99	1·88
Mean	0·95	0·95		539	521		2·62	2·78	
SEM (edf 44)	0·006			17·0			0·111		
Statistical significance									
Lysine (L)		***			***			***	
Sex (S)		NS			*			**	
L × S		NS			*			***	
L: Linear		***			***			***	
Quadratic		*			***			***	
S × L: Linear		NS			NS			NS	
Quadratic		**			**			***	

NS, not significant ($P > 0·05$); DE, digestible energy.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

RESULTS

Increasing dietary lysine concentration resulted in significant increases in gain/d, and decreases in FCR on both a live-weight and empty-body-weight basis, P_2 and the proportion empty-body-weight:live weight (Tables 3 and 4). Males responded to higher lysine concentrations than females for gain/d and FCR on both a live-weight and empty-body-weight basis (Tables 3, 4 and 10).

Increasing the lysine concentration decreased the gross energy and fat contents of the pigs at slaughter, and increased the protein content ($P < 0·001$) (Table 5). Protein deposition/d increased with increasing lysine concentration to a predicted maximum of 129 g/d for males at an estimated lysine concentration of 0·93 g/MJ DE and 112 g/d at 0·74 g lysine/MJ DE for females (Tables 6 and 10).

The efficiency of protein retention:DE intake increased with increasing lysine concentration (Table 7). Mean retention of DE intake was 0·45 and there were small quadratic ($P < 0·001$) effects of lysine concentration on this retention.

Protein retention:ileal digestible protein intake increased in a quadratic response ($P < 0·001$) to lysine concentration from a minimum of 0·36 at 0·1 g lysine/MJ DE to an estimated maximum of 0·66 at 0·42 g lysine/MJ DE (Tables 8 and 10). The efficiency of protein retention:ileal digestible protein intake was 0·75 up to an intake of 147 g/d and 0·19 thereafter (Fig. 1).

There were significant linear or quadratic effects of dietary lysine concentration on the concentration of a number of essential and non-essential amino acids in the protein retained by the pigs (Table 9). Lysine concentration increased linearly and curvilinearly ($P < 0·01$) from 5·8 to 6·6 g lysine/16 g N with increasing dietary lysine concentration.

Table 5. *Protein, fat and energy concentration in the empty body of male (M) and female (F) pigs given increasing concentrations of dietary lysine during the 20–45 kg growth phase*

Lysine (g/MJ DE)	Protein (g/kg)			Fat (g/kg)			Energy (MJ/kg)		
	M	F	Mean	M	F	Mean	M	F	Mean
0·1	96	108	102	424	376	400	19·1	17·5	18·3
0·2	113	109	111	354	365	360	16·8	17·1	16·9
0·3	132	129	130	293	299	296	14·8	15·0	14·9
0·4	145	146	145	251	268	259	13·4	14·1	13·8
0·5	150	155	152	205	227	216	11·8	12·7	12·2
0·6	153	157	155	192	187	189	11·3	11·2	11·2
0·7	157	154	155	155	199	177	9·9	11·6	10·8
0·8	158	158	158	174	199	186	10·7	11·7	11·2
Mean	138	139		256	265		13·5	13·9	
SEM (edf 39)	3·2			10·5			0·39		
Statistical significance									
Lysine (L)		***			***			***	
Sex (S)		NS			NS			*	
L × S		NS			**			**	
L: Linear		***			***			***	
Quadratic		***			***			***	
S × L: Linear		NS			***			***	
Quadratic		NS			NS			NS	

NS, not significant ($P > 0·05$); DE, digestible energy.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

Table 6. *Protein, fat and energy deposition of male (M) and female (F) pigs when given increasing concentrations of dietary lysine during the 20–45 kg growth phase*

Lysine (g/MJ DE)	Protein (g/d)			Fat (g/d)			Energy (MJ/d)		
	M	F	Mean	M	F	Mean	M	F	Mean
0·1	9	8	8	174	122	148	7·1	5·0	6·1
0·2	36	34	35	205	206	206	9·0	9·0	9·0
0·3	58	56	57	193	191	192	9·1	8·9	9·0
0·4	80	84	82	184	196	190	9·2	9·8	9·5
0·5	100	101	100	167	172	169	9·0	9·3	9·1
0·6	106	110	108	153	140	146	8·6	8·2	8·4
0·7	123	108	115	125	153	139	7·9	8·7	8·3
0·8	125	111	118	150	152	151	9·0	8·7	8·9
Mean	80	76		169	167		8·6	8·4	
SEM (edf 39)	3·4			10·7			0·42		
Statistical significance									
Lysine (L)		***			***			***	
Sex (S)		NS			NS			NS	
L × S		*			**			*	
L: Linear		***			***			***	
Quadratic		***			***			***	
S × L: Linear		*			*			*	
Quadratic		**			NS			*	

NS, not significant ($P > 0·05$); DE, digestible energy.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

Table 7. *Protein, fat and energy deposition per unit digestible energy (DE) intake of male (M) and female (F) pigs given increasing concentrations of dietary lysine during the 20–45 kg growth phase*

Lysine (g/MJ DE)	Protein (kg/MJ)			Fat (kg/MJ)			Energy (MJ/MJ)		
	M	F	Mean	M	F	Mean	M	F	Mean
0·1	0·5	0·6	0·5	11·1	8·8	9·9	0·45	0·36	0·41
0·2	1·9	1·7	1·8	10·7	10·6	10·6	0·47	0·46	0·47
0·3	3·0	2·9	2·9	9·8	9·7	9·8	0·46	0·45	0·46
0·4	4·0	4·2	4·1	9·2	9·8	9·5	0·46	0·49	0·48
0·5	5·1	5·1	5·1	8·4	8·8	8·6	0·46	0·47	0·46
0·6	5·4	5·5	5·5	7·8	7·0	7·4	0·44	0·41	0·42
0·7	6·2	5·3	5·8	6·4	7·6	7·0	0·40	0·43	0·42
0·8	6·3	5·6	5·9	7·5	7·7	7·6	0·45	0·44	0·45
Mean	4·0	3·9		8·9	8·7		0·45	0·44	
SEM (edf 39)	0·17			0·46			0·173		
Statistical significance									
Lysine (L)		***			***			***	
Sex (S)		*			NS			NS	
L × S		**			**			**	
L: Linear		***			***			NS	
Quadratic		***			NS			***	
S × L: Linear		**			**			*	
Quadratic		**			NS			*	

NS, not significant ($P > 0·05$).
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

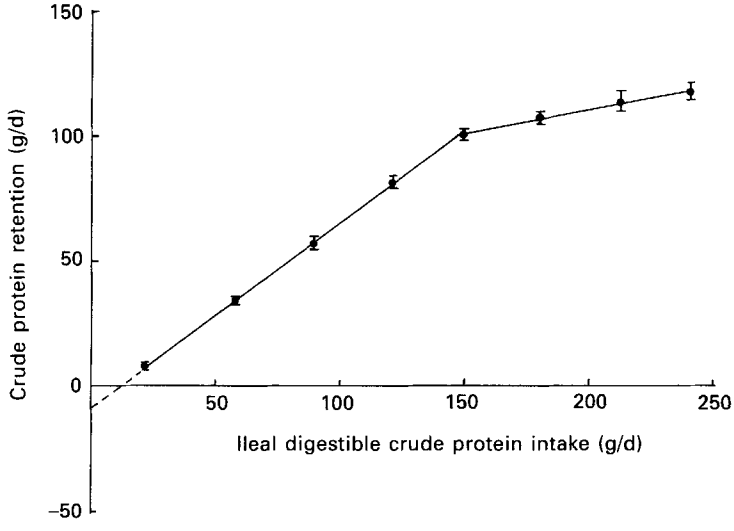

Fig. 1. Protein retained (PR) (g/d) as a function of ileal digestible protein intake (IDPI) (g/d). Regression equations for the two slopes were:

PR = 0·75 IDPI (SE 0·017) − 8·9 (SE 1·67) r^2 0·98, linear response $P < 0·001$, inflection point 147 (SE 6·1) g/d
PR = 0·19 IDPI (SE 0·043) + 72·8 (SE 8·79) r^2 0·42, linear response $P < 0·001$.

Values are means with vertical bars representing the standard error of the mean.

Lysine retention:ileal digestible lysine intake responded in a linear and curvilinear manner ($P < 0.001$) to lysine concentration, from a minimum of 0·16 at 0·1 g lysine/MJ DE to a maximum of 0·73 at 0·47 g lysine/MJ DE (Fig. 2). The efficiency of lysine retention:ileal digestible lysine intake was 0·86 up to an intake of 9·1 g/d and 0·16 thereafter (Fig. 3). The endogenous lysine loss was estimated at 0·94 g/d.

DISCUSSION

The results indicate that dietary lysine concentration has a substantial effect on the overall amount of ileal digestible lysine retained. Minimum overall lysine retention (0·16) occurred with the lowest lysine concentration (0·1 g lysine/MJ DE), increased to a maximum of 0·73 at 0·47 g lysine/MJ DE and then declined. The low retention at low levels of lysine intake is presumably a reflection of a greater proportion of the lysine being used for maintenance for the slower growing pigs. Similarly, the decline in the overall retention at the higher levels of dietary lysine concentration coincided with the lowering of efficiency of lysine retention as lysine intake approached or exceeded maximum needs, or both. That a maximum of only 0·73 lysine was retained indicates that 0·27 of the lysine was catabolized. This catabolism may have been due to inherent physiological responses of the pig or to a portion of the lysine being absorbed in a form that was unavailable for protein metabolism (Batterham *et al.* 1990), or both.

The maximum overall retention of 0·73 for ileal digestible lysine is slightly higher than that reported by Batterham *et al.* (1990) (0·63), but is lower than that reported by Leibholz (1985) (0·86–0·94). However, in the latter study both protein and lysine contents in the carcasses were not determined but estimated from values from piglets in previous experiments, and this may be the reason for the higher values. The retention value of 0·73 is also lower than the estimated availability of lysine in soya-bean meal, as determined with slope-ratio assays (0·88; Standing Committee on Agriculture, 1987). The linear and quadratic nature of the response in pigs, together with the maximum retention of only 0·73, indicates that overall retention values do not provide information as to whether ileal digestibility values reflect availability, as was suggested by Leibholz (1985).

The regression equation relating protein retained to ileal digestible protein intake (Fig. 1) indicates that the apparent biological value of the dietary protein was 0·75 and the estimated endogenous protein loss was 8·9 g/d. These estimates are slightly higher than estimates of 0·60 and 7·6 g/d reported by Campbell *et al.* (1988) for weaner pigs fed on a cereal-based diet. The higher estimate for apparent biological value of the protein indicates the advantages of using soya-bean meal supplemented with free amino acids in sugar-based diets for requirement studies, compared with conventional cereal-based diets. In contrast to the results of Campbell *et al.* (1988) where protein retention reached a plateau, in the present experiment protein continued to be deposited after the inflection point, but with a much reduced efficiency.

The regression equation relating lysine retention to ileal digestible lysine intake (Fig. 3) indicates that, as with protein, lysine was also used with a constant efficiency (0·86) up to an intake of 9·1 g ileal digestible lysine/d and then declined. However, in contrast to the protein results, in the second phase the linear response was not significant ($P > 0.05$), which appeared to be due to an increase in the variability in the data. The efficiency of lysine retention in the first phase (0·86) is similar to that reported for rats (0·83; Bolton & Miller, 1985). In that study, the response was also linear. As lysine was retained with an efficiency of 0·86 it indicates that 0·14 of the apparently absorbed lysine was catabolized. This estimate of 0·14 is lower than that indicated by relating overall lysine retention to ileal digestible lysine intake (minimum of 0·27 of the lysine catabolized, Fig. 2). This difference

Table 8. *Protein retained: ileal digestible protein intake and lysine retained: lysine intake of male (M) and female (F) pigs given increasing concentrations of dietary lysine during the 20–45 kg growth phase*

Lysine (g/MJ DE)	Protein retained: ileal digestible protein intake (kg/kg)			Lysine retained: lysine intake (kg/kg)		
	M	F	Mean	M	F	Mean
0·1	0·35	0·37	0·36	0·14	0·13	0·14
0·2	0·62	0·57	0·60	0·55	0·50	0·53
0·3	0·65	0·63	0·64	0·60	0·57	0·58
0·4	0·66	0·69	0·67	0·64	0·67	0·66
0·5	0·67	0·68	0·67	0·66	0·67	0·67
0·6	0·59	0·60	0·60	0·61	0·62	0·61
0·7	0·59	0·50	0·54	0·56	0·48	0·52
0·8	0·52	0·46	0·49	0·52	0·46	0·49
Mean	0·58	0·56		0·53	0·51	
SEM (edf 39)	0·033			0·033		
Statistical significance						
Lysine (L)		***			***	
Sex (S)		NS			NS	
L × S		NS			NS	
L: Linear		NS			***	
Quadratic		***			***	
S × L: Linear		NS			NS	
Quadratic		NS			NS	

NS, not significant ($P > 0·05$); DE, digestible energy.
*** $P < 0·001$.

is presumably due to the allowance for the endogenous loss of lysine to maintain zero balance (0·94 g/d) with the former estimate. The efficiency of retention of apparently absorbed lysine would not be expected to reach 1·0 as some of the absorbed lysine could be expected to be lost in normal physiological processes during growth, and some of the absorbed lysine may be in a form that is unavailable for protein synthesis. It is doubtful whether the latter was significant with soya-bean meal as estimates of ileal digestibility of lysine and lysine availability are similar (Standing Committee on Agriculture, 1987; Batterham *et al.* 1990), indicating that reduced ileal digestibility is the main reason for reduced availability. If this was the case in this experiment, then 0·14 of the absorbed lysine was lost in normal physiological processes in the pig during growth.

The efficiency of retention of ileal digestible lysine was greater (0·86, Fig. 3) than for ileal digestible protein retention (0·75, Fig. 1). This is not surprising as the diets were designed to be lysine-deficient and contained a minimum 20% surplus of the other essential amino acids. In addition, the essential: non-essential amino acid ratio was 39:61, which indicates that there was also a surplus of non-essential amino acids relative to the ideal ratio of 46:54 (Fuller & Wang, 1987).

The linear and curvilinear responses in protein deposition (g/d) initially indicated similar efficiency of use of lysine by both sexes for protein deposition. However, the responses indicated that males had a greater capacity for lean deposition than females and thus responded more to higher dietary lysine concentrations. Such differences between male and female grower pigs have been recorded previously under *ad lib.* feeding conditions but not with restricted feeding regimens (Giles *et al.* 1987). The availability of lysine in soya-bean meal was estimated as 0·88 (Standing Committee on Agriculture, 1987) and hence the

Table 9. *Amino acid composition (g/16 g nitrogen, empty-body-weight basis) of pigs slaughtered at 20 kg and at 45 kg live weight when given diets increasing from 0·1 to 0·8 g lysine/MJ digestible energy*

Amino acid	Pigs at 20 kg	Diet 1	2	3	4	5	6	7	8	Statistical significance: 20 kg *v.* diets 1–8	Diets 1–8: Diet	Linear	Quadratic	SEM (edf 8)
Aspartic acid	8·23	8·02	8·21	8·19	8·31	8·13	8·13	8·21	8·39	NS	NS	NS	NS	0·101
Threonine	3·87	3·69	3·96	3·84	3·88	3·76	3·70	3·54	4·09	NS	NS	NS	NS	0·129
Serine	4·54	4·53	4·46	4·44	4·39	4·48	4·53	4·40	4·39	NS	NS	NS	NS	0·071
Glutamic acid	13·15	12·85	13·36	13·01	13·14	13·17	13·26	13·28	13·13	NS	NS	NS	NS	0·202
Glycine	8·21	11·70	9·82	9·91	9·17	8·61	7·90	8·98	8·49	*	**	***	**	0·468
Alanine	6·50	7·31	6·93	6·89	6·70	6·83	6·45	6·66	6·62	NS	NS	*	NS	0·248
Valine	4·20	3·92	4·04	3·99	4·17	4·22	4·26	4·13	4·11	NS	NS	NS	NS	0·157
Cystine	1·27	1·04	0·73	0·63	0·78	0·71	1·03	1·04	1·06	NS	NS	NS	NS	0·273
Methionine	1·96	1·67	1·81	1·88	1·80	2·01	2·07	1·96	1·91	NS	*	**	NS	0·082
Isoleucine	3·16	2·78	3·03	3·18	3·17	3·19	3·38	3·10	3·15	NS	NS	*	*	0·126
Leucine	7·02	6·25	6·53	6·56	6·63	6·76	6·93	6·81	6·87	*	*	**	NS	0·148
Tyrosine	2·67	2·09	2·32	2·37	2·54	2·71	2·87	2·49	2·68	NS	*	***	*	0·132
Phenylalanine	3·98	3·38	3·39	3·39	3·39	3·56	3·72	3·76	3·69	**	*	**	NS	0·147
Histidine	3·42	2·72	3·14	3·29	3·20	3·41	3·29	3·16	3·43	NS	NS	*	NS	0·187
Ammonia	1·33	1·30	1·31	1·24	1·30	1·32	1·31	1·20	1·24	NS	*	NS	NS	0·035
Lysine	6·50	5·83	6·19	6·24	6·47	6·54	6·64	6·33	6·57	NS	*	***	**	0·125
Arginine	5·48	6·44	6·27	6·44	6·46	6·08	6·02	6·42	5·66	***	***	***	NS	0·124
Proline†	6·05	6·05	6·05	6·05	6·05	6·05	6·05	6·05	6·05					
Hydroxyproline†	2·69	2·69	2·69	2·69	2·69	2·69	2·69	2·69	2·69					
Tryptophan†	0·78	0·78	0·78	0·78	0·78	0·78	0·78	0·78	0·78					

NS, not significant ($P > 0·05$).
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Not detected by high-performance liquid chromatographic analyses; values are from Campbell *et al.* (1988).

Table 10. *Regression equations relating various response variables to dietary lysine concentration (g total lysine/MJ digestible energy)*

Sex	Variable	Regression equation: Intercept		Lysine		Lysine^2	Predicted optimal value	Critical lysine concentration (g/MJ DE)	r^2	Residual SD
M	Empty-body-wt gain (g/d)	92·9	+	1482·6	−	865·7	728	0·86	0·95	42·0
F	Empty-body-wt gain (g/d)	2·2	+	2017·3	−	1524·2	670	0·66	0·96	33·8
M	FCR (empty-body-wt basis)	4·465	−	6·957	+	4·544	1·80	0·77	0·94	0·135
F	FCR (empty-body-wt basis)	4·582	−	7·886	+	5·875	1·94	0·67	0·92	0·139
M	Crude protein* deposited (g/d)	−22·4	+	326·1	−	175·2	129	0·93	0·98	5·8
F	Crude protein deposited (g/d)	−31·3	+	387·7	−	262·3	112	0·74	0·98	6·0
MF	Protein retained : ileal digestible protein intake	0·4355	+	1·076	−	1·283	0·66	0·42	0·63	0·050

M, male; F, female; FCR, food conversion ratio.
* Nitrogen × 6·25.

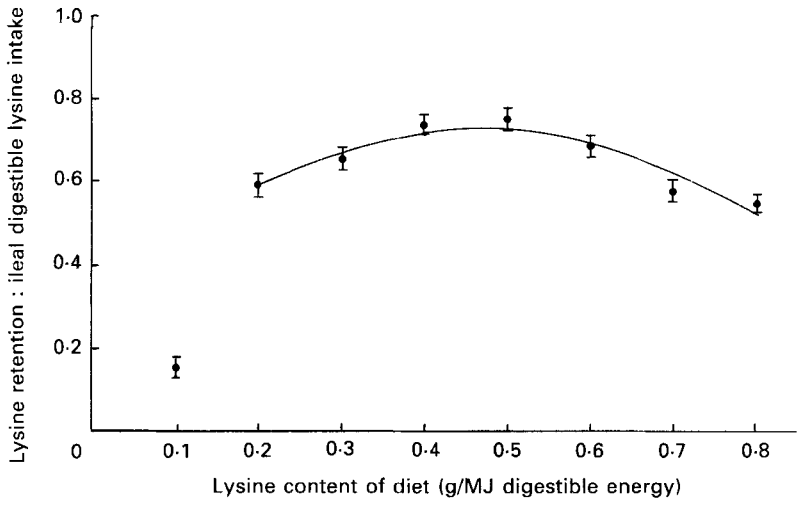

Fig. 2. Lysine retained (LR):ileal digestible lysine intake (IDLI) as a function of lysine concentration (L) in the diet (g/MJ digestible energy (DE)). The regression equation was:

$$LR:IDLI = 1{\cdot}745\ L\ (SE\ 0{\cdot}0871) - 1{\cdot}857\ L^2\ (SE\ 0{\cdot}0851) + 0{\cdot}316\ (SE\ 0{\cdot}0197)$$

Predicted maximum value 0·73 at 0·47 g lysine/MJ DE. r^2 0·60.

Values are means with vertical bars representing the standard error of the mean.

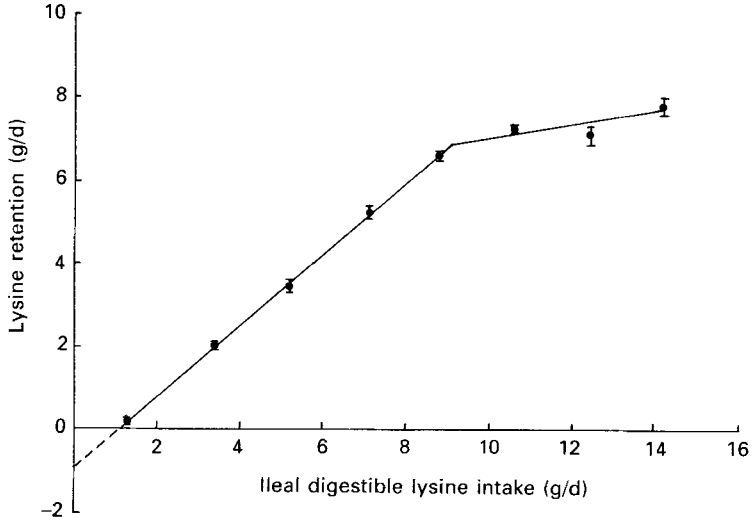

Fig. 3. Lysine retained (LR) (g/d) as a function of ileal digestible lysine intake (IDLI) (g/d). Regression equations for the two slopes were:

$$LR = 0{\cdot}86\ IDLI\ (SE\ 0{\cdot}019) - 0{\cdot}94\ (SE\ 0{\cdot}109)\quad r^2\ 0{\cdot}98,\ \text{linear response } P < 0{\cdot}001,\ \text{inflection point } 9{\cdot}11\ (SE\ 0{\cdot}398)\ g/d$$

$$LR = 0{\cdot}16\ IDLI\ (SE\ 0{\cdot}090) + 5{\cdot}43\ (SE\ 1{\cdot}141)\quad r^2\ 0{\cdot}10,\ \text{linear response } P < 0{\cdot}1.$$

Values are means with vertical bars representing the standard error of the mean.

estimated values for maximum protein deposition corresponded to 0·82 and 0·65 g available lysine/MJ DE for males and females respectively. For maximum empty-body-weight gain/d, however, males responded to a maximum of 0·76 g available lysine/MJ DE and females to 0·58, whilst for minimum FCR, males responded to a maximum of 0·68 g available lysine/MJ DE and females to 0·59. These results indicate that the requirements for maximum protein deposition are higher than for maximum growth rate, which in turn are higher than for minimum FCR. It should also be emphasized, however, that because of the curvilinear nature of the responses, maximum economical levels for feeding may be considerably below the optimum biological responses. This is in agreement with the findings of Giles *et al.* (1987).

Although there was a quadratic response in efficiency of energy retention to lysine concentration, the overall effect was minimal. This indicates that the efficiency of retention of DE was approximately 0·45 and was largely unaffected by lysine concentration. However, the results for protein and fat deposition indicate that there are substantial differences in the partitioning of the energy in the body. At low lysine concentration, protein deposition is minimal and the majority of energy is retained as fat. However, as dietary lysine concentration increases, protein deposition increases and the energy stored as fat decreases.

The small changes in some of the amino acid concentrations in the pigs indicate that the amino acid profile can be altered by dietary lysine concentration. This is in agreement with the work of Jelic (1977) and Campbell *et al.* (1988) who also found that amino acid concentrations in pigs were influenced by increasing dietary lysine or protein concentration. These changes presumably reflect changes in the proportions of different amino acids used for maintenance and growth. These proportions could be expected to vary as growth rates increased with increasing dietary lysine concentration. The maximum value of 6·6 g lysine/16 g N agrees well with the values of 6·5 (Campbell *et al.* 1988), 6·8–7·1 (Zhang *et al.* 1986) and that of 'ideal' protein (7·0, Agricultural Research Council, 1981). However, the slight changes in the lysine and other amino acids in the protein of pigs indicate that the concept of an 'ideal' ratio of amino acids in the feed as recommended by the Agricultural Research Council (1981) may not necessarily apply, as the requirements of amino acids for maintenance and growth differ (Fuller & Wang, 1987). Thus, an 'ideal' ratio of amino acid requirements needs to be defined for a given level of production or energy intake (i.e. for three times maintenance as used in the present experiment). Alternatively, amino-acid needs can be assessed by computer-simulation models which estimate the amino-acid needs for maintenance and production at given levels of energy intake (e.g. Black *et al.* 1986).

These results indicate that the overall retention of ileal digestible lysine is affected by the dietary lysine concentration. Maximum retention was 0·73 at a dietary lysine concentration of 0·47 g lysine/MJ DE. The 0·27 portion of lysine apparently absorbed and not recovered in the empty body was catabolized either during normal protein metabolism for maintenance and growth or because some was absorbed in a form that was not available for protein metabolism, or both. As the overall retention of ileal digestible lysine varied with lysine concentration and maximum retention was only 0·73, retention values do not provide information as to whether ileal digestibility values reflect the availability of amino acids for the pig.

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