Utilization of ileal digestible amino acids by pigs: lysine

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Two experiments were conducted to determine the utilization of ileal digestible lysine by pigs. In the first, the apparent ileal digestibility of amino acids in cottonseed meal, meat-and-bone meal and soya-bean meal was determined in pigs fitted with 'T'-shaped cannulas. In the second experiment, three lysine-deficient diets were formulated to 0·36 g ileal digestible lysine/MJ digestible energy (DE), with lysine contributed from the three protein concentrates as the only source of lysine in sugar-based diets. An additional three diets were formulated with supplements of lysine to verify that lysine was limiting in the first three diets. The growth performance and retention of lysine by pigs given the six diets over the 20–45 kg growth phase were then determined. The apparent ileal digestibility of lysine in the three protein concentrates (proportion of total) was: cottonseed meal 0·74, meat-and-bone meal 0·78, soya-bean meal 0·89. Growth rates (g/d) of the pigs given the three diets formulated to 0·36 g ileal digestible lysine/MJ DE were significantly different ($P < 0·001$): cottonseed meal 377, meat-and-bone meal 492, soya-bean meal 541. The response of pigs to the addition of lysine confirmed that lysine was limiting in these diets. Crude protein (nitrogen × 6·25) deposited by the pigs was significantly higher ($P < 0·001$) for those given soya-bean meal (77 g/d), relative to meat-and-bone meal (66 g/d) and cottonseed meal (38 g/d). The proportion of ileal digestible lysine retained by pigs given the three protein concentrates was: cottonseed meal 0·36, meat-and-bone meal 0·60, soya-bean meal 0·75. The results indicate that values for the ileal digestibility of lysine in protein concentrates are unsuitable in dietary formulations as the assay does not reflect the proportion of lysine that can be utilized by the pig. It appears that, with heat-processed meals, a considerable proportion of the lysine is absorbed in a form(s) that is (are) inefficiently utilized.

Ileal digestibility: Lysine utilization: Protein concentrates: Pigs

Interest has centred on the use of the ileal digestibility assay to estimate amino acid availability. This assay has the advantage that the digestibility of all amino acids can be assessed at the same time and only small numbers of pigs are required per assay. The assumption is made that, if an amino acid is not recovered at the terminal ileum, then it has been absorbed in a form that can be utilized by the pig. With weaner pigs, Leibholz (1985) reported that the retention of apparently absorbed lysine at the terminal ileum was 0·86–0·94 for five diets containing different protein sources, and suggested that the apparent digestibility of lysine could be used to predict lysine availability.

However, in a previous study (Batterham *et al.* 1990*a*), there was close agreement between ileal digestibility and lysine availability in soya-bean meal (0·89, 0·90 respectively) but not for cottonseed meal (0·58–0·72 ileal digestibility, 0·27–0·30 lysine availability). Formulating diets containing cottonseed or soya-bean meals on an available lysine basis

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Table 1. *Composition (g/kg, air-dry basis) of the cottonseed meal, meat-and-bone meal and soya-bean meal*

Protein concentrate…	Cottonseed meal	Meat-and-bone meal	Soya-bean meal
Crude protein (nitrogen × 6·25)	408	525	463
Dry matter	885	953	883
Light petroleum (b.p. 40–60°) extract	17	95	14
Fibre: Crude	102	—	43
Neutral-detergent	296	—	111
Ash	63	323	66
Amino acids			
Aspartic acid	39·7	36·0	53·2
Threonine	14·9	16·8	19·2
Serine	20·6	22·4	25·3
Glutamic acid	86·1	64·2	85·9
Glycine	17·7	77·4	20·1
Alanine	16·7	42·7	20·2
Cystine	8·5	6·3	9·1
Valine	15·5	18·2	16·8
Methionine: 1*	4·8	6·4	4·3
2	6·4	7·7	7·0
Isoleucine	11·7	12·1	17·5
Leucine	25·1	28·9	35·0
Tyrosine	11·8	11·0	16·0
Phenylalanine	21·6	15·8	22·9
Histidine	13·5	13·2	13·9
Lysine	19·7	25·6	26·9
Arginine	47·9	39·5	35·4
Tryptophan	5·3	2·7	6·8

* 1, Acid-hydrolysis; 2, oxidized before acid-hydrolysis (see p. 683).

confirmed that the availability values were applicable to pigs (Batterham *et al.* 1990*a*). These results indicate that a portion of the ileal digestible lysine in cottonseed meal was not utilized by the pig.

The objectives of the work reported in the present paper were to determine the ileal digestibility of lysine in three protein concentrates, to use these values in dietary formulations, and to assess growth response and the utilization of the ileal digestible lysine by pigs.

EXPERIMENTAL

Protein concentrates

The three protein concentrates used were a 'prepress' solvent-extracted cottonseed meal, a meat-and-bone meal and a 'prepress' solvent-extracted soya-bean meal (Table 1). These three meals represented the range in estimated availability of lysine in protein concentrates (Standing Committee on Agriculture, 1987). Cottonseed meal represents a meal of estimated low lysine availability (0·40). It contains no anti-nutritional factors for pigs, other than free gossypol, which can be inactivated by the addition of ferrous sulphate to the diet, which binds the free gossypol (Tanksley & Knabe, 1981). Pigs can tolerate 100 mg free gossypol/kg in the diet without effect, or at least 500 mg/kg with ferrous sulphate (free gossypol–iron; 1:1, w/w). This is over twice the level of free gossypol that was used in the present study (224 mg/kg). Meat-and-bone meal is of medium lysine availability (0·70). Provided zinc and Fe levels are adequate, pigs can tolerate the calcium contributed by these

Table 2. *Expt 1. Composition of the diets for the ileal and faecal digestibility studies*

Protein concentrate...	Cottonseed meal	Meat-and-bone meal	Soya-bean meal
Protein concentrate	300	300	300
Minerals and vitamins*	5	5	5
Dicalcium phosphate	30	—	30
$FeSO_4.7H_2O$	0·1	—	—
Chromic oxide	2	2	2
Soya-bean oil	15	15	15
Sugar	648	678	648

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

Table 3. *Expt 2. Composition (g/kg, air-dry basis) of the diets*

Diet no....	1	2	3	4	5	6
Components						
Cottonseed meal	350	—	—	350	—	—
Meat-and-bone meal	—	275	—	—	275	—
Soya-bean meal	—	—	235	—	—	235
L-Lysine hydrochloride	—	—	—	1·92	1·92	2·05
Amino acids*	3·44	14·96	10·35	3·44	14·96	10·35
Mineral and vitamin premix†	5	10·10	5	5	10·10	5
Dicalcium phosphate	30	—	30	30	—	30
$FeSO_4.7H_2O$	1·1	0·25	—	1·1	0·25	—
Soya-bean oil	15	15	15	15	15	15
Raw sugar (sucrose)	595·46	684·69	704·65	593·54	682·77	702·60
Composition						
Digestible energy (DE; estimated; MJ/kg)	14·3	15·3	15·6	14·3	15·3	15·6
Ileal digestible lysine: g/kg	5·1	5·5	6·6	5·6	7·0	7·2
g/MJ DE	0·36	0·36	0·36	0·46	0·46	0·46
EAA:NEAA	35:65	34:66	41:59	35:65	34:66	41:59

EAA:NEAA, essential:non-essential amino acids.

* Contributed the following (g/kg) to the cottonseed, meat-and-bone meal and soya-bean meal diets respectively: DL-methionine 0·78, 2·18, 2·28, L-threonine 0·80, 1·82, 1·71, L-valine 0·86, 1·80, 2·45, L-isoleucine 0·69, 1·72, 0·75, L-leucine 0·18, 1·64, 0·66, L-tyrosine 0, 2·25, 0·84, L-phenylalanine 0, 0·83, 0, L-histidine 0·13, 1·80, 1·33, L-tryptophan 0, 0·92, 0·33.

† Composition as described in Table 2 except additional supplements of zinc oxide (100 mg/kg) and potassium sulphate (5 g/kg) were added to diets 2 and 5.

meals. Soya-bean meal represents a meal of high lysine availability (0·88) and adequately processed meal contains no anti-nutritional factors for pigs.

Expt 1. Ileal digestibility of amino acids

Diets. Three diets were formulated with the cottonseed meal, meat-and-bone meal and soya-bean meal as the only source of amino acids in sugar-based diets (Table 2). The cottonseed meal contained 12500 and 640 mg total and free gossypol/kg respectively and ferrous sulphate was added to inactivate any effects that the free gossypol may have on the pigs (Tanksley & Knabe, 1981). Chromic oxide was used as an indigestible marker to calculate digestibilities.

Animals and procedures. Four male pigs of approximately 40 kg live weight were fitted with 'T'-shaped cannulas about 300 mm anterior to the terminal ileum. After 7 d the pigs were gradually introduced to the experimental diets. The pigs were given each diet in a completely randomized design. The pigs were given 0·70 kg diet mixed with about 2 litres water at 12 h intervals. The diets were offered for 14 d and samples of faeces were collected over the 10–14 d period. On days 12 and 13 ileal digesta samples of 70–100 g were collected from the cannulas over the 2–8 h period after feeding.

The samples were stored at $-15°$ until the completion of the collections, then thawed, bulked for each collection period for each diet, freeze-dried and ground, before chemical analyses.

Expt 2. Utilization of ileal digestible lysine

Diets. Three diets were formulated to contain 0·36 g ileal digestible lysine/MJ digestible energy (DE; diet nos. 1, 2 and 3; Table 3). This level of lysine was chosen as it represents an area where the pig responds in a linear manner to lysine concentration as regards growth rate but it is near the plateau for lysine retention (Batterham *et al.* 1990*b*). To ensure that lysine was the limiting amino acid in the diet, supplements of other essential amino acids were added to provide a minimum of at least a 0·28 surplus, relative to lysine, according to the estimate of the Agricultural Research Council (1981), Fuller & Wang (1987) and as estimated by computer simulation studies using the 'Auspig' model (Black *et al.* 1986) for the Wollongbar genotype. Diet nos. 4, 5 and 6 were supplemented with lysine to verify that lysine was limiting in diet nos. 1–3. The DE content of the three protein concentrates was determined in Expt 1 and the DE content of the other ingredients was estimated from previous determinations at this Institute.

Animals and procedures. The six diets were arranged in a randomized block design. Ten pigs (five males and five females) were allocated to each diet (except diet no. 4 where only nine were allocated). The pigs were blocked on 7-week weight, sex and position in the experimental facilities. The pigs were of the Large White breed and they 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 a feeding scale of three times maintenance. The pigs were fed every 3 h, with an automatic feeder to ensure the utilization of the added free amino acids (Batterham & Murison, 1981). The feed was offered dry and daily feeding rates were adjusted after the weekly weighings of the pigs.

The pigs were slaughtered by electric stunning after reaching a minimum weight of 45 kg. The blood was collected and the viscera washed to remove undigested material. The blood and washed viscera were then combined and then 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 mixed blood and washed 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 in a similar manner as the 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

Table 4. *Expt 1. Apparent ileal digestibility of amino acids, nitrogen and dry matter in cottonseed meal, meat-and-bone meal and soya-bean meal*

Protein concentrate...	Cottonseed meal	Meat-and-bone meal	Soya-bean meal	Statistical significance of difference	SEM
Aspartic acid	0·82	0·64	0·89	***	0·024
Threonine	0·76	0·72	0·85	**	0·024
Serine	0·80	0·69	0·87	***	0·018
Glutamic acid	0·90	0·76	0·92	***	0·018
Glycine	0·76	0·75	0·78	NS	0·023
Alanine	0·75	0·77	0·85	*	0·024
Cystine	0·90	0·63	0·91	***	0·020
Valine	0·85	0·80	0·89	**	0·015
Methionine: 1†	0·79	0·81	0·84	NS	0·022
2	0·79	0·86	0·91	**	0·020
Isoleucine	0·85	0·81	0·92	**	0·015
Leucine	0·83	0·79	0·91	**	0·016
Tyrosine	0·82	0·72	0·89	***	0·016
Phenylalanine	0·88	0·79	0·91	**	0·016
Histidine	0·66	0·57	0·68	NS	0·058
Lysine	0·74	0·78	0·89	**	0·022
Arginine	0·91	0·78	0·93	***	0·020
Tryptophan	0·81	0·65	0·90	***	0·018
N	0·78	0·71	0·85	**	0·020
Dry matter	0·81	0·80	0·85	NS	0·016

NS, $P > 0·05$.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† 1, Acid-hydrolysis; 2, oxidized before acid-hydrolysis (see below).

retention:protein intake; lysine retention:total lysine intake and lysine retention:apparent ileal digestible lysine intake.

The following factors were used in the previously described calculations: 6·25 to convert nitrogen to crude protein (Agricultural Research Council, 1981); 0·928 to convert initial live weight to estimated initial empty-body-weight; 7·75 to calculate the energy (MJ/kg) and 140 to calculate the protein (g/kg) in the empty bodies of the pigs at the commencement of the experiment (these factors were determined on the four males and four females slaughtered at 20 kg live weight). Energy stored as protein was calculated as protein (kg) × 24·2 (Jordan & Brown, 1970). Fat content was calculated as (total energy − protein energy):39·6 (Burlacu *et al.* 1973).

The results were analysed by analysis of variance and treatment means separated by least significance difference (LSD).

Chemical analyses

The techniques used were as reported by Batterham *et al.* (1990*b*) with the addition that chromium determinations were based on the methods of Kimura & Miller (1957) and Scott (1978). The total amino acid contents of composite samples of blood plus viscera and carcasses of the pigs fed on each diet and for those slaughtered at 20 kg live weight were determined and used to calculate the amino acid content of the pigs. The amino acid profiles were adjusted to an estimated 0·95 recovery of Kjeldahl N (Association of Official Analytical Chemists, 1984).

Table 5. *Expt 1. Apparent faecal digestibilities of amino acids, nitrogen and dry matter in cottonseed meal, meat-and-bone meal and soya-bean meal*

Protein concentrate...	Cottonseed meal	Meat-and-bone meal	Soya-bean meal	Statistical significance of difference	SEM
Aspartic acid	0·83	0·91	0·92	NS	0·035
Threonine	0·77	0·91	0·90	NS	0·048
Serine	0·82	0·90	0·92	NS	0·037
Glutamic acid	0·89	0·92	0·94	NS	0·022
Glycine	0·79	0·93	0·88	NS	0·044
Alanine	0·72	0·92	0·86	NS	0·056
Cystine	0·92	0·87	0·97	**	0·017
Valine	0·82	0·93	0·91	NS	0·035
Methionine	0·68	0·93	0·82	NS	0·065
Isoleucine	0·80	0·92	0·91	NS	0·038
Leucine	0·80	0·92	0·92	NS	0·042
Tyrosine	0·80	0·90	0·90	NS	0·041
Phenylalanine	0·86	0·92	0·92	NS	0·030
Histidine	0·80	0·88	0·84	NS	0·049
Lysine	0·70	0·93	0·91	*	0·055
Arginine	0·91	0·91	0·94	NS	0·016
N	0·80	0·91	0·89	NS	0·039
Dry matter	0·87	0·92	0·93	NS	0·026

NS, $P > 0{\cdot}05$.
* $P < 0{\cdot}05$, ** $P < 0{\cdot}01$.

RESULTS

Expt 1. Ileal digestibility of amino acids

The digestibilities of amino acids and N in the diets are given in Table 4. The apparent digestibilities of most amino acids and of N were higher in the soya-bean meal, and least in the meat-and-bone-meal.

There were no significant differences ($P > 0{\cdot}05$) in faecal digestibility for the majority of amino acids (Table 5), although the digestibility of the amino acids in the cottonseed meal was in most cases slightly lower than the other two meals. Overall faecal digestibility of amino acids in cottonseed meal was similar to the ileal digestibility values, whilst for meat-and-bone-meal, the faecal digestibilities were higher than the ileal values.

Mean DE contents of the cottonseed meal, meat-and-bone meal and soya-bean meal were (MJ/kg) 11·6 (SE 1·72), 12·4 (SE 0·49), 14·9 (SE 0·45) respectively.

Expt 2. Utilization of ileal digestible lysine

One pig given diet no. 2 and one given diet no. 5, both containing meat-and-bone meal, died with post-mortem symptoms of slow blood clotting and haemorrhaging from gastric ulcers. These pigs were treated as missing plots in the statistical analyses. A 1·2 mg supplement of menaphthone (as menaphthone sodium bisulphite)/kg was then included in the diets as a precaution against vitamin K deficiency. All other pigs remained healthy during the experiment.

Growth rates of the pigs given the three diets formulated to 0·36 g ileal digestible lysine/MJ DE were significantly different ($P < 0{\cdot}001$); cottonseed meal 377 g/d, meat-and-bone meal 492 g/d, soya-bean meal 541 g/d (Table 6). The addition of lysine to the three diets increased growth rates and lowered the FCR ($P < 0{\cdot}001$).

Table 6. *Expt 2. The effect of formulating diets on an apparent ileal digestible lysine basis on the growth performance of pigs over the 20–45 kg growth phase*

Diet no.† …	1	2	3	4	5	6	Statistical analysis				
Protein source …	Cot	Meat	Soya	Cot +lysine	Meat +lysine	Soya +lysine	Protein (P)	Lysine	P × Lysine	LSD $P = 0.05$ (between diets)	SEM
Apparent ileal digestible lysine content (g/MJ DE) …	0·36	0·36	0·36	0·46	0·46	0·46					
Gain (g/d)	377	492	541	502	559	591	***	***	**	31	11·5
Food conversion ratio	3·47	2·59	2·31	2·72	2·28	2·10	***	***	***	0·18	0·066
Empty-body-wt:live wt (kg/kg)	0·95	0·96	0·95	0·93	0·96	0·95	**	NS	NS	0·02	0·006
Gain (g/d) (empty-body-wt basis)	365	487	524	470	555	575	***	***	*	26	9·1
Food conversion ratio (empty-body-wt basis)	3·57	2·61	2·38	2·90	2·29	2·16	***	***	***	0·15	0·057
Backfat (P_2; mm)	17	15	14	16	14	14	**	NS	NS	3	0·8

NS, not significant; LSD, least significant difference; DE, digestible energy; Cot, cottonseed meal; Meat, meat-and-bone meal; Soya, soya-bean meal.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† For details, see Tables 1 and 3.

Table 7. *Expt 2. The effect of formulating diets on an apparent ileal digestible lysine basis on the concentrations, deposition rates and efficiencies of retention of protein, fat and energy in growing pigs (20–45 kg live weight)*

Diet no.† ...	1	2	3	4	5	6	Statistical analysis				
Protein source ...	Cot	Meat	Soya	Cot +lysine	Meat +lysine	Soya +lysine	Protein (P)	Lysine	P × Lysine	LSD $P = 0.05$ (between diets)	SEM
Apparent ileal digestible lysine content (g/MJ DE)...	0·36	0·36	0·36	0·46	0·46	0·46					
Composition (empty-body basis)											
Protein (kg/kg)	0·121	0·136	0·143	0·134	0·147	0·144	***	***	**	0·005	0·0019
Fat (kg/kg)	0·284	0·236	0·222	0·230	0·198	0·205	***	***	**	0·015	0·0055
Energy (MJ/kg)	14·2	12·6	12·2	12·3	11·4	11·6	***	***	*	0·6	0·21
Deposition rates											
Protein (g/d)	38	66	77	61	85	85	***	***	***	5	1·6
Fat (g/d)	155	155	158	148	141	152	NS	NS	NS	–	5·7
Energy (MJ/kg)	7·1	7·7	8·1	7·3	7·6	8·1	**	NS	NS	0·7	0·25
Retentions (ratios)											
Protein retained:											
protein intake (g/kg)	0·20	0·33	0·52	0·31	0·42	0·58	***	***	*	0·03	0·010
DE intake (g/MJ)	2·1	3·4	3·9	3·2	4·4	4·4	***	***	***	0·3	0·08
Fat retained:											
DE intake (g/MJ)	8·4	8·0	8·1	7·6	7·2	7·9	NS	*	NS	0·77	0·30
Energy retained:											
DE intake (MJ/MJ)	0·38	0·40	0·42	0·38	0·39	0·42	**	NS	NS	0·03	0·012

NS, not significant; LSD, least significant difference; DE, digestible energy; Cot, cottonseed meal; Meat, meat-and-bone meal; Soya, soya-bean meal.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† For details, see Tables 1 and 3.

Table 8. *Expt 2. 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 diet nos 1–6**

	20 kg pigs	Diet 1	2	3	4	5	6
Aspartic acid	8·1	8·2	8·4	8·1	8·1	8·3	8·3
Threonine	3·7	3·9	3·7	3·9	3·8	3·9	3·9
Serine	4·5	4·4	4·2	4·2	4·3	4·3	4·2
Glutamic acid	12·9	13·1	13·0	13·2	13·2	13·3	13·2
Glycine	8·9	9·5	8·6	8·3	8·5	8·5	7·9
Alanine	6·5	6·4	6·2	6·1	6·3	6·2	6·1
Valine	4·2	4·1	4·2	4·1	4·1	4·1	4·2
Cystine	1·1	1·1	1·3	1·3	1·1	1·1	1·4
Methionine	1·7	1·7	1·9	1·9	1·9	1·9	1·9
Isoleucine	3·1	3·0	3·0	3·1	3·1	3·1	3·3
Leucine	6·8	6·8	6·8	6·9	6·8	6·9	7·0
Tyrosine	3·0	2·7	2·9	2·9	2·9	2·7	3·1
Phenylalanine	3·9	3·8	3·9	3·9	3·9	3·8	3·9
Histidine	2·6	2·0	2·1	2·1	2·7	2·7	2·3
Ammonia	1·9	2·4	2·7	2·8	2·5	2·3	2·7
Lysine	6·2	6·2	6·3	6·5	6·3	6·4	6·7
Arginine	6·4	6·3	5·6	6·1	5·6	5·9	5·7

* Proline, hydroxyproline and tryptophan were not detected by high-performance liquid chromatographic analysis, values of 6·1, 2·7 and 0·8 g/16 g N respectively were assumed from Campbell *et al.* (1988); for details of diets, see Tables 1 and 3.

Crude protein deposition was greater in the pigs given soya-bean meal (77 g/d) relative to those given meat-and-bone meal (66 g/d) and cottonseed meal (38 g/d); $P < 0·001$; (Table 7).

Lysine content in the pigs varied from 6·2 to 6·7 g/16 g N and was lower in pigs fed on cottonseed meal and higher in pigs fed on soya-bean meal (Table 8).

Retention of ileal digestible lysine was 0·36, 0·60 and 0·75 for pigs given cottonseed meal, meat-and-bone meal and soya-bean meal respectively (Table 9).

DISCUSSION

Expt 1. Ileal digestibility of amino acids

The ileal digestibility of lysine in the cottonseed meal (0·74) was slightly higher than that reported previously (mean 0·65, range 0·56–0·71) by Batterham *et al.* (1990*a*), or by Sauer & Ozimek (1986) in a collation of published values for cottonseed meals (mean 0·62, range 0·53–0·70). The value for meat-and-bone meal was also slightly higher, and that of soya-bean meal was similar to values reported in the literature (Taverner *et al.* 1983; Sauer & Ozimek, 1986; Batterham *et al.* 1990*a*).

The results indicate that there was no apparent net effect of microbial synthesis or degradation of amino acids in the hind-gut with the cottonseed meal, whereas for meat-and-bone meal, there was considerable loss of amino acids. This is consistent with reports that, with cottonseed meal, there is little degradation or synthesis of amino acids in the hind-gut, possibly due to inhibitory effects of gossypol on the microflora, to resistance of the protein due to denaturing, or to protein–gossypol complexes formed during the processing of cottonseed meal (Sauer & Ozimek, 1986). The large disappearance of amino acids from meat-and-bone meal indicates that little energy was reaching the hind-gut and

Table 9. *Expt 2. The effect of formulating diets on an apparent ileal digestible lysine basis on the retention of lysine by growing pigs over the 20–45 kg growth phase*

Diet no.† ...	1	2	3	4	5	6	Statistical analysis				
Protein source ...	Cot	Meat	Soya	Cot +lysine	Meat +lysine	Soya +lysine	Protein (P)	Lysine	P × Lysine	LSD $P = 0.05$ (between diets)	SEM
Apparent ileal digestible lysine content (g/MJ DE) ...	0·36	0·36	0·36	0·46	0·46	0·46					
Lysine retention (ratios):											
total lysine intake (g/g)	0·27	0·47	0·67	0·34	0·52	0·62	***	**	***	0·03	0·011
ileal digestible lysine intake (g/g)	0·36	0·60	0·75	0·43	0·63	0·68	***	NS	***	0·03	0·012

NS, not significant; LSD, least significant difference; DE, digestible energy; Cot, cottonseed meal; Meat, meat-and-bone meal; Soya, soya-bean meal.
** $P < 0.01$; *** $P < 0.001$.
† For details, see Tables 1 and 3.

that the undigested protein was degraded by microbes (Sauer & Ozimek, 1986). This is not unexpected as sugar is a highly digestible source of energy. The magnitude and variability of the differences in ileal and faecal digestibilities for the three protein sources confirm the limitation of faecal digestible values for assessing amino acid digestibility.

Expt 2. Utilization of ileal digestible lysine

The significant responses in growth and protein deposition of the pigs to supplements of lysine in diet nos. 4–6 confirmed that lysine was the limiting amino acid in diet nos. 1–3. The results indicate that there are considerable differences in the utilization of ileal digestible lysine. For cottonseed meal, only 0·36 of the ileal digestible lysine was retained in the pig, compared with 0·75 for soya-bean meal. Growth rate, FCR and protein deposition were all markedly inferior for pigs given cottonseed meal relative to meat-and-bone meal and soya-bean meal. However, if the utilization of estimated available lysine intakes from the three meals are compared (using availability values of 0·40, 0·70 and 0·89; Standing Committee on Agriculture, 1987), retention rates are closer (0·68, 0·67 and 0·76 for pigs fed on cottonseed meal, meat-and-bone meal and soya-bean meal respectively). This indicates that a considerable proportion of the ileal digestible lysine in cottonseed meal and meat-and-bone meal is absorbed in a form that is not efficiently utilized. Possible mechanisms for this are discussed by Batterham *et al.* (1990*a*).

The lysine concentrations in the protein of the pigs were similar to previous reports (Campbell *et al.* 1988; Batterham *et al.* 1990*b*). The small differences in lysine concentration are in agreement with previous findings that the level of dietary lysine can influence the lysine concentration in the protein of pigs (Campbell *et al.* 1988; Batterham *et al.* 1990*b*).

The results also indicate that the use of single-protein diets using a non-protein energy source as the base, has advantages compared with using cereal-protein concentrate diets for assessing the utilization of an amino acid. In the ileal digestibility studies, there were no complications in having to partition overall dietary digestibilities into individual digestibilities for the protein concentrate and cereal base as is normally required. Furthermore, apparent ileal digestibilities rather than true digestibilities could be used in the dietary formulations and have the advantage of allowing for the endogenous cost of digestion of the particular protein concentrate. In the growth studies, the use of a single protein source as the only source of dietary lysine also allows an assessment of lysine utilization, free of confounding effects of the cereal base.

Our results are in contrast to those of Leibholz (1985) who reported close agreement between the apparent digestion of lysine at the ileum and lysine retention for five diets containing different protein concentrates for weaner pigs. However, in that study, lysine and crude protein contents in the carcasses were not determined, but estimated from values from other weaner pigs. As both the crude protein content and the concentration of lysine in the protein in pigs varies with dietary lysine concentration (Campbell *et al.* 1988; Batterham *et al.* 1990*b*; present study) this may have introduced variation contributing to the differences in results.

Overall, the results indicate that values for the ileal digestibility of lysine in protein concentrates are unsuitable in dietary formulations. It appears that a considerable proportion of the ileal digestible lysine may be absorbed in a form(s) that is (are) inefficiently utilized. Thus the assay is not a reliable indicator of lysine availability in heat-processed meals. There is a need to determine whether the other essential amino acids are affected in a similar manner.

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