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Digestion in the pig between 7 and 35 d of age

1. The performance of pigs given milk and soya-bean proteins

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1. One hundred and fourteen pigs between 7 and 35 d of age were given diets containing milk or soya-bean proteins in four separate experiments.

2. The substitution of milk protein by soya-bean meal (SBM) to 75% of the total dietary protein reduced the weight gains and food conversion efficiencies of the pigs by 85% between 7 and 14 d of age and 31% between 21 and 28 d of age.

3. The treatment of soya-bean protein with alkali did not improve the performance of the pigs.

4. The substitution of milk protein by two different isolated soya-bean proteins (ISP) resulted in weight gains of 34 and 60% of the gains of pigs given milk protein diets.

5. Supplementation of the soya-bean-protein diets with methionine to 13·7 g/kg (5 g/16 g nitrogen) resulted in reduced food intakes and weight gains of the pigs and a 20-fold increase in the concentration of methionine in the blood plasma.

6. Supplementation of soya-bean-protein diets with lysine to 22 g/kg (8 g/16 g N) in addition to methionine doubled the concentration of lysine in the blood plasma.

7. The apparent digestibility (AD) of dry matter (DM) and N of the diets containing soya-bean protein increased with increasing age of the pigs, but the AD of the milk-protein diet was not affected by the age of the pigs. The retention of N as a percentage of the N intake increased from 57–67% for soya-bean protein over the duration of the experiments while the average value for the milk-fed pigs was 85% at all ages.

8. At 35 d of age, the fat content of the carcasses of the pigs given the ISP diet was 249 g/kg DM compared to 164 g/kg DM for the pigs given the milk diets.

Artificial rearing of pigs from 2 d of age has been successful using liquid milk diets (Braude *et al.* 1970). However, it has been demonstrated (Wilson & Leibholz, 1979) that growth rates of 250 g/d can be achieved by pigs from 7–28 d of age given dry pelleted diets in which the source of dietary protein was milk.

Soya-bean proteins have been extensively fed to older pigs, but with pigs of 14 d of age or less, the performance has always been lower on diets containing soya-beans proteins than for pigs given milk proteins (Hays *et al.* 1959; Maner *et al.* 1961). It was, therefore, of interest to study the factors limiting the utilization of soya-bean protein for young pigs and to determine if soya-bean proteins could be improved by processing. Alkali treatment of soya-bean proteins has been shown to result in an improvement of pig performance (Lennon *et al.* 1971) while variations in the growth rates of turkey poults given different soya-bean-protein isolates have been noted (Vohra & Kratzer, 1967).

There is limited information on the sites of absorption of nutrients from the gastrointestinal tract of young pigs given different protein sources, although there have been studies on older animals (eg. Zebrowska, 1973). Hence a detailed study of their performance and the absorption of nutrients from the gastrointestinal tract when given either milk or soya-bean proteins was carried out. The results are reported in this and subsequent papers (Wilson & Leibholz, 1981 *a*, *b*, *c*, *d*).

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EXPERIMENTAL

Animals and management

Large White × Landrace male pigs were selected from different litters and taken from the sow between 4 and 5 d of age. Before weaning the pigs had their eye-teeth cut, tails docked, received 80 mg iron intramuscularly and were given an ear identification number.

The pigs were housed in tiered cages in groups of nine to ten for a preliminary period of 2–3 d during which time they were encouraged to consume pelleted food from the feeding troughs.

At an average age of 7 d, the pigs were allocated, one or two per pen, to the experimental diets. Randomized block designs were used, with each block consisting of pigs of similar weight.

The cages were in a draught-free, controlled-environment room, which was maintained at 32° for the first 7 d of the experiment and at 30° thereafter. Artificial lighting was continuous at a low intensity. No mortalities occurred during the experiments.

Experimental design

Expt 1. Thirty-two pigs (mean weight 2·04 kg) were allocated to four dietary treatments with four replicates of two pigs per replicate. The treatments compared the performance of pigs given diets in which SBM contributed 0, 25, 50 and 75% of the total dietary protein in isonitrogenous milk-based diets. The duration of the experiment was 21 d.

Expt 2. Thirty-two pigs (mean weight 2·09 kg) were allocated to four dietary treatments with four replicates of two pigs per replicate. Isonitrogenous diets were formulated in which the protein source was milk, soya-bean flour (SBF), alkali-treated SBF or alkali-treated SBM. The duration of the experiment was 17 d.

Expt 3. Thirty-six pigs (mean weight 2·05 kg) were allocated to six diets as a 3 × 2 factorial with three replicates of two pigs per replicate. Three protein sources were compared in isonitrogenous diets: milk, isolated soya-bean protein (ISP) (Promine D; Central Soya Co., Chicago, Ill.) and SBM each with and without methionine supplementation, and lysine supplementation of the ISP and SBM diets. The duration of the experiment was 17 d. At this stage, one pig per pen was removed and the remaining eighteen pigs, i.e. three replicates of one pig, were given the experimental diets for a further 5 d. The diets fed during these 5 d were sprayed with indigestible markers (Wilson & Leibholz, 1981 *a*). Individual food intakes were measured daily with these remaining eighteen pigs. At 28 d of age blood samples were collected from the vena cava of the pigs about 1 h after the daily feeding. The pigs were then slaughtered for sampling of stomach and intestinal contents (Wilson & Leibholz, 1981 *a*).

Expt 4. An all-milk-protein diet fed either pelleted or liquid was compared to a pelleted diet in which the protein source was ISP (Supro 610; Ralston Purina, St. Louis, Mo.). Fourteen pigs (mean weight 2·43 kg) were allocated to the dietary treatments with five replicates of one pig per replicate for the two pelleted treatments and four replicates on the liquid-fed treatment. The duration of the experiment was 28 d and at 35 d of age the pigs were slaughtered for collection of samples as in Expt 3.

In all experiments there were two 5 d faeces and urine collection periods from 10–15 d of age and 17–22 d of age (Expts 1 and 2), 19–24 d of age (Expt 3) and 30–35 d of age (Expt 4). The faeces were collected on screens above a sloping tray which drained the urine into bottles containing 100 ml of 5 M-HCl. All pigs were fed *ad lib.* with fresh food being offered daily, except that the liquid-fed pigs in Expt 4 were fed to maintain a DM intake similar to those pigs given the same diet in pelleted form. Also, during the second collection period of Expt 4, all the pigs were fed at 2 g nitrogen/kg live weight $(LW)^{0.75}$ per d in 12 two-hourly

Table 1. *Expt* 1. *Composition of the diets*

	Soya-bean meal (g/kg)			
Variable ingredients (g/kg)*	0	250	500	750
Dried skim milk	471·5	471·5	295·5	90·6
Casein	85·5	10·4	—	—
Soya-bean meal	—	140·6	281·2	422·0
Lactose	—	—	91·5	198·0
Wheat starch	263·7	199·6	147·4	98·4
Maize oil	4·3	2·9	1·4	—
Dicalcium phosphate	—	—	8·0	16·0
Lysine	—	1·5	2·7	3·8
Methionine	—	0·4	1·6	2·9
Chemical composition				
Dry matter (DM) (g/kg)	932	937	945	939
Nitrogen (g/kg DM)	46·1	46·2	45·1	45·3
Calculated composition (g/kg)				
Total fat	43	43	43	43
Lactose	300	300	300	300
Calcium	9·1	9·0	9·1	9·0
Phosphorus	6·7	6·8	7·4	7·8
Lysine	21·7	21·7	21·7	21·7
Methionine+cystine	10·2	10·2	10·1	10·2

* All diets contained (g/kg): 150 dried whole milk, 20 calcium stearate, 5 vitamin and mineral supplement supplying (mg/kg diet): 1·5 retinol, 0·025 cholecalciferol, 20 α-tocopheryl, 2 menadione, 200 ascorbic acid, 20 μg cyanocobalamin, 1·5 thiamine, 6 riboflavin, 20 niacin, 10 pantothenic acid, 3 pyridoxine, 1 g choline chloride, 3 folic acid, 0·1 biotin. Minerals (mg/kg): 200 magnesium, 100 iron, 10 copper, 40 manganese, 70 zinc, 2·5 cobalt, 0·1 iodine, 0·1 selenium, 2600 potassium, 700 sodium. Other additives (mg/kg): 50 ethoxyquin, 50 oxytetracycline, 50 neomycin sulphate.

feeds. Two-hourly feeding was chosen to equalize food intake prior to slaughter (Wilson & Leibholz, 1981*a*).

The pigs were weighed and food consumption was recorded every 7 d except during the collection periods when food intake was recorded daily.

Diets

Expt 1. Solvent-extracted SBM replaced dried skim milk and casein in isonitrogenous diets. The composition of the diets is shown in Table 1.

Expt 2. The alkali-treated SBF and SBM were prepared by mixing (40:60, w/v) the protein meals with sodium hydroxide (5 g/l for SBF, 4·5 g/l for SBM). This gave a mix of pH 10·6 which was stirred continuously for 0·5 h at 30°. The mixture was then dried for 12 h at 60°, flash-dried at 250° for 15 s and reground for mixing in the diets. The composition of the diets is shown in Table 2.

Expt 3. Diets containing milk, ISP or SBM as the source of protein were supplemented with DL-methionine to raise the total methionine and cystine content to the methionine and cystine content of whole egg (5·4 g/16 g N; Orr & Watt, 1968) as Walker & Kirk (1975) showed that this methionine level maximizes N retention in preruminant lambs. The ISP and SBM diets were also supplemented with lysine. The composition of the diets is shown in Table 3.

Expt 4. The composition of the diets is shown in Table 4. The liquid-milk diets given to pigs on this treatment contained 150 g dry matter (DM)/kg, prepared daily and stored at 5°. The pigs were bottle-fed six times daily.

Table 2. *Expt 2. Composition of the diets*

	Diets		
	A	B and C	D
Variable ingredients (g/kg)*			
Dried skim milk	471·5	—	—
Casein	85·5	—	—
Soya-bean flour	—	465	—
Soya-bean meal	—	—	484·5
Lactose	—	245	245
Wheat starch	268	95	75·5
Dicalcium phosphate	—	20	20
Lysine	—	4·0	4·2
Methionine	—	2·8	3·5
Chemical composition			
Dry matter (DM) (g/kg)	965	940	942
Nitrogen (g/kg DM)	45·0	45·9	46·0
Calculated composition (g/kg)			
Total fat	40	44	45
Lactose	300	300	300
Calcium	9·1	9·1	9·1
Phosphorus	6·7	8·2	8·1
Lysine	21·7	21·7	21·7
Methionine+cystine	10·2	10·2	10·2

A, milk protein; B, soya-bean flour (SBF); C, alkali-treated SBF; D, alkali-treated SBM, for details, see p. 303.
* For details of supplements, see Table 1.

Table 3. *Expt 3. Composition of the diets*

	Protein source		
	Milk	Isolated soya-bean protein*	Soya-bean meal
Variable ingredients (g/kg)†			
Dried skim milk	471·5	—	—
Casein	85·5	—	—
Isolated soya-bean protein	—	258·5	—
Soya-bean meal	—	—	484·5
Lactose	—	245	245
Wheat starch	268	299	75·5
Dicalcium phosphate	—	22·5	20·0
Lysine‡	—	— (2·8)	— (4·4)
Methionine‡	— (4·6)	— (10·0)	— (8·2)
Chemical composition			
Dry matter (DM) (g/kg)	926	944	932
Nitrogen (g/kg DM)	47·8	46·4	46·1
Lysine (g/kg DM)‡	22·3	19·7 (21·9)	18·2 (21·6)
Methionine (g/kg DM)‡	7·6 (12·7)	3·7 (13·7)	4·8 (13·3)
Calculated composition (g/kg)			
Total fat	40	40	45
Lactose	300	300	300
Calcium	9·1	9·1	9·1
Phosphorus	6·7	7·8	8·1

* Promine D, Central Soya Co., Chicago, Ill.
† For details of supplements, see Table 1.
‡ Amino acid-supplemented diets in parentheses.

Table 4. *Expt* 4. *Composition of the diets*

	Protein source	
	Milk	Isolated soya-bean protein*
Variable ingredients (g/kg)†		
Dried skim milk	471·5	—
Casein	86·5	—
Isolated soya-bean protein†	—	258·5
Lactose	—	245
Wheat starch	267	299
Dicalcium phosphate	—	22·5
Chemical composition		
Dry matter (DM) (g/kg)	922	902
Nitrogen (g/kg DM)	47·2	47·5
Ash (g/kg DM)	53	51
Lysine (g/kg DM)	23·0	18·7
Methionine (g/kg DM)	7·8	3·5
Calculated composition (g/kg)		
Total fat	40	40
Lactose	300	300
Calcium	9·1	9·1
Phosphorus	6·7	7·6

* Supro 610; Ralston Purina, St Louis, Mo.
† For details of supplements, see Table 1.

Carcass preparation (*Expts* 3 *and* 4)

The empty bodies of the pigs (total carcass minus stomach, intestine and bladder contents) were weighed and stored at −20° until prepared for analysis. The frozen carcasses were sawn into pieces and minced through a cutter-grinder fitted with a 5 mm screen plate.

Analytical methods

DM was determined on samples of ground food and fresh carcass in a forced air oven at 95° for 24 h. Total N was determined by the Kjeldahl method on food, faeces, urine and freeze-dried carcass. Carcass fat was determined on freeze-dried material by the Soxhlet method (Association of Official Agricultural Chemists, 1975), extracting the samples with light petroleum (b.pt 40–60°) for 18 h. Plasma urea was determined by the method of Chaney & Marbach (1962) and amino acid concentration in food samples by ion-exchange chromatography (TSM Amino Acid AutoAnalyzer; Technicon Equipment Pty Ltd, Sydney) following hydrolysis in 6 M-hydrochloric acid for 24 h at 136° in an oil bath (Roach, 1968). Blood plasma samples were deproteinized with 30 g sulphosalicylic acid/l.

Statistical methods

The data were subjected to analysis of variance and least significant differences ($P < 0.05$) were used to statistically compare means (Steel & Torrie, 1960). In Expt 4, with unequal replication the larger standard errors of the means were used and are given in the Tables.

Table 5. *Expt* 1. *Performance of pigs given diets containing varying levels of soya-bean meal*

Soya-bean meal level (g/kg total protein)	Age (d) 7–14	14–21	21–28	7–28	7–28
	Live-wt gain (g/d)†				FCR
0	131·7	189·4	427·7	264·7	0·80
250	126·6	160·0	365·5	217·3	0·89
500	67·2	124·0	369·6	187·7	0·96
750	71·0	136·8	327·1	178·2	0·95
SEM	12·30	21·50	36·77	20·71	0·04
Level of significance	**	NS	NS	*	*

FCR, food conversion ratio (g dry matter intake/g weight gain); NS, not significant.
* $P < 0.05$, ** $P < 0.01$.
† Live-weight gains were adjusted for initial live weight at 7 d of age.

RESULTS

Growth

Expt 1. The live-weight gains in Table 5 have been adjusted for initial live weight at 7 d of age by covariance analysis. Food conversion ratios were calculated over the 21 d period. The substitution of milk protein by SBM reduced live-weight gains at each level of SBM inclusion. During the period from 7 – 14 d of age, the weight gains of pigs given the diets in which SBM supplied 50 and 75% of the total dietary protein was 51 and 54% respectively of that of pigs given the all-milk-protein diet. By 21–28 d of age, this difference in performance was only 16 and 31% respectively.

The relationship between the level of SBM fed and the individual live-weight gain of the pigs was described by the following equation:

$$\text{average daily gain (g/d)} = 254{\cdot}6 - 1{\cdot}14 \text{ (percentage of soya-bean protein in diet).}$$

$$\text{SD } 44{\cdot}86, \quad \text{SE}_b\, 0{\cdot}28, \quad r - 0{\cdot}61.$$

The regression coefficient differed significantly from zero ($P < 0.01$).

Expt 2. Malfunctions in the air-conditioning and heating equipment during this experiment caused fluctuations in the temperature from 20–32°. This reduced the performance of pigs in this trial (Table 6). The live-weight gains of pigs given the milk-protein diet in this experiment were approximately 55% below that achieved by pigs receiving a similar diet in Expt 1. The performance of pigs given the diets in which the protein source was from milk or alkali-treated SBM was significantly greater than the performance of pigs given the two SBF diets. Pigs given the milk-protein diet had significantly better weight gains and food conversion ratios than those given alkali-treated SBM as the protein source. The alkali treatment of SBF did not improve the performance of pigs above those fed untreated SBF as the protein source.

Expt 3. At all age-periods, the performance of pigs given the milk-protein diet was significantly greater than pigs given either ISP or SBM as the source of protein (Table 7). Over the 21 d period there were no significant differences between the weight gains of pigs given the ISP or SBM diets. The addition of methionine and lysine to the ISP and SBM diets did not significantly improve weight gains at any age-period. During the period from 21–24 d of age amino acid supplementation significantly reduced live-weight gains and food conversion ratios of pigs fed the ISP diets. The addition of methionine to the milk-protein

Table 6. *Expt 2. Performance of pigs given diets containing milk protein, untreated or alkali-treated soya-bean flour and soya-bean meal*

	Age (d)				
	7–14	14–21	21–24	7–24	7–24
Protein source	Live-wt gain (g/d)†				FCR
Milk	98·2	188·2	302·1	170·6	0·82
Soya-bean flour	−9·0	11·8	33·5	10·3	5·07
Alkaline soya-bean flour	−11·1	26·3	43·5	14·0	4·97
Alkaline soya-bean meal	50·1	150·1	149·7	108·9	1·24
SEM	18·94	15·93	20·03	14·50	0·216
Level of significance	**	***	***	***	*

FCR, food conversion ratio (g dry matter intake/g weight gain).
* $P<0.05$, ** $P<0.01$, *** $P<0.001$.
† Live-weight gains were adjusted for initial live weight at 7 d of age.

diet resulted in a significant reduction in weight gains over the age-periods from 14–21, 21–24 and the entire 17 d period although there were no significant differences in the food conversion ratios between the unsupplemented and methionine-supplemented milk-protein diets.

Expt 4. Pigs given the pelleted milk-protein diet had significantly improved performances over pigs given the pelleted ISP diet (Table 8). There was no significant difference between the live-weight gains over the 21 d period of pigs given the liquid-milk-protein diet and the pelleted milk or pelleted ISP diet. However, when live-weight gains were adjusted for DM intake over the 21 d period, the performance of the liquid milk protein-fed pigs was significantly below that of pigs given the same diet in the pelleted form.

Apparent digestibility (AD) and N retention

Expt 1. The AD of DM and N decreased with increasing levels of SBM in the diet (Table 9). There were no significant differences between the two collection periods. N retention expressed as g/d, g/d per kg LW or as a proportion of intake remained similar for all diets in each collection period. However, there was a significant improvement in N retention (g/d) between the first and second collection periods for all diets and a significant improvement in N retention (g/d per kg LW) between the two collection periods for the two diets containing the highest inclusions of SBM.

Expt 2. Pigs given the all-milk-protein diet had significantly greater AD of DM and N during both collection periods than pigs given diets containing soya-bean proteins (Table 10). The alkali treatment of SBF resulted in significantly lower AD of DM and N than in pigs given the untreated SBF during the first collection period, though during the second collection period there were no significant differences between the SBF diets. The apparent DM and N digestibility of pigs given the alkali-treated SBM was significantly greater than for pigs given the alkali-treated SBF at both collection periods. The improvement in the AD of DM or N with age of pigs for all diets was not significant.

The retention of N was significantly greater for pigs given the milk-protein and alkali-treated SBM diets than for pigs given the two SBF diets. Alkali treatment of SBF did not have any significant effect on N retention of pigs.

Expt 3. Pigs given the diet containing all-milk protein had significantly greater AD of DM and N during both collection periods than did pigs given diets containing ISP or SBM

Table 7. *Expt* 3. *Performance of pigs given diets containing milk protein, isolated soya-bean protein or soya-bean meal*

			Protein source			Significance of differences and SEM due to:		
	Age (d)	Amino acid supplement	Milk	Isolated soya-bean protein†	Soya-bean meal	Protein source	Amino acid	Protein × amino acid
Live-wt gain (g/d)‡	7–14	–	185·5	55·2	37·0	10·39***	8·49 NS	14·69*
		+	153·5	33·1	52·1			
	14–21	–	282·8	101·5	112·4	10·15***	8·29 NS	14·35*
		+	247·3	86·3	129·4			
	21–24	–	339·2	153·9	146·3	16·27***	13·28*	23·00*
		+	248·2	93·0	122·8			
	7–24	–	252·6	91·6	89·5	9·14***	7·47 NS	12·92*
		+	208·9	65·4	96·5			
Dry matter (DM) intake (g/d)	7–24	–	186·9	118·1	125·7	7·36***	6·01*	10·41*
		+	158·1	87·5	117·7			
Food conversion ratio (g DM intake/g gain)	7–24	–	0·73	1·23	1·27	0·028**	0·023**	0·039**
		+	0·78	1·50	1·30			

+, With supplement; –, without supplement.
NS, not significant.
* $P < 0·05$, ** $P < 0·001$, *** $P < 0·001$.
† Promine D; Central Soya Co., Chicago, Ill.
‡ Live-weight gains were adjusted for initial live weight at 7 d of age.

Table 8. *Expt 4. Performance of pigs given diets containing isolated soya-bean protein or milk in pelleted or liquid form*

	Age (d)					
	7–14	14–21	21–28	7–28	7–28	7–28
Protein source	Live-wt gain (g/d)†				FCR	DM intake (g/d)
Milk (pelleted)	201·9	285·0	351·1	277·7	0·77	210·5
Milk (liquid)	79·9	216·6	301·0	215·1	1·07	222·1
Isolated soya-bean protein (pelleted)‡	107·1	152·1	247·2	167·3	0·97	156·0
SEM	15·63	24·25	32·10	20·23	0·05	15·13
Level of significance	***	**	NS	**	**	*

FCR, food conversion ratio (g dry matter intake/g weight gain); DM, dry matter; NS, not significant.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Live-weight gains were adjusted for initial live weight at 7 d of age.
‡ Supro 610; Ralston Purina, St. Louis, Mo.

Table 9. *Expt 1. Mean values for the apparent digestibilities of dry matter (DM) and nitrogen and N retention in pigs given diets containing varying levels of soya-bean meal*

	Collection period†	Soya-bean meal level (g/kg dietary protein)				Significance of difference and SEM due to:		
		0	250	500	750	Treatment	Age	Treatment × age
DM digestibility	1	0·969	0·948	0·924	0·901	0·0058***	0·0034 NS	0·0068 NS
	2	0·966	0·947	0·932	0·920			
N digestibility	1	0·971	0·943	0·891	0·861	0·0090***	0·0048 NS	0·0096 NS
	2	0·966	0·930	0·822	0·684			
N retention	1	6·45	5·60	4·42	4·35	0·986 NS	0·532***	1·064 NS
	2	12·10	9·92	9·07	8·97			
N retention (g/d per kg LW)	1	2·18	1·88	1·83	1·76	0·306 NS	0·132***	0·264 NS
	2	2·94	2·42	2·97	2·59			
N retention (relative to intake)	1	0·698	0·644	0·600	0·604	0·0366 NS	0·0231*	0·0462 NS
	2	0·780	0·725	0·697	0·690			

LW, live weight; NS, not significant.
* $P < 0·05$, *** $P < 0·001$.
† Period 1, 10–15 d of age; period 2, 17–22 d of age.

Table 10. *Expt 2. Mean values for the apparent digestibilities of dry matter (DM) and nitrogen and N retention in pigs given diets containing milk protein, untreated or alkali-treated soya-bean flour and soya-bean meal*

	Collection period†	Diet				Significance of difference and SEM due to:		
		A	B	C	D	Treatment	Age	Treatment × age
DM digestibility	1	0·951	0·840	0·789	0·854	0·0124***	0·0063 NS	0·0126 NS
	2	0·975	0·841	0·816	0·878			
N digestibility	1	0·950	0·725	0·592	0·773	0·0023***	0·0134 NS	0·0268 NS
	2	0·978	0·734	0·650	0·806			
N retention (g/d)	1	2·60	0·45	0·73	2·09	0·507***	0·229***	0·458*
	2	5·99	1·15	1·29	5·04			
N retention (g/d per kg LW)	1	0·91	0·24	0·36	0·84	0·105***	0·069**	0·138 NS
	2	1·45	0·53	0·58	1·42			
N retention (relative to intake	1	0·709	0·238	0·267	0·559	0·0474***	0·0208**	0·0416 NS
	2	0·749	0·402	0·368	0·649			

A, milk protein; B, soya-bean flour (SBF); C, alkali-treated SBF; D, alkali-treated soya-bean meal (for details, see Table 2); LW, live weight; NS, not significant.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† Period 1, 10–15 d of age; period 2, 17–22 d of age.

Table 11. *Expt 3. Mean values for the apparent digestibilities of dry matter* (DM) *and nitrogen and N retention in pigs given diets containing milk protein, isolated soya-bean protein or soya-bean meal*

Protein source...		Milk		Isolated soya-bean protein†		Soya-bean meal		Significance of difference and SEM due to:			
Methionine... Lysine...	Collection period‡	− −	+ −	− −	+ +	− −	+ +	Protein source	Age	Amino acid supplement	Amino acid supplement × protein source
DM digestibility	1	0·980	0·978	0·927	0·916	0·880	0·852	0·0051***	0·0029*	0·0042*	0·0072**
	2	0·978	0·979	0·935	0·920	0·899	0·869				
N digestibility	1	0·989	0·977	0·915	0·875	0·844	0·784	0·0092***	0·0047 NS	0·0075**	0·0129*
	2	0·987	0·988	0·918	0·876	0·872	0·823				
N retention (g/d)	1	13·86	12·03	5·19	4·15	5·51	5·91	0·932***	0·269***	0·761*	1·318***
	2	23·32	18·39	11·06	6·56	12·11	9·84				
N retention (g/d per kg LW)	1	4·02	3·96	2·06	1·96	2·21	2·56	0·241**	0·118*	0·197 NS	0·341 NS
	2	4·42	3·36	2·95	2·22	3·43	2·75				
N retention (relative to intake)	1	0·866	0·825	0·584	0·544	0·573	0·583	0·0298***	0·0079***	0·0243**	0·0421**
	2	0·873	0·845	0·689	0·617	0·725	0·612				

+, With supplement; −, without supplement.
LW, live weight; NS, not significant.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† Promine D; Central Soya Co., Chicago, Ill.
‡ Period 1, 10–15 d of age; period 2, 19–24 d of age.

Table 12. *Expt 4. Mean values for the apparent digestibilities of dry matter (DM) and nitrogen and N retention in pigs given diets containing isolated soya-bean protein or milk in pelleted or liquid form*

		Protein source			Significance of difference and SEM due to:		
	Collection period†	Milk (pelleted)	Milk (liquid)	Isolated soya-bean protein‡ (pelleted)	Treatment	Age	Treatment × age
DM digestibility	1	0·975	0·981	0·945	0·0039***	0·0041 NS	0·0071 NS
	2	0·968	0·980	0·942			
N digestibility	1	0·989	0·986	0·947	0·0050***	0·0046 NS	0·0080 NS
	2	0·980	0·989	0·944			
N retention (g/d)	1	6·84	5·86	3·54	0·409**	0·249 NS	0·431 NS
	2	6·27	5·18	4·79			
N retention (relative to intake)	1	0·877	0·822	0·699	0·0287 NS	0·0175**	0·0303*
	2	0·755	0·712	0·738			

NS, not significant.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Period 1, 10–15 d of age; period 2, 17–22 d of age.
‡ Supro 610; Ralston Purina, St. Louis, Mo.

as the protein source (Table 11). The addition of methionine or methionine plus lysine did not influence the AD of DM or N for pigs given the milk of ISP diets. However, for pigs given the SBM diet, methionine plus lysine additions reduced the AD of DM and N during both collection periods.

The retention of N of pigs given the milk-protein diet was greater than for pigs given the ISP or SBM diets. Amino acid supplementation of each of the protein sources resulted in a reduction in N retention.

Expt 4. The AD of DM and N were significantly greater for pigs given the milk-protein diets as compared to the ISP diet (Table 12). The retention of N during the collection period between 10 and 15 d of age was significantly greater for pigs given the milk-protein diets than for pigs given the ISP diet. However, during the second collection period there were no significant differences in N retention of pigs between the two protein sources as all pigs received 2 g N/kg $LW^{0.75}$ per d. When N retention was expressed relative to N intake the N retained was lower for pigs during the second collection period than the first collection period. There were no significant differences in any of the measurements due to the method of feeding the milk-protein diet.

Plasma amino acids and urea

Expt 3. The plasma concentrations of free lysine, methionine, cystine and phenylalanine were lower in pigs given the ISP or SBM diets than for pigs given the milk-protein diet (Table 13). However, the feed intake of the pigs given milk was greater than that of the pigs given ISP or SBM.

The total amino acid concentration in the plasma increased with amino acid supplementation of the protein sources fed. The indispensable amino acids as a proportion of the total amino acids increased with amino acid supplementation, but the increase was only significant for the pigs given the SBM diet.

Lysine supplementation of the ISP and SBM diets resulted in an increase in the plasma concentration of lysine, however, this increase was only significant for the pigs given SBM. Methionine supplementation resulted in large and significant increases in the plasma methionine concentrations and to a lesser extent increases in the plasma concentrations of cystine.

Concentrations of urea in the plasma were significantly lower in the pigs given the milk-protein diet than in pigs given the ISP or SBM diets.

Carcass composition

Expt 3. As there were no significant differences in the chemical composition of the carcasses with dietary amino acid supplementation of the respective protein sources, the values of the unsupplemented and amino acid-supplemented treatments have been grouped giving mean values of six pigs per treatment.

The amounts of crude protein (N × 6·25/g per kg DM) and total fat (g/kg DM) in the carcass of pigs given the three protein sources follow the trend of the empty-body-weights (Table 14). Significantly lower amounts of protein and greater amounts of total fat were in the carcasses of pigs given the ISP and SBM diets than in the carcasses of pigs given the milk-protein diet. When calculated on a fat-free basis the carcasses of pigs given SBM contained significantly greater amounts of water and crude protein than pigs given the milk or ISP diets.

Expt 4. There were no significant differences in the amounts of DM (g/kg) or crude protein (g/kg DM) in the carcasses of pigs given either protein source although the empty-body-weights of pigs given the ISP diet were significantly lower than the empty-body-weights of pigs given the pelleted milk-protein diets (Table 15). However, the level of fat (g/kg DM)in the carcasses

Table 13. *Expt 3. The concentration of indispensable free amino acids and urea-nitrogen in the blood plasma (mmol/l) of pigs given diets containing milk protein, isolated soya-bean protein or soya-bean meal*

Protein source...	Milk		Isolated soya-bean protein†		Soya-bean meal			
Methione...	−	+	−	+	−	+		Level of
Lysine...	−	−	−	+	−	+	SEM	significance
Arginine	0·188	0·096	0·297	0·255	0·220	0·168	0·040	NS
Histidine	0·141	0·141	0·232	0·190	0·124	0·096	0·032	NS
Isoleucine	0·131	0·132	0·173	0·101	0·155	0·086	0·018	NS
Leucine	0·211	0·193	0·214	0·116	0·189	0·141	0·230	NS
Lysine	0·542	0·363	0·266	0·381	0·232	0·512	0·057	*
Methionine	0·154	1·152	0·577	1·221	0·356	0·877	0·068	***
Cystine	0·045	0·045	0·021	0·041	0·041	0·063	0·006	•
Phenylalanine	0·122	0·083	0·085	0·072	0·068	0·068	0·019	NS
Threonine	0·383	0·353	0·463	0·328	0·205	0·238	0·053	NS
Valine	0·305	0·310	0·317	0·239	0·277	0·188	0·034	NS
Total amino acids	4·979	5·557	5·643	5·928	4·471	4·823	0·238	—
Indispensable amino acids (mmol/mmol total)	0·446	0·516	0·469	0·497	0·417	0·505	0·0212	**
Urea (mg/100 l)	13·8	17·2	25·5	22·5	31·2	28·7	2·54	*

+, With supplement; −, without supplement.
NS, not significant.
• $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† See Table 3.

Table 14. *Expt 3. Empty-body-weights and proportion of dry matter* (DM), *crude protein (nitrogen × 6·25) and total fat in carcasses*

Protein source	Empty-body-wt (kg)	DM (g/kg)	Crude protein (g/kg DM)	Total fat (g/kg DM)
Milk	6·82	245	727	167
Isolated soya-bean protein†	4·05	267	672	227
Soya-bean meal	4·13	285	680	262
SEM	0·191	4·59	13·18	19·38
Level of significance	***	*	*	***

* $P < 0.05$, *** $P < 0.001$.
† See Table 3.

Table 15. *Expt 4. Empty-body-weights and proportion of dry matter* (DM), *crude protein (nitrogen × 6·25) and total fat in carcasses*

Protein source	Empty-body-wt (kg)	DM (g/kg)	Crude protein (g/kg DM)	Total fat (g/kg DM)
Milk (pelleted)	8·68	246	723	171
Milk (liquid)	7·30	252	717	157
Isolated soya-bean protein†	6·62	261	709	249
SEM	0·495	4·59	9·69	15·44
Level of significance	**	NS	NS	**

NS, not significant.
** $P < 0.01$.
† See Table 4.

of pigs given the ISP diet was significantly greater than in the carcasses of pigs given the milk-protein diets. When calculated on a fat-free basis, there were no significant differences in the amounts of water or crude protein in the carcasses of pigs given the two protein sources.

DISCUSSION

The live-weight gains of the pigs given the all-milk-protein diets in these experiments ranged from 250–280 g/d with food conversion ratios of 0·73–0·80 over the period from 7–28 d of age. Daily gains of suckling pigs from birth to 2 weeks of age have been reported to range from 165–226 g/d (Young & Smith, 1973; Aherne & Speer, 1974).

Liquid and pelleted milk diets

There were no significant differences in the live-weights gains of pigs from 7–28 d of age given milk-protein diets either in liquid or pelleted form (Expt 4). This experiment was not a strict comparison of liquid *v*. dry feeding, as the food intakes of the liquid-fed pigs were restricted to maintain DM intakes similar to pigs given the pelleted diets, approximately 210 g/d. DM intakes were similar to those reported by Braude & Newport (1977) for young pigs given pelleted diets. The latter authors found no difference in food conversion ratio between pigs given liquid or pelleted milk diets. However, the food intakes of the pigs given liquid milk were 59–76% greater than that of pigs given the pelleted diets. As the maintenance requirement for energy was a smaller proportion of the total energy intake in the liquid-fed pigs with the higher growth rates and food intakes, there should have been a lower food conversion ratio for the pigs given the liquid diet as compared to those given the pelleted diet. This would suggest that if the pigs of Braude & Newport (1977) and also Eddie & McCracken (1972) had been fed at the same intake on both liquid and pelleted diets, the food conversion ratio of the liquid-fed pigs would be greater than that of pigs given the pelleted diet. This agrees with the results of Expt 4 where the food conversion ratio of the pigs given the liquid diet was greater than that of the pigs given the pelleted diet, when both groups were fed at 210 g/d.

There were no differences in the AD of DM or N when milk diets were fed in a liquid or pelleted form. This would suggest that there was a difference in the utilization of absorbed nutrients which may have been due to a difference in the retention time of liquid milk and dry milk in the digestive tract of pigs. In fact, in a subsequent experiment it was shown that the retention time of dry-milk diets in the stomach was much greater than that of liquid-milk diets (Wilson & Leibholz, 1981*a*). Hence, the rapid gastric emptying after feeding liquid diets may result in a less efficient utilization of nutrients.

Soya-bean and milk proteins in the diet

The present results clearly indicate that soya-bean proteins as the only dietary protein source do not support similar performances for pigs up to 4 weeks of age as those given diets containing milk protein. Similar conclusions have been reached by numerous workers using ISP (Hays *et al.* 1959; Maner *et al.* 1961), SBF (Bayley & Holmes, 1972) or SBM (Hays *et al.* 1959).

The effect of substituting SBM for milk protein in diets for young pigs resulted in a linear decrease in growth rates. Sherry *et al.* (1978) have also shown that daily gains and food efficiencies decreased as the amount of milk protein in the diet decreased for pigs from 2–23 d of age, but Zamora *et al.* (1975) concluded that SBM could be a major source of protein for artificially-reared pigs. However, their diets containing SBM contained 260 g crude protein/kg while the crude protein content of their milk diet was only 240 g/kg. Also, the weight gains of the pigs in the study of Zamora *et al.* (1975) ranged from 100–150 g/d which is approximately half the weight gains obtained in the present experiment.

With pigs from 21–36 d of age, Jones *et al.* (1977) found that SBF as a source of protein was equivalent to milk, but pigs of less than 18 d of age were not able to utilize SBF efficiently. Colvin & Ramsey (1968) found that acid or alkali treatment of SBF produced gains in calves similar to that obtained with conventional milk substitutes. Also, Lennon *et al.* (1971) showed that alkali treatment of SBF and SBM fed in liquid diets to young pigs increased weight gains by 54–68% and 60–77% respectively over that obtained by pigs receiving untreated protein sources. However, in Expt 2, the alkali treatment of SBF did not result in any significant improvement in performance of the pigs over that of pigs receiving the untreated SBF. In the present experiment the pigs were 7–28 d of age while those of Lennon *et al.* (1971) were from 28–56 d of age. It has been shown that the pig's ability to utilize soya-bean protein increases with age from 2–5 weeks of age (Hays *et al.* 1959; Jones *et al.* 1977).

The method of preparation of ISP may explain the differences in performance obtained by pigs given either Promine D or Supro 610 as the only source of dietary protein. Alkali treatment is commonly used in the processing of soya-bean isolates (Circle & Smith, 1972) and strong alkali, pH 12·2, has resulted in the formation of lysine-alanine (de Groot & Slump, 1969) which is poorly absorbed. Vohra & Kratzer (1967) obtained differences in growth rates of turkey poults when given different ISP. Smith & Sisson (1975) gave soya-bean isolates and concentrates to preruminant calves, and they found that the method of preparation influenced the flow of N from the abomasum. The AD of N of the two soya-bean-protein isolates fed in the present experiment were 0·945 for Supro 610 and 0·916 for Promine D.

The small improvement in the AD of DM and N with increasing age of the pigs from 10–24 d when diets containing soya-bean proteins were fed confirms the observations of Hays *et al.* (1959), but the AD of DM and N did not improve with increasing age of pigs given milk diets.

N retention as a proportion of dietary N intake was greater for pigs given milk-protein diets than soya-bean-protein diets. Similar results were obtained by Hays *et al.* (1959) who showed that the N retention in pigs at 2 weeks of age was greater when they were given diets containing milk protein than when they were given diets containing SBM (0·76 *v.* 0·51) although by 5 weeks of age the N retention had decreased for pigs fed the milk diets and remained at a similar level for pigs fed SBM diets.

Amino acid supplementation

Supplementation of the milk-protein diets with DL-methionine to a similar level of total sulphur amino acids as in whole egg protein (5·4 g/16 g N) reduced food intakes and live-weight gains and increased the plasma concentration of methionine in the pigs in Expt 3. Other workers have shown no response to methionine supplementation of milk diets for young pigs (Schiller & Ocio, 1963; Braude *et al.* 1977) although Walker & Kirk (1975) showed that the preruminant lamb receiving a similar dietary methionine level had increased N balance and the efficiency with which the apparently digested N was retained over lambs receiving an unsupplemented milk-protein diet. The addition of DL-methionine and lysine to the ISP and SBM diets reduced food intakes and increased the plasma concentration of methionine and lysine. Hays *et al.* (1959) showed that methionine supplementation of ISP and SBM diets increased weight gains and improved the food conversion and N retention of young pigs. However, the methionine concentration of their supplemented diets was only 2·7 g/16 g N. In the present experiment, methionine was added to 5·4 g/16 g N, or 13·5 g/kg diet, and it is concluded that these levels of dietary methionine may have been toxic to pigs of this age.

Methionine fed in excess has previously been shown to depress food intakes and growth (Benevenga & Harper, 1967) and these depressions are accompanied by an elevation in the plasma concentration of methionine (Harper & Benevenga, 1973). Plasma amino acid concentrations may provide signals to reduce voluntary food intake via the central regulatory mechanism in the hypothalamus and other brain receptors. Rotruck & Boggs (1977) showed that the food intake of rats was depressed and symptoms of toxicity produced by more than 8–12 g methionine/kg in low-protein diets, but methionine:crude protein in these experiments with rats was twice that in the present experiment.

Growth depression resulting from the ingestion of excess methionine is caused only partly by the reduction in voluntary food intake, as when birds were fed at equal intakes, weight gains were less for birds given excess methionine than those given a methionine-adequate diet (Baker, 1976). So methionine *per se* results in a growth depression separate from that caused by a reduction in food intake. Harper & Benevenga (1973) associated elevated plasma methione concentrations in rats given excess methionine with a reduction in the rate of stomach emptying. This was not the situation in Expt 3 as the rate of stomach emptying of pigs given the amino acid-supplemented diets was not significantly different from that of pigs given the unsupplemented diets (Wilson & Leibholz, 1981 *a*), but the plasma levels of methionine were elevated 20-fold over that of pigs given the unsupplemented diets. Fitzpatrick *et al.* (1975) found that the concentration of methionine in the plasma was unaffected by dietary concentration of S amino acids less than 9 g/kg, but doubled as the level in the diet was increased to 15 g/kg in the rat.

In Expt 3 increasing the lysine content of the ISP and SBM diets from 6·5–7·6 g/16 g N increased the plasma concentration of lysine by 30 and 55% respectively Chavez & Bayley

(1976) gave pigs aged between 3 and 7 weeks dietary lysine levels from 2·6–7·8 g/16 g N and found that the level of lysine had no significant effect on the lysine concentration in the plasma. However, Mitchell *et al.* (1968) gave diets containing 3·1–5·4 g lysine/16 g N and found that the lysine content of the plasma increased rapidly when the lysine content of the diet exceeded 4·9 g/16 g N.

Blood urea

The concentrations of urea in the blood plasma were higher in the pigs given soya-bean proteins than milk proteins which supports the finding of Eggum (1970) that the level of blood urea is inversely proportional to the efficiency of N utilization.

Carcass composition

The influence of protein intake on body composition would be most apparent with young rapidly-growing animals. The lower protein intakes (through reduced food intakes) of pigs given the soya-bean-protein diets in Expt 3 decreased the crude protein content and increased the total fat content of the body. In Expt 4 the lower food intakes and hence protein intakes of pigs given the ISP (Supro 610) also increased fat content of the body. Studies with milk-fed lambs (Norton *et al.* 1970) have shown that feeding protein-deficient diets will depress growth rates and increase the fat content of the body at a given weight.

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