Amino acid and energy digestibility of protein sources for growing pigs[1,2]

R. O. Gottlob,* J. M. DeRouchey,*[3] M. D. Tokach,* R. D. Goodband,* S. S. Dritz,* J. L. Nelssen,* C. W. Hastad,* and D. A. Knabe†

*Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506-0201; and †Department of Animal Science, Texas A & M University, College Station 77843-2471

ABSTRACT: Two experiments were conducted to determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of AA and DE, and to estimate ME and NE of rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, and spray-dried plasma protein. In Exp. 1, 6 barrows (initially 29.5 ± 2.5 kg of BW) were fitted with ileal T-cannulas and fed each of 5 cornstarch-based diets in a balanced crossover design over 35 d. During a given week, there were either 1 or 2 replications of each treatment, resulting in 6 total replications over 5 wk. The 4 test diets (fed from d 0 to 28) were formulated to contain 12.5% CP by using analyzed nutrient compositions of rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, or spray-dried plasma protein. The fifth (N-free) diet was fed from d 28 to 35 to estimate basal endogenous losses of CP and AA, which were used to calculate SID. Ileal digesta were collected and analyzed, and AID and SID values were calculated. Apparent ileal digestible Lys, Met, and Thr values were 80.0 ± 3.3, 65.6 ± 3.1, and 68.4 ± 4.5% for rice protein concentrate; 85.6 ± 4.8, 85.5 ± 4.3, and 69.8 ± 8.5% for salmon protein hydrolysate; 93.3 ± 1.4, 89.9 ± 5.8, and 83.6 ± 5.3% for whey protein concentrate; and 92.8 ± 0.9, 85.7 ± 2.1, 86.5 ± 2.3% for spray-dried plasma protein, respectively. In Exp. 2, 6 barrows (initially 37.6 ± 1.7 kg of BW) were fed each of 5 corn-based diets in a balanced crossover design over 35 d. During a given week, there were either 1 or 2 replications of each treatment, resulting in 6 total replications over 5 wk. The 4 diets containing the test ingredients were formulated to contain approximately 20% CP by using their analyzed nutrient compositions. The fifth (corn control) diet containing 8.2% CP was also used to calculate energy values by difference. Feces were collected to determine DE. The ME and NE contents were estimated using published regression equations. The DE, ME, and NE (as-fed) values were 4,724 ± 461, 4,226 ± 437, and 3,235 ± 380 kcal/kg for rice protein concentrate; 4,173 ± 1,052, 3,523 ± 1,002, and 2,623 ± 872 kcal/kg for salmon protein hydrolysate; 4,949 ± 1,002, 4,352 ± 955, and 3,344 ± 831 kcal/kg for whey protein concentrate; and 4,546 ± 673, 3,979 ± 652, and 3,020 ± 567 kcal/kg for spray-dried plasma protein, respectively. The excellent AA digestibility and relatively high DE, ME, and NE values indicate that these protein sources warrant further investigation as ingredients for growing pig diets.

Key words: amino acid, digestibility, energy, protein source, pig

 J. Anim. Sci. 2006. 84:1396–1402

INTRODUCTION

The inclusion of high-quality protein ingredients in nursery and growing pig diets is a common practice in the swine industry. As new protein products become available, however, reliable and accurate AA digestibility and energy values must be determined so nutritionists have greater confidence in these products when formulating diets. Although new protein products may have high concentrations of protein and AA, the standardized digestibility of these AA needs to be established for proper diet formulation.

The effect of spray-dried plasma protein on pig growth performance has been evaluated in numerous experiments (Hansen et al., 1993; Kats et al., 1994; DeRouchey et al., 2004). However, little research has focused on high-protein whey protein concentrate (Grinstead et al., 2000) or salmon protein hydrolysate (Husby, 1991), and no data are available for rice protein concentrate.

There currently is no published standardized ileal AA digestibility data for rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, or spray-dried plasma protein. Furthermore, only spray-dried

[1]Contribution No. 05-339-J of the Kansas Agric. Exp. Sta., Manhattan 66506-0210.

[2]Appreciation is expressed to International Quality Ingredients, The Netherlands, for partial financial support and for supplying the rice protein concentrate and salmon protein hydrolysate.

[3]Corresponding author: jderouch@ksu.edu

Received September 2, 2005.

Accepted January 16, 2006.

plasma protein has values published for apparent ileal AA digestibility (NRC, 1998; Chae et al., 1999). Also, all 4 protein products lack published information on DE, ME, or NE values.

The objective of these experiments was to determine the apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of AA, DE, and ME, and to estimate NE, for rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, and spray-dried plasma protein.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the experiments. All protein products were analyzed to determine GE (Parr Instruments, Moline, IL), DM, CP, ash, and AA content (AOAC, 1995; methods 934.01, 990.03, 942.05, and 985.30, respectively) before the experiments began.

Experiment 1

Six nonlittermate barrows (initially 29.5 ± 2.5 kg of BW) were used in a 35-d experiment to determine the apparent and standardized ileal AA digestibility of rice protein concentrate (International Quality Ingredients, The Netherlands), salmon protein hydrolysate (International Quality Ingredients, The Netherlands), whey protein concentrate (Agri-Mark, Onalaska, WI), and spray-dried plasma protein (American Proteins, Ames, IA). Each pig was surgically fitted with a simple T-cannula approximately 15 cm cranial to the ileocecal valve, using procedures described by Knabe et al. (1989). Pigs were individually housed in stainless steel metabolism cages (1.5 × 0.6 m) in an environmentally controlled building, and allotted to 1 of 5 dietary treatments in a balanced crossover design. During a given week, there were either 1 or 2 replications of each treatment, resulting in 6 total replications over 5 wk. Upon completion of the experiment, the cannulas were surgically removed.

All diets were formulated by using analyzed values of the experimental protein sources (Table 1). Four of the treatment diets were based on cornstarch and were formulated to contain 12.5% CP by using analyzed nutrient compositions of rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, or spray-dried plasma protein (Tables 2 and 3). The fifth treatment was an N-free diet based on cornstarch. All diets contained 0.25% chromic oxide as an indigestible marker.

Each 7-d feeding period consisted of a 6-d acclimation period followed by 1 d (12 h/d) of ileal digesta collection. Feed was divided into 2 equal meals and fed at 0600 and 1800 each day. Pigs were weighed each week, and feed allowance was calculated to maintain intakes of 2.5% of BW. Water was provided at a rate of 2:1 water:feed (wt:wt). Average BW of the pigs at the end of the experiment was 41.7 ± 3.0 kg.

Ileal digesta were collected between 0600 and 1800 for 1 d during each period by attaching a transparent, 100-mL latex collection bag to the cannula. During the 12-h collection period, digesta were collected every 30 min and immediately frozen. At the end of each day's collection, the digesta from each pig was pooled and stored. At the conclusion of collection for the experiment, digesta from each pig in its respective periods was homogenized and a 200-g subsample was taken. The samples were then freeze-dried and finely ground before analysis for chromium (Kimura and Miller, 1957), DM, CP, ash, and AA content (AOAC, 1995; methods 934.01, 990.03, 942.05, and 982.30, respectively). Nutrient digestibilities were calculated based on the analyzed chromium concentrations in the digesta and feed, based on methods described by Stein et al. (2004).

The apparent ileal digestibility for AA in the experimental protein sources were calculated using the following equation (Stein et al., 1999):

$$\mathrm{AID} = (100 - [\{\mathrm{AAd}/\mathrm{AAf}\} \times \{\mathrm{Crf}/\mathrm{Crd}\}]) \times 100, \quad [1]$$

where AID (%) is the apparent ileal digestibility of an AA, AAd is the AA concentration in the ileal digesta DM, AAf is the AA concentration in the feed DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM.

The basal endogenous AA loss (**EAL**) to the ileum of each AA was determined based on the digesta obtained after feeding the N-free diet using the following equation (Stein et al., 2001):

$$\mathrm{EAL} = (\mathrm{AAd} \times [\mathrm{Crf}/\mathrm{Crd}]), \quad [2]$$

where EAL is the basal endogenous AA loss (g/kg of DMI), AAd is the AA concentration in the ileal digesta DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM.

Standardized ileal digestibilities of each AA were then calculated by correcting the AID for the EAL for each AA using the following equation (Stein et al., 2001):

$$\mathrm{SID} = (\mathrm{AID} + [\mathrm{EAL}/\mathrm{AAf}]), \quad [3]$$

where SID is the standardized ileal digestibility of an AA (%).

Experiment 2

Six nonlittermate barrows (initially 37.6 ± 1.7 kg of BW) were used in a 35-d experiment to determine DE, ME, and NE values for the protein sources used in Exp. 1. Pigs were housed in stainless-steel metabolism cages designed to allow collection of feces, were kept in the same facility as described in Exp. 1, and were allotted to 1 of 5 dietary treatments in a balanced crossover design. During a given week, there were either 1 or 2 replications of each treatment, resulting in 6 total replications over 5 wk.

Table 1. Analyzed nutrient composition of ingredients (as-fed basis)[1]

Nutrient, %	Rice protein concentrate	Salmon protein hydrolysate	Whey protein concentrate	Spray-dried plasma protein
DM	92.68	91.44	94.69	90.85
CP	67.51	92.70	80.18	77.95
Ash	3.41	6.84	2.46	8.60
Ca	0.10	0.13	0.63	0.15
P	0.75	1.03	0.38	1.71
Indispensable AA				
Arg	5.26	5.47	2.03	4.57
His	1.65	1.59	1.56	2.61
Ile	2.91	2.16	5.15	2.90
Leu	5.31	3.97	8.69	7.51
Lys	2.21	5.05	7.49	6.90
Met	1.77	1.89	1.64	0.69
Phe	3.52	2.10	2.65	4.38
Thr	2.12	2.62	5.01	4.33
Trp	0.81	0.48	1.61	1.38
Val	4.13	2.78	4.82	5.20
Dispensable AA				
Ala	3.47	5.93	3.81	4.18
Asp	5.39	6.18	8.21	7.35
Cys	1.45	0.42	1.83	2.73
Glu	10.87	10.01	13.80	11.53
Gly	2.77	11.99	1.44	2.76
Pro	2.94	6.17	4.92	4.44
Ser	2.36	2.60	2.96	3.98
Tyr	3.32	1.32	2.38	4.04

[1]Values represent the means of 1 sample for each ingredient analyzed in duplicate.

All diets were formulated by using analyzed values of the experimental protein sources (Table 1). The 4 experimental ingredients were obtained from the same lots as those used in Exp. 1. Four of the treatment diets were corn-based and were formulated to contain approximately 20.0% CP by using analyzed nutrient compositions of rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, or spray-dried plasma

Table 2. Composition of experimental diets (Exp. 1, as-fed basis)

Item	Nitrogen free	Rice protein concentrate	Salmon protein hydrolysate	Whey protein concentrate	Spray-dried plasma protein
Ingredient	%				
Cornstarch	80.80	74.12	79.59	70.46	70.95
Rice protein concentrate	—	18.55	—	—	—
Salmon protein hydrolysate	—	—	13.48	—	—
Whey protein concentrate	—	—	—	16.60	—
Spray-dried plasma protein	—	—	—	—	16.45
Sucrose	10.00	—	—	—	—
Solka floc	3.00	—	—	6.00	6.00
Soy oil	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.45	2.85	2.20	2.55	1.55
Limestone	0.30	0.48	0.75	0.38	1.05
Salt	0.40	0.35	0.35	0.35	0.35
Vitamin premix[1]	0.05	0.25	0.25	0.25	0.25
Trace mineral premix[2]	0.25	0.15	0.15	0.15	0.15
Potassium carbonate	0.40	—	—	—	—
Magnesium oxide	0.10	—	—	—	—
Chromic oxide	0.25	0.25	0.25	0.25	0.25

[1]Provided per kilogram of complete diet: 11,026 IU of vitamin A; 1,654 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin K (menadione sodium bisulfite); 55.1 mg of niacin, 33.1 mg of pantothenic acid (as D-calcium pantothenate); 9.9 mg of riboflavin; and 0.044 mg of B_{12}.

[2]Provided per kilogram of complete diet: 39.7 mg of Mn (oxide), 165.4 mg of Fe (sulfate), 165 mg of Zn (oxide), 16.5 mg of Cu (sulfate), 0.30 mg of I (as Ca iodate), and 0.30 mg of Se (as Na selenite).

Table 3. Nutrient composition of diets (Exp. 1, as-fed basis)

Nutrient	Nitrogen free	Rice protein concentrate	Salmon protein hydrolysate	Whey protein concentrate	Spray-dried plasma protein
Calculated			%		
Ca	0.38	0.71	0.71	0.72	0.71
P	0.31	0.60	0.60	0.60	0.61
Analyzed					
CP	—	12.50	12.50	12.50	12.50
Indispensable AA[1]					
Arg	—	0.96	0.76	0.34	0.72
His	—	0.29	0.22	0.25	0.42
Ile	—	0.51	0.29	0.77	0.47
Leu	—	1.01	0.58	1.39	1.27
Lys	—	0.42	0.71	1.17	1.12
Met	—	0.33	0.27	0.23	0.12
Phe	—	0.67	0.30	0.43	0.74
Thr	—	0.41	0.41	0.88	0.73
Trp	—	0.13	0.06	0.22	0.22
Val	—	0.73	0.39	0.77	0.85
Dispensable AA[1]					
Ala	—	0.67	0.88	0.66	0.70
Asp	—	1.04	0.92	1.36	1.23
Cys	—	0.25	0.07	0.26	0.42
Glu	—	2.05	1.45	2.22	1.81
Gly	—	0.52	1.68	0.26	0.46
Pro	—	0.53	0.84	0.71	0.73
Ser	—	0.50	0.46	0.62	0.65
Tyr	—	0.50	0.17	0.32	0.55

[1]Values calculated using analyzed nutrient composition of ingredients reported in Table 1.

protein (Table 4). The fifth treatment was a corn-based control diet that contained 8.2% CP. Because the corn in each experimental diet also supplied energy, the fifth diet was fed to determine the energy value of corn so that the DE of the experimental diets and protein products could be calculated by the difference.

Feed was divided into 2 equal meals and fed at 0600 and 1800 each day. Pigs were weighed every week, and feed allowance was calculated to maintain daily intakes of 3.0% of BW. Water was provided twice daily at a rate of 2:1 water:feed (wt:wt). Average BW of the pigs at the end of period 5 was 50.9 ± 2.4 kg.

The 5 feeding periods consisted of 3 d of diet acclimation followed by 4 d of total fecal collection. Ferric oxide (1% of diet) was added to the first and last meals of the collection period as the indigestible marker to identify the beginning and end of fecal collection. Collection began with the appearance of marked feces and continued until the second appearance of marked feces stopped. Feces were collected twice daily and later pooled for each period. The feces were then mixed, dried, and ground. Representative subsamples were taken and finely ground for analyses. Feed and feces were analyzed for DM (AOAC, 1995; method 934.01) and for GE by using adiabatic bomb calorimetry (Parr Instruments, Moline, IL).

The DE values of diets were then calculated by subtracting the GE of DM excreted from GE of DM intake. This value was then expressed as a percentage and multiplied by the DM GE value for the feed to represent the DM DE of each diet in kilocalories per kilogram. By correcting the DM energy concentrations in each diet for nonenergy-containing feed ingredients, the amount of DM energy contributed by corn, the experimental protein source, or both was determined. This value was further corrected by subtracting the energy fraction from corn to estimate the DM DE in the ingredient. Finally, this value for each ingredient was multiplied by the respective DM percentage to express a DE (as-fed) value for each experimental protein source.

Urine was collected for analysis during the experiment, but because of complications and malfunction in our laboratory, ME values were not able to be determined with the assistance of analytical procedures. Thus, ME values of each ingredient were determined according to the DE and CP of diets containing each protein product using the following equation: $ME = DE \times (1.003 - [0.0021 \times \%CP])$ ($R^2 = 0.48$; Noblet and Perez, 1993). Individual ME values were then calculated by difference from the ME value determined from the corn used in the diets. Net energy values for each ingredient were calculated by using the equation: $NE = ([0.870 \times ME] - 442)$ ($R^2 = 0.94$; Noblet et al., 1994).

RESULTS AND DISCUSSION

Rice protein concentrate is a tan-colored, fine-textured powder. Although rice protein concentrate contains a

Table 4. Composition of experimental diets (Exp. 2, as-fed basis)

Item	Corn control[1]	Rice protein concentrate	Salmon protein hydrolysate	Whey protein concentrate	Spray-dried plasma protein
Ingredient	%				
Corn	96.18	75.97	82.51	78.82	79.42
Rice protein concentrate	—	20.05	—	—	—
Salmon protein hydrolysate	—	—	13.98	—	—
Whey protein concentrate	—	—	—	17.70	—
Spray-dried plasma protein	—	—	—	—	17.45
Monocalcium phosphate, 21% P	1.80	2.10	1.30	1.73	0.60
Limestone	1.03	0.90	1.23	0.78	1.55
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15
Chromic oxide	0.25	0.25	0.25	0.25	0.25
Calculated analysis[4]					
CP, %	8.2	20.0	20.0	20.9	20.3
GE, kcal/kg	4,575	4,889	4,751	4,858	4,763
Ca, %	0.75	0.75	0.75	0.75	0.75
P, %	0.65	0.65	0.65	0.65	0.65

[1]The corn diet was used to determine the energy value of corn so that energy values of the test protein products could be determined by the difference.

[2]Provided per kilogram of complete diet: 11,026 IU of vitamin A, 1,654 IU of vitamin D_3, 44 IU of vitamin E, 4.4 mg of vitamin K (menadione sodium bisulfite), 55.1 mg of niacin, 33.1 mg of pantothenic acid (as D-calcium pantothenate), 9.9 mg of riboflavin, and 0.044 mg of B_{12}.

[3]Provided per kilogram of complete diet: 39.7 mg of Mn (oxide), 165.4 mg of Fe (sulfate), 165 mg of Zn (oxide), 16.5 mg of Cu (sulfate), 0.30 mg of I (as Ca iodate), and 0.30 mg of Se (as Na selenite).

[4]Values for diets containing experimental protein sources based on analyzed values reported in Table 1. Values for corn control diet based on NRC (1998) values for yellow corn.

high CP concentration, it is relatively low in Lys and Thr concentrations (Table 1). Apparent ileal digestible Lys, Met, and Thr values for rice protein concentrate were 80.0, 65.6, and 68.4%, respectively, and SID Lys, Met, and Thr values were 86.6, 69.0, and 78.9%, respectively (Table 5). The AA digestibility values for rice protein concentrate are lower than those for soybean meal (NRC, 1998). Digestible, metabolizable, and net energy values for rice protein concentrate were 4,724, 4,226, and 3,235 kcal/kg, respectively (Table 6).

Salmon protein hydrolysate is a product of the salmon fishing and farming industry. Salmon fishing and farming occurs off the shores of Alaska, Nova Scotia, New England, Chile, and many other coastline areas. When salmon are processed for human consumption, the remaining parts are hydrolyzed, spray-dried, and sold as a protein hydrolysate product.

The sum of the CP and ash contents of salmon protein hydrolysate is greater than the determined DM, indicating an erroneous CP value. The large CP value could be due in part to the presence of adulterants like urea, ammonium sulfate, or other NPN materials (PCARRD, 2005). Because salmon protein hydrolysate is composed mainly of salmon heads, frames, and viscera, a portion of the N detected in CP analysis is from nucleic acids (Bates, 2005). This type of N is not detected by common analysis for other NPN sources such as urea and ammonium compounds (Bates, 2005).

Salmon protein hydrolysate has an odor, texture, and consistency similar to that of menhaden fish meal. Although salmon protein hydrolysate contains more CP, it has lower apparent and standardized ileal digestibility for nearly all AA compared with NRC (1998) values for menhaden fish meal.

Apparent ileal digestible Lys, Met, and Thr values for salmon protein hydrolysate were 85.6, 85.5, and 69.8%, respectively, and SID Lys, Met, and Thr values were 89.7, 88.7, and 80.2%, respectively (Table 5). The salmon protein hydrolysate product had greater DE, ME, and NE (4,173, 3,523, and 2,623 kcal/kg, respectively; Table 6) than menhaden fish meal (3,770, 3,360 and 2,335 kcal/kg, respectively; NRC, 1998). Salmon protein hydrolysate, like other rendered animal by-products, also has a greater ash content than plant and milk protein ingredients. Salmon protein hydrolysate has been found to improve growth when fed to nursery pigs at up to 10% of the diet, whereas decreased ADG was observed at a 17.6% inclusion rate (Husby, 1991). Husby (1991) reported that the decreased ADG was likely a response to decreased feed intake, although there were only numerical differences in ADFI.

After mixing and during the storage period of these experiments, the salmon protein hydrolysate product and the corresponding diets hardened and clumped. The product used in our experiments was 8.56% moisture. Fish meals containing more than 10% water are usually avoided in animal feeds because moisture content in excess of 10% favors bacterial growth and hardening during storage (Husby, 1991). Hardened clumps were, however, easily broken and blended before each feeding to provide the pig with a consistent and uniform diet.

Table 5. Apparent (AID) and standardized ileal digestibility (SID) coefficients (%) of ingredients (Exp. 1)[1,2]

	Rice protein concentrate		Salmon protein hydrolysate		Whey protein concentrate		Spray-dried plasma protein	
Item	AID	SID	AID	SID	AID	SID	AID	SID
Indispensable AA								
Arg	86.8 (1.6)	89.9 (1.6)	90.6 (3.0)	94.6 (2.8)	86.0 (4.4)	94.5 (4.7)	92.7 (0.8)	96.8 (1.2)
His	80.0 (2.1)	82.9 (1.9)	78.5 (7.2)	81.8 (6.5)	88.0 (2.4)	90.9 (3.6)	91.8 (1.3)	93.5 (1.4)
Ile	75.6 (2.8)	80.7 (2.3)	72.2 (9.0)	81.2 (7.7)	90.8 (1.5)	94.3 (2.0)	87.1 (1.5)	92.8 (2.2)
Leu	75.5 (2.9)	79.3 (2.5)	76.1 (8.1)	82.9 (7.5)	92.3 (1.8)	95.2 (1.7)	90.6 (1.2)	93.7 (1.5)
Lys	80.0 (3.3)	86.6 (1.6)	85.6 (4.8)	89.7 (4.5)	93.3 (1.4)	95.7 (2.2)	92.8 (0.9)	95.4 (1.1)
Met	65.6 (3.1)	69.0 (2.5)	85.5 (4.3)	88.7 (4.3)	89.9 (5.8)	93.9 (4.8)	85.7 (2.1)	93.5 (7.0)
Phe	77.4 (2.6)	80.5 (1.9)	73.2 (9.9)	80.4 (8.9)	84.7 (4.4)	90.0 (4.7)	89.4 (1.8)	92.5 (2.1)
Thr	68.4 (4.5)	78.9 (4.0)	69.8 (8.5)	80.2 (7.6)	83.6 (5.3)	88.4 (5.9)	86.5 (2.3)	92.2 (2.2)
Trp	84.7 (2.9)	103.9 (4.0)	65.4 (14.0)	104.8 (11.8)	92.3 (2.8)	102.2 (2.4)	91.2 (1.3)	101.0 (2.7)
Val	76.0 (2.8)	81.3 (2.2)	73.7 (8.6)	83.4 (7.9)	87.4 (2.3)	92.5 (2.9)	89.2 (1.4)	93.8 (1.5)
Dispensable AA								
Ala	74.0 (3.6)	79.5 (2.9)	84.5 (5.1)	88.8 (4.4)	85.2 (2.1)	91.4 (3.9)	87.6 (1.7)	93.3 (2.6)
Asp	77.2 (2.7)	81.2 (2.3)	66.1 (11.2)	68.5 (10.4)	89.9 (1.8)	93.1 (2.8)	87.9 (1.6)	91.4 (1.0)
Cys	64.7 (3.2)	63.5 (3.6)	38.2 (12.3)	33.9 (14.3)	86.4 (3.1)	84.8 (3.2)	91.0 (1.4)	90.0 (1.1)
Glu	72.8 (2.8)	74.6 (2.5)	83.3 (5.6)	86.3 (5.1)	90.2 (2.1)	92.1 (2.5)	90.3 (1.5)	92.7 (1.4)
Gly	72.7 (3.8)	84.6 (3.1)	84.2 (5.3)	87.9 (4.6)	52.6 (20.2)	76.0 (25.1)	74.6 (6.0)	87.8 (4.0)
Pro	69.5 (4.1)	77.8 (4.1)	81.4 (5.7)	86.6 (4.4)	83.9 (3.8)	89.9 (5.8)	87.8 (2.2)	93.7 (1.6)
Ser	73.3 (3.8)	79.7 (4.0)	79.5 (6.2)	86.6 (5.6)	84.7 (3.4)	89.8 (4.3)	88.7 (1.8)	93.5 (1.3)
Tyr	72.3 (3.9)	76.9 (4.2)	62.7 (14.9)	73.9 (15.1)	80.6 (6.2)	86.0 (5.7)	90.7 (1.8)	93.9 (2.0)

[1]Values are the means of 6 observations. Standard deviation for each digestibility value is shown in parentheses.
[2]The SID represents the corrected AID accounting for basal endogenous loss of an AA. Calculated basal endogenous losses after feeding the N-free diet were (g/kg of DMI): Arg, 0.61; His, 0.16; Ile, 0.59; Leu, 0.88; Lys, 0.67; Met, 0.22; Phe, 0.52; Thr, 0.90; Trp, 0.43; Val, 0.86; Ala, 0.90; Asp, 0.97; Cys, 0.07; Glu, 1.00; Gly, 1.33; Pro, 0.92; Ser, 0.67; Tyr, 0.38.

Whey protein concentrate is a product of the dairy industry made from sweet dairy whey that has been spray-dried. It is commonly used in infant formulas, exercise drinks, and bakery products. Milk manufacturing processes have recently changed (Grinstead et al., 2000), and the quality of whey products is increasing (Chadan, 1997).

The whey protein concentrate used in our experiments was high in CP concentration, low in ash content, and had relatively high Lys, Ile, Leu, Thr, and Trp contents. Apparent ileal digestible Lys, Met, and Thr values were 93.3, 89.9, and 83.6%, respectively, and SID Lys, Met, and Thr values were 95.7, 93.9, and 88.4%, respectively (Table 5). In addition, the whey protein concentrate products used in these experiments had greater CP and AA contents than NRC (1998) values for dried whey, and also had greater AID and SID for all AA. The DE, ME, and NE for whey protein concentrate were 4,949, 4,352, and 3,344 kcal/kg, respectively (Table 6), whereas the NRC (1998) DE, ME, and NE values for dried whey are 3,335, 3,190, and 2,215 kcal/kg, respectively.

Standardized ileal digestibility values have not previously been reported for spray-dried plasma protein. Apparent ileal digestible Lys, Met, and Thr values for plasma were 92.8, 85.7, 86.5%, respectively, and SID Lys, Met, and Thr values were 95.7, 93.9, and 88.4%, respectively, in this experiment (Table 5). The AID values determined in this experiment for spray-dried plasma protein are greater for all AA than those reported by Chae et al. (1999), but are very similar to AID values for spray-dried blood meal (NRC, 1998). The SID values for spray-dried plasma protein, which were very similar to NRC (1998) values for spray-dried blood meal, are very high and reflect the usefulness of this ingredient

Table 6. Digestible and metabolizable energy values of ingredients (Exp. 2, as-fed basis)[1]

Ingredient, %	Rice protein concentrate	Salmon protein hydrolysate	Whey protein concentrate	Spray-dried plasma protein	Corn[2]
Gross energy, kcal/kg	4,954	4,808	5,245	4,627	4,059
Digestibility energy, kcal/kg	4,724 (461)	4,173 (1,052)	4,949 (1,002)	4,546 (673)	3,331 (136)
Metabolizable energy,[3] kcal/kg	4,226 (437)	3,523 (1,002)	4,352 (955)	3,979 (652)	3,283 (134)
Net energy,[4] kcal/kg	3,235 (380)	2,623 (872)	3,344 (831)	3,020 (567)	2,414 (116)

[1]Standard deviation for each energy value is shown in parentheses.
[2]The energy value of corn was determined so that energy values of the test protein products could be determined by the difference.
[3]The ME values of each ingredient were calculated by using the equation: ME = DE × (1.003 − [0.0021 × %CP]) (R^2 = 0.48; Noblet and Perez, 1993).
[4]The NE values of each ingredient were calculated by using the equation: NE = ([0.870 × ME] − 442) (R^2 = 0.94; Noblet et al., 1994).

in growing pig diets. The DE, ME, and NE values for spray-dried animal plasma have not been reported previously, and those values were 4,546, 3,979, and 3,020 kcal/kg, respectively, in the present experiment (Table 6). These values are larger than the DE, ME, and NE values for spray-dried blood meal (3,370, 2,945, and 2,070 kcal/kg, respectively; NRC, 1998).

IMPLICATIONS

The apparent and standardized ileal digestibility values and digestible and metabolizable energy values were measured for protein products for growing pigs. Although values varied somewhat, all protein products tested have relatively high amino acid digestibility coefficients. The use of spray-dried plasma protein for pig diets has been extensively researched, but the feeding values of rice protein concentrate and salmon protein hydrolysate have not been evaluated. Further research to determine growth performance of growing pigs fed these protein products is needed for practical application by nutritionists.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Bates, L. S. 2005. Aquaculture feed microscopy: A practical approach to quality control. Alteca, Ltd., Manhattan, KS. Available: http://www.alteca.com/aquaculture.htm Accessed May 10, 2005.

Chadan, R. 1997. Milk concentrates. Pages 30–33 in Dairy-Based Ingredients. Am. Assoc. Cereal Chem., St. Paul, MN.

Chae, B. J., I. K. Han, J. H. Kim, C. J. Yang, J. D. Hancock, I. H. Kim, and D. A. Anderson. 1999. Effects of dietary protein sources on ileal digestibility and growth performance for early-weaned pigs. Livest. Prod. Sci. 58:45–54.

DeRouchey, J. M., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. C. Woodworth, B. W. James, M. J. Webster, and C. W. Hastad. 2004. Evaluation of methods to reduce bacteria concentrations in spray-dried animal plasma and its effects on nursery pig performance. J. Anim. Sci. 82:250–261.

Grinstead, G. S., R. D. Goodband, S. S. Dritz, M. D. Tokach, J. L. Nelssen, J. C. Woodworth, and M. Molitor. 2000. Effects of a whey protein product and spray-dried animal plasma on growth performance of weanling pigs. J. Anim. Sci. 78:647–657.

Hansen, J. A., J. L. Nelssen, R. D. Goodband, and T. L. Weeden. 1993. Evaluation of animal protein supplements in diets of early-weaned pigs. J. Anim. Sci. 71:1853–1862.

Husby, F. M. 1991. Nutritional and feeding value of a salmon protein hydrolysate in diets for weanling pigs. Alaska Fisheries Dev. Found. Inc., Anchorage, AK.

Kats, L. J., J. L. Nelssen, M. D. Tokach, R. D. Goodband, J. A. Hansen, and J. L. Laurin. 1994. The effects of spray-dried porcine plasma on growth performance in the early-weaned pig. J. Anim. Sci. 72:2075–2081.

Kimura, F., and V. L. Miller. 1957. Improved determination of chromic oxide in cow feed and feces. J. Agric. Food Chem. 5:216.

Knabe, D. A., D. C. LaRue, E. J. Gregg, G. M. Martinez, and T. D. Tanksley, Jr. 1989. Apparent digestibility of nitrogen and amino acids in protein feedstuffs by growing pigs. J. Anim. Sci. 67:441–458.

Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344–354.

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389–3398.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

PCARRD. 2005. Protein Feeds. Philippine Council for Agriculture, Forestry and Natural Resources Research and Development. Los Baños, Laguna, Philippines. Available: http://www.pcarrd.dost.gov.ph/infocenter/hosted%20sites/philsan/protein.htm Accessed May 10, 2005.

Stein, H. H., S. Aref, and R. A. Easter. 1999. Comparative protein and amino acid digestibilities in growing pigs and sows. J. Anim. Sci. 77:1169–1179.

Stein, H. H., G. Benzoni, R. A. Bohlke, and D. N. Peters. 2004. Assessment of the feeding value of South Dakota-grown field peas (*Pisum sativum* L.) for growing pigs. J. Anim. Sci. 82:2568–2578.

Stein, H. H., S. W. Kim, T. T. Nielsen, and R. A. Easter. 2001. Standardized amino acid digestibilities in growing pigs and sows. J. Anim. Sci. 79:2113–2122.