JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Amino acid digestibility and concentration of digestible and metabolizable energy in copra meal, palm kernel expellers, and palm kernel meal fed to growing pigs

R. C. Sulabo, W. S. Ju and H. H. Stein

J ANIM SCI 2013, 91:1391-1399.
doi: 10.2527/jas.2012-5281 originally published online January 10, 2013

Amino acid digestibility and concentration of digestible and metabolizable energy in copra meal, palm kernel expellers, and palm kernel meal fed to growing pigs

R. C. Sulabo, W. S. Ju,[1] and H. H. Stein[2]

Department of Animal Sciences, University of Illinois at Urbana-Champaign, Urbana 61801

ABSTRACT: Two experiments were conducted to determine apparent ileal digestibility (AID) and standardized (SID) ileal digestibility of AA (Exp. 1) and the concentration of DE and ME (Exp. 2) in copra meal (CM), palm kernel expellers from Indonesia (PKE-IN), palm kernel expellers from Costa Rica (PKE-CR), palm kernel meal from Costa Rica (PKM), and soybean meal (SBM). In Exp. 1, 6 barrows (BW = 34.0 ± 1.4 kg) were randomly allotted to a 6 × 6 Latin square design with 6 diets and 6 periods. One diet contained 30% SBM and 4 diets were formulated with 20% SBM and 30% (as-fed basis) CM, PKE-IN, PKE-CR, or PKM. The last diet was an N-free diet that was used to measure basal endogenous losses of CP and AA. The SID of CP and all indispensable AA except Met, Thr, and Trp was less ($P < 0.05$) in CM than in SBM, and the SID of CP and all indispensable AA except Trp was less ($P < 0.05$) in PKE-IN than in SBM. There were no differences ($P > 0.05$) in the SID of CP and all indispensable AA between PKE-CR and SBM, but the SID of CP and all indispensable AA were less ($P < 0.05$) in PKM than in SBM. The SID of CP was less ($P < 0.05$) in PKM compared with CM and PKE-CR, but there were no differences ($P > 0.05$) in the SID of all indispensable AA among CM, PKE-IN, PKE-CR, and PKM. In Exp. 2, 48 barrows (BW = 35.2 ± 3.0 kg) were housed individually in metabolism cages and allotted to 6 diets in a randomized complete block design with 8 replicate pigs per diet. A corn-based diet and 5 diets containing 70% of the corn diet and 30% of CM, PKE-IN, PKE-CR, PKM, or SBM were formulated, and the DE and ME in CM, PKE-IN, PKE-CR, PKM, and SBM were calculated using the substitution procedure. The DE (3692, 3304, 2994, and 2905 kcal/kg DM) and ME (3496, 3184, 2883, and 2766 kcal/kg DM) in CM, PKE-IN, PKE-CR, and PKM, respectively, were less ($P < 0.05$) than the DE and ME in SBM (4275 and 4062 kcal/kg DM, respectively). Copra meal had greater ($P < 0.05$) DE than PKE-IN, PKE-CR, and PKM and greater ($P < 0.05$) ME than PKE-CR and PKM. The DE in PKE-IN was greater ($P < 0.05$) than in PKM. In conclusion, the SID of most indispensable AA is less in CM, PKE-IN, and PKM than in SBM, but no differences among CM, PKE-IN, PKE-CR, and PKM were observed. The concentrations of DE and ME are less in CM, PKE-IN, PKE-CR, and PKM than in SBM. The DE and ME of CM are greater than in PKE-CR and PKM.

Key words: amino acids, copra meal, energy, palm kernel expellers, palm kernel meal, pigs

J. Anim. Sci. 2013.91:1391–1399
doi:10.2527/jas2012-5281

INTRODUCTION

The importance of agricultural coproducts as feedstuffs for swine has increased due to increases in the cost of traditional feed ingredients (Wachenheim et al., 2006). Oilseed meals are co-products of the vegetable oil industry and are used in diets fed to poultry and livestock to provide CP and AA (Ravindran and Blair, 1992). Soybean meal (**SBM**) is the most used oilseed meal in animal feeds due to its wide availability and favorable AA composition (Ramachandran et al., 2007), but other oilseed meals such as copra and palm kernel products may also be used. These ingredients are primarily produced in tropical countries, but as the cost of SBM has increased, the interest in using copra and palm kernel ingredients has also increased.

Copra meal (**CM**) is produced after oil is extracted from the dried endosperm of the coconut (*Cocos nucifera*). Palm kernel products are coproducts from the

[1]Current address: Cheil Jedang Corp., Seoul, 100-400 South Korea
[2]Corresponding author: hstein@illinois.edu
Received March 10, 2012.
Accepted December 19, 2012.

kernels of the oil palm fruit (*Elaeis guineensis*) and are produced after the fruits have been deoiled. Processing plants use mechanical pressing, solvent (hexane) extraction, or a combination of these 2 methods to extract the oil. Palm kernel products of mechanical extraction are referred to as palm kernel expellers (**PKE**) and coproducts of solvent extraction are called palm kernel meal (**PKM**). Solvent extraction is more efficient than mechanical pressing in removing oil from the palm kernels, and PKM, therefore, usually contains less residual oil than PKE. The use of copra or palm kernel products in swine diets has been evaluated, but effects on growth performance have been variable (Babatunde et al., 1975; Rhule, 1996; O'Doherty and McKeon, 2000). One of the reasons for these variable results may be that there are limited data on the digestibility of AA and energy in copra and palm kernel products to allow accurate feed formulation. The objectives of this work, therefore, were to determine digestibility of AA and the concentration of DE and ME in CM, PKE, and PKM, and to compare these values to those for SBM.

MATERIALS AND METHODS

Two experiments were conducted following protocols approval from the Institutional Animal Care and Use Committee at the University of Illinois.

The same sources of CM, PKE, PKM, and SBM were used in both experiments (Table 1). Copra meal was obtained from Stance Global, Pty Ltd. (Chapel Hill, Queensland, Australia), and PKM was produced by and obtained from Industrial de Oleaginosas Americanas S.A. (INOLASA; Puntarenas, Costa Rica). Two sources of PKE were used. Indonesian PKE (**PKE-IN**) was obtained from PPC Logistics (Oakland, CA), and Costa Rican PKE (**PKE-CR**) was sourced from Unimar (San José, Costa Rica). Soybean meal was obtained locally (Solae LLC, Gibson City, IL). Pigs used in the experiments were the offspring of G-Performer boars that were mated to Fertilium 25 females (Genetiporc, Alexandria, MN).

AA Digestibility, Experiment 1

Exp. 1 was designed to compare the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of AA in CM, PKE-IN, PKE-CR, PKM, with the AID and SID of CP and AA in SBM. Six growing barrows (initial BW = 34.0 ± 1.4 kg) were randomly allotted to a 6 × 6 Latin square design with 6 diets and 6 periods, using a spreadsheet-based program to balance potential residual effects (Kim and Stein, 2009). Pigs were equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998), and all pigs were housed in individual pens (1.2 × 1.5 m) in an environmentally controlled room after surgery. Each pen was equipped with a feeder and a nipple drinker and had fully slatted T-bar floors.

Six diets were prepared (Tables 2 and 3). One diet contained cornstarch, sucrose, and 30% (as-fed basis) SBM as the sole source of AA. Four diets were formulated with 20% SBM and 30% (as-fed basis) CM, PKE-IN, PKE-CR, or PKM. The last diet was an N-free diet that was used to measure basal endogenous losses of CP and AA. All diets contained 0.4% chromic oxide as an indigestible marker and vitamins and minerals were included to meet or exceed current requirement estimates (NRC, 1998). All pigs were provided daily feed at a level of 3 times their maintenance energy requirement (i.e., 106 kcal ME per $kg^{0.75}$; NRC, 1998), and equal meals were provided every day at 0800 and 1700 h. Animals had free access to water throughout the experiment.

Pig BW were recorded at the beginning of the experiment and at the end of each period. The initial 5 d

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

Item	Ingredient[1] CM	PKE-IN	PKE-CR	PKM	SBM
DM, %	92.9	90.8	93.0	91.9	87.8
GE, kcal/kg	4445	4447	4517	4250	4345
CP (N × 6.25), %	22.0	14.2	14.4	13.6	47.0
AEE[2], %	1.9	7.4	6.3	1.3	1.9
NDF, %	54.8	68.5	72.6	77.9	6.9
ADF, %	26.9	41.9	44.1	49.4	4.2
Ash, %	6.0	4.0	3.8	3.8	6.0
Indispensable AA, %					
Arg	2.08	1.52	1.53	1.36	3.34
His	0.35	0.20	0.20	0.17	1.16
Ile	0.66	0.48	0.46	0.41	2.15
Leu	1.20	0.84	0.79	0.71	3.51
Lys	0.42	0.34	0.39	0.36	2.91
Met	0.27	0.26	0.24	0.22	0.66
Phe	0.79	0.55	0.51	0.47	2.30
Thr	0.55	0.38	0.36	0.33	1.73
Trp	0.15	0.12	0.12	0.05	0.62
Val	0.97	0.67	0.63	0.57	2.27
Dispensable AA, %					
Ala	0.85	0.54	0.51	0.46	2.02
Asp	1.50	1.02	0.97	0.89	5.22
Cys	0.28	0.17	0.16	0.17	0.66
Glu	3.34	2.36	2.22	2.02	8.02
Gly	0.82	0.59	0.57	0.53	1.92
Pro	0.60	0.39	0.40	0.36	2.60
Ser	0.71	0.51	0.48	0.44	2.01
Tyr	0.41	0.30	0.28	0.29	1.63

[1]CM = copra meal; PKE-IN = palm kernel expellers from Indonesia; PKE-CR = palm kernel expellers from Costa Rica; PKM = palm kernel meal; and SBM = soybean meal.

[2]AEE = acid-hydrolyzed ether extract.

of each period were considered an adaptation period to the diet. Ileal digesta were collected for 8 h on d 6 and 7 by attaching a plastic bag to the cannula barrel, which allowed for collection of digesta flowing into the bag. Bags were removed whenever they were filled with digesta, or at least once every 30 min, and stored at -20°C to prevent bacterial degradation of AA in the digesta. On the completion of 1 experimental period, animals were deprived of feed overnight, and the next morning a new experimental diet was offered.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was collected for chemical analysis. A sample of CM, PKE-IN, PKE-CR, PKM, and SBM and of each diet was also collected. Digesta samples were lyophilized and finely ground before chemical analysis. All samples were analyzed for DM by oven drying duplicate samples at 135°C for 2 h (Method 930.15; AOAC International, 2007). The concentration of N in all samples was determined using the combustion procedure (Method 990.03; AOAC International, 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and CP was calculated as N × 6.25.

Amino acids were analyzed on a Hitachi Amino Acid Analyzer (Model L8800; Hitachi High Technologies America Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6*N* HCl for 24 h at 110°C (Method 982.30 E (a, b, c); AOAC, 2007). Methionine and Cys were analyzed as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis. Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C. Concentrations of Cr in diets and ileal digesta were measured using an inductive coupled plasma atomic emission spectrometric method (Method 990.08; AOAC International, 2007) after nitric acid-perchloric acid wet ash sample preparation (Method 968.088D; AOAC International, 2007). Ingredients were also analyzed

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

	Diet[1]					
Item	CM	PKE-IN	PKE-CR	PKM	SBM	N-Free
Ingredient, %						
CM	30.00	–	–	–	–	–
PKE-IN	–	30.00	–	–	–	–
PKE-CR	–	–	30.00	–	–	–
PKM	–	–	–	30.00	–	–
SBM (47% CP)	20.00	20.00	20.00	20.00	30.00	–
Cornstarch	23.00	23.00	23.00	23.00	43.00	68.10
Soybean oil	4.00	4.00	4.00	4.00	4.00	4.00
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00
Solka-floc[2]	–	–	–	–	–	4.00
Limestone	0.70	0.70	0.70	0.70	0.70	0.80
Dicalcium phosphate	1.20	1.20	1.20	1.20	1.20	1.50
Magnesium oxide	–	–	–	–	–	0.10
Potassium carbonate	–	–	–	–	–	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1]CM = copra meal; PKE-IN = palm kernel expellers from Indonesia; PKE-CR = palm kernel expellers from Costa Rica; PKM = palm kernel meal; and SBM = soybean meal.

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]The vitamin-mineral premix provided the following quantities of vitamins and minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D3 as cholecalciferol, 2204 IU; vitamin E as DL-α-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamine as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide, 1.0 mg, and nicotinic acid, 43.0 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3. Analyzed nutrient composition of experimental diets (as-fed basis), Exp. 1

	Diet[1]					
Item	CM	PKE-IN	PKE-CR	PKM	SBM	N-Free
DM, %	93.6	92.9	93.1	93.5	92.8	92.3
CP (N × 6.25), %	17.6	15.3	15.6	14.6	17.0	0.4
Indispensable AA, %						
Arg	1.31	1.14	1.11	1.23	0.97	0.02
His	0.35	0.30	0.28	0.32	0.35	0.01
Ile	0.61	0.58	0.55	0.61	0.65	0.02
Leu	1.09	0.98	0.91	1.04	1.07	0.04
Lys	0.72	0.70	0.68	0.76	0.88	0.02
Met	0.21	0.21	0.20	0.22	0.19	0.01
Phe	0.71	0.64	0.59	0.67	0.69	0.02
Thr	0.54	0.47	0.43	0.51	0.51	0.01
Trp	0.18	0.15	0.15	0.17	0.22	0.04
Val	0.73	0.67	0.63	0.70	0.70	0.02
Mean	6.45	5.84	5.53	6.23	6.23	0.21
Dispensable AA, %						
Ala	0.67	0.58	0.54	0.61	0.62	0.02
Asp	1.54	1.39	1.29	1.48	1.59	0.03
Cys	0.21	0.18	0.17	0.20	0.20	0.01
Glu	2.68	2.37	2.21	2.52	2.49	0.08
Gly	0.65	0.58	0.54	0.61	0.59	0.02
Pro	0.68	0.59	0.55	0.61	0.67	0.02
Ser	0.66	0.56	0.50	0.62	0.59	0.01
Tyr	0.43	0.38	0.35	0.42	0.38	0.01
Mean	7.60	6.70	6.21	7.14	7.20	0.28
All AA	14.05	12.54	11.74	13.37	13.43	0.49

[1]CM = copra meal; PKE-IN = palm kernel expellers from Indonesia; PKE-CR = palm kernel expellers from Costa Rica; PKM = palm kernel meal; and SBM = soybean meal.

for ADF (Method 973.18; AOAC International, 2007), NDF (Holst, 1973), acid-hydrolyzed ether extract (**AEE**, Method 2003.06; AOAC International, 2007), and ash (Method 942.05; AOAC International, 2007).

Values for AID and SID of CP and AA were calculated for each diet (Stein et al., 2007). The AID and SID values for SBM were used to calculate the contribution of SBM to the diets containing CM, PKE-IN, PKE-CR, and PKM. The AID and SID in CM, PKE-IN, PKE-CR, and PKM were then calculated by difference (Fan and Sauer, 1995). Homogeneity of variances was confirmed and outliers were tested using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC), but no outliers were detected. Data were analyzed using the MIXED procedure. The model included diet as the fixed effect and pig and period as random effects. Least squares means were calculated for each independent variable. When diet was a significant source of variation, means were separated using the PDIFF option of SAS with a Tukey-Kramer adjustment. The pig was the experimental unit for all calculations, and the α level used to determine significance among means was 0.05.

Energy Measurements, Experiment 2

Exp. 2 was designed to compare the apparent total tract digestibility (**ATTD**) of GE and the DE and ME content in CM, PKE-IN, PKE-CR, PKM, with values determined for SBM. A total of 48 growing barrows (initial BW = 35.2 ± 3.0 kg) were used in this experiment with 8 replicate pigs per diet. Pigs were placed in metabolism cages that were equipped with a feeder and a bowl drinker, fully slatted floors, a screen floor, and urine trays, which allowed for the total, but separate, collection of urine and fecal materials from each pig.

A corn diet consisting of 96.28% corn (as-fed basis) and vitamins and minerals was formulated (Table 4). Five additional diets were formulated by mixing 70% (as-fed basis) of the basal diet with 30% (as-fed basis) of CM, PKE-IN, PKE-CR, PKM, or SBM. The quantity of feed provided per pig daily was calculated as 3 times the estimated requirement for maintenance energy for the smallest pig in each replicate at the start of the experimental period and divided into 2 equal meals that were provided at 0700 and 1600 h. Water was available at all times. The experiment lasted 14 d. The initial 7 d were considered an adaptation period to the diet, and urine and fecal materials were collected during the next 5 d according to the marker-to-marker approach (Adeola, 2001). Urine was collected over a preservative of 50 mL of 6*N* HCl. Fecal samples and 20% of the collected urine were stored at −20°C immediately after collection.

At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was lyophilized and used for analysis (Kim et al., 2009). Fecal samples were dried in a forced-air oven and finely ground before analysis. Fecal, urine, diet, and ingredient samples were analyzed in duplicate for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL), and the ATTD of GE in each diet was calculated (Adeola, 2001). The amount of energy lost in the feces and in the urine, respectively, was calculated as well, and the quantities of DE and ME in each of the 6 diets were calculated (Adeola, 2001). The DE and ME in the corn diet was then multiplied by 70% to calculate the contribution from the corn diet to the DE and ME in diets containing CM, PKE-IN, PKE-CR, PKM, or SBM. The DE and ME in CM, PKE-IN, PKE-CR, PKM, and SBM were then calculated by difference (Widmer et al., 2007). Data were analyzed using the MIXED procedure as outlined for Exp. 1. The model included diet as the fixed effect and replicate as the random effect.

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

	Diet[1]					
Item	Corn	CM	PKE-IN	PKE-CR	PKM	SBM
Ingredient, %						
Corn	96.28	67.40	67.40	67.40	67.40	67.40
CM	–	30.00	–	–	–	–
PKE-IN	–	–	30.00	–	–	–
PKE-CR	–	–	–	30.00	–	–
PKM	–	–	–	–	30.00	–
SBM (48% CP)	–	–	–	–	–	30.00
Limestone	1.29	0.90	0.90	0.90	0.90	0.90
Dicalcium phosphate	1.43	1.00	1.00	1.00	1.00	1.00
Salt	0.57	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.43	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition						
GE, kcal/kg	3849	3947	3979	3988	3940	3880

[1]CM = copra meal; PKE-IN = palm kernel expellers from Indonesia; PKE-CR = palm kernel expellers from Costa Rica; PKM = palm kernel meal; and SBM = soybean meal.

[2]The vitamin-mineral premix provided the following quantities of vitamins and minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D3 as cholecalciferol, 2204 IU; vitamin E as DL-α-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamine as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide, 1.0 mg, and nicotinic acid, 43.0 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

RESULTS

Nutrient Composition of Ingredients

The concentration of CP in CM was 22.0% (as-fed basis), whereas the CP concentration in PKE-IN, PKE-CR, and PKM was between 13.6 and 14.4% (as-fed basis; Table 1). Gross energy concentrations in CM, PKE-IN, PKE-CR, PKM, and SBM were 4445, 4447, 4517, 4250, and 4345 kcal/kg, respectively (as-fed basis). The concentration of AEE in PKE-IN and PKE-CR was 7.4 and 6.3%, respectively (as-fed basis), but the concentration of AEE in CM, PKM, and SBM was between 1.3 and 1.9% (as-fed basis). The NDF and ADF concentrations in PKE-IN, PKE-CR, and PKM were between 68.5 and 77.9% (as-fed basis) and 41.9 and 49.4% (as-fed basis), respectively, whereas CM contained 54.8% NDF and 26.8% ADF (as-fed basis), and the NDF and ADF concentrations in SBM were only 6.9 and 4.2%, respectively (as-fed basis). The concentration of ash was 6.0% (as-fed basis) in both CM and SBM, but only 4.0, 3.8, and 3.8% (as-fed basis) in PKE-IN, PKE-CR, and PKM, respectively.

AA Digestibility, Experiment 1

The AID of CP in CM, PKE-IN, and PKM were less ($P < 0.05$) than in SBM (Table 5). However, CM and PKE-CR had greater ($P < 0.05$) AID of CP compared with PKM. There were no differences ($P > 0.05$) in the AID of CP between CM, PKE-IN, and PKE-CR. The AID of all indispensable AA was less ($P < 0.05$) in PKE-IN and PKM than in SBM, and CM had less ($P < 0.05$) AID of all indispensable AA except for Arg, Met, Phe, and Thr compared with SBM. Except for Thr, the AID of all indispensable AA in PKE-CR was not different ($P > 0.05$) from values obtained in SBM. There were no differences ($P > 0.05$) in the AID of all indispensable AA in CM, PKE-IN, PKE-CR, and PKM. Except for Gly, Pro, and Tyr, the AID of all dispensable AA was less ($P < 0.05$) in CM, PKE-IN, and PKE-CR than in SBM. The AID of all dispensable AA in PKM was less ($P < 0.05$) than in SBM.

The SID of CP and all indispensable and dispensable AA were less ($P < 0.05$) in PKM than in SBM (Table 6). Likewise, the SID of CP and all indispensable AA except Trp was less ($P < 0.05$) in PKE-IN than in SBM, and the SID of CP and all indispensable AA except Met, Thr, and Trp was less ($P < 0.05$) in CM than in SBM. However, there were no differences ($P > 0.05$) in the SID of CP and all indispensable AA between PKE-CR and SBM. The SID of CP was less ($P < 0.05$) in PKM compared with CM and PKE-CR, but there were no differences ($P > 0.05$) in the SID of all indispensable AA among CM, PKE-IN, PKE-CR, and PKM. For most dispensable AA, no differences ($P > 0.05$) in SID values were observed among CM, PKE-IN, PKE-CR, and PKM.

Energy Measurements, Experiment 2

When calculated on an as-fed basis, no differences ($P > 0.05$) in DE and ME among corn, CM, and SBM were observed (Table 7), but the DE and ME in PKE-IN, PKE-CR, and PKM were less ($P < 0.05$) than in corn and SBM. The DE and ME in CM were greater ($P < 0.05$) than in PKE-CR and PKM. Copra meal also had greater ($P < 0.05$) DE than PKE-IN. The DE and ME were not different ($P > 0.05$) among PKE-IN, PKE-CR, and PKM.

On a DM basis, the DE of corn was less ($P < 0.05$) than in SBM, but there were no differences ($P > 0.05$) in ME between corn and SBM. The DE and ME in CM were less ($P < 0.05$) than in SBM, but not different ($P > 0.05$) from the DE and ME of corn. However, PKE-IN, PKE-CR, and PKM contained less ($P < 0.05$) DE and

Table 5. Apparent ileal digestibility (AID, %) of CP and AA in copra meal (CM), palm kernel expellers from Indonesia (PKE-IN), palm kernel expellers from Costa Rica (PKE-CR), palm kernel meal (PKM), and soybean meal (SBM)[1], Exp. 1

	Ingredient					
Item	CM	PKE-IN	PKE-CR	PKM	SBM	SEM
CP	69.8^{b}	67.0^{bc}	73.7^{ab}	59.1^{c}	80.9^{a}	2.5
Indispensable AA, %						
Arg	85.8^{ab}	82.0^{b}	86.2^{ab}	82.6^{b}	89.2^{a}	1.6
His	77.8^{b}	76.2^{b}	79.6^{ab}	75.7^{b}	85.6^{a}	2.1
Ile	77.6^{b}	77.5^{b}	80.8^{ab}	76.5^{b}	86.0^{a}	1.7
Leu	77.9^{b}	76.3^{b}	79.9^{ab}	75.8^{b}	84.8^{a}	2.0
Lys	67.6^{b}	68.7^{b}	73.2^{ab}	66.1^{b}	83.3^{a}	3.3
Met	82.6^{ab}	80.0^{b}	83.9^{ab}	79.4^{b}	86.1^{a}	1.8
Phe	81.0^{ab}	79.4^{b}	81.9^{ab}	78.6^{b}	86.1^{a}	1.6
Thr	68.3^{ab}	66.6^{b}	67.7^{b}	65.1^{b}	75.9^{a}	2.5
Trp	83.5^{b}	82.9^{b}	84.1^{ab}	82.3^{b}	88.2^{a}	1.5
Val	73.8^{b}	73.5^{b}	76.8^{ab}	71.8^{b}	81.3^{a}	2.2
Mean	77.7^{b}	76.2^{b}	79.6^{ab}	75.3^{b}	84.6^{a}	1.9
Dispensable AA, %						
Ala	70.1^{b}	66.8^{bc}	71.8^{b}	63.6^{c}	78.3^{a}	2.9
Asp	74.7^{b}	71.9^{b}	73.5^{b}	71.4^{b}	85.2^{a}	1.8
Cys	61.2^{b}	67.5^{b}	69.1^{b}	64.6^{b}	78.9^{a}	2.6
Glu	77.0^{b}	76.3^{b}	80.8^{b}	78.2^{b}	88.3^{a}	1.5
Gly	51.1^{ab}	44.1^{ab}	53.7^{ab}	38.4^{b}	60.9^{a}	6.4
Pro	28.3^{a}	-11.1^{ab}	13.2^{a}	−57.1^{b}	35.0^{a}	17.9
Ser	75.0^{ab}	71.9^{b}	73.4^{b}	72.5^{b}	80.4^{a}	2.1
Tyr	78.3^{ab}	76.6^{ab}	78.2^{ab}	75.5^{b}	82.4^{a}	2.0
Mean	68.9^{ab}	63.5^{bc}	69.1^{ab}	59.5^{c}	78.3^{a}	3.2
All AA	73.0^{b}	69.4^{b}	74.0^{ab}	66.8^{b}	81.2^{a}	2.5

[a–c]Values within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 6 observations for all treatments.

ME than corn and SBM. Copra meal also had greater ($P < 0.05$) DE than PKE-IN, PKE-CR, and PKM, and greater ($P < 0.05$) ME than PKE-CR and PKM. The DE in PKE-IN was greater ($P < 0.05$) than in PKM, but there were no differences ($P > 0.05$) in ME among PKE-IN, PKE-CR, and PKM.

DISCUSSION

Composition of Ingredients

The nutrient composition of SBM and CM is in agreement with published values (Sauvant et al., 2004; NRC, 1998) and the composition of PKE-IN and PKE-CR is also in agreement with reported values (Agunbiade et al., 1999; Kim et al., 2001; Février et al., 2001; Sauvant et al., 2004; Ezieshi and Olomu, 2007). However, there are limited data on the nutrient composition of PKM. Copra meal also contained less GE and more NDF compared with published values for copra expellers (O'Doherty and McKeon, 2000; Sauvant et al., 2004; PHILSAN, 2010), which is likely a result of the reduced concentration of fat in CM compared with copra expellers.

Table 6. Standardized ileal digestibility (SID, %) of CP and AA in copra meal (CM), palm kernel expellers from Indonesia (PKE-IN), palm kernel expellers from Costa Rica (PKE-CR), palm kernel meal (PKM), and soybean meal (SBM),[1,2] Exp. 1

	Ingredient					
Item	CM	PKE-IN	PKE-CR	PKM	SBM	SEM
CP	79.9[b]	78.5b[c]	85.0a[b]	71.3[c]	91.3[a]	2.5
Indispensable AA, %						
Arg	91.2[b]	88.2[b]	92.5[ab]	88.3[b]	96.5[a]	1.6
His	82.5[b]	81.7[b]	85.4[ab]	80.8[b]	90.3[a]	2.1
Ile	81.6[b]	81.7[b]	85.2[ab]	80.4[b]	89.7[a]	1.7
Leu	81.6[b]	80.4[b]	84.3[ab]	79.7[b]	88.5[a]	2.0
Lys	72.8[b]	74.1[b]	78.8[ab]	71.1[b]	87.6[a]	3.3
Met	85.5[ab]	82.9[b]	87.0[ab]	82.2[b]	89.2[a]	1.8
Phe	84.5[b]	83.2[b]	86.0[ab]	82.2[b]	89.6[a]	1.6
Thr	76.7[ab]	76.1[b]	78.2[ab]	73.9[b]	84.7[a]	2.5
Trp	88.4[ab]	88.8[ab]	90.0[ab]	87.5[b]	92.2[a]	1.5
Val	79.0[b]	79.1[b]	82.8[ab]	77.2[b]	86.7[a]	2.2
Mean	82.6[b]	81.5[b]	85.2[ab]	80.3[b]	89.6[a]	1.9
Dispensable AA, %						
Ala	78.2[bc]	76.1[bc]	81.8[ab]	72.5[c]	86.7[a]	2.9
Asp	78.9[b]	76.5[b]	78.4[b]	75.8[b]	89.2[a]	1.8
Cys	68.0[c]	75.3[bc]	77.5[ab]	71.7[bc]	86.0[a]	2.6
Glu	79.9[b]	79.6[b]	84.3[b]	81.2[b]	91.4[a]	1.5
Gly	76.2[ab]	72.0[ab]	83.8[ab]	65.1[b]	88.3[a]	6.4
Pro	128.8[a]	104.0[ab]	137.0[a]	54.9[b]	136.2[a]	17.9
Ser	82.0[ab]	80.2[b]	82.7[ab]	80.0[b]	88.2[a]	2.1
Tyr	82.8[ab]	81.6[ab]	83.7[ab]	80.1[b]	87.5[a]	2.0
Mean	83.7[bc]	80.2[bc]	87.2[ab]	75.2[c]	93.8[a]	3.2
All AA	83.2[bc]	80.8[bc]	86.2[ab]	77.6[c]	91.8[a]	2.5

[a–c]Values within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 6 observations for all treatments.

[2]Standardized ileal digestibility values were calculated by correcting the values for apparent ileal digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined as (g/kg of DMI): CP, 19.04; Arg, 0.76; His, 0.18; Ile, 0.26; Leu, 0.43; Lys, 0.41; Met, 0.06; Phe, 0.26; Thr, 0.48; Trp, 0.09; Val, 0.41; Ala, 0.58; Asp, 0.69; Cys, 0.15; Glu, 0.83; Gly, 1.74; Pro, 7.31; Ser, 0.50; Tyr, 0.21; and all AA, 15.38.

AA Digestibility, Experiment 1

The AID and SID values for AA in SBM are in agreement with published values (NRC, 1998; Sauvant et al., 2004), but the AID of AA in CM that were determined in this experiment were greater than values reported by NRC (1998) and Han et al. (2003). Specifically, the AID of Lys that was calculated for CM in this experiment is much greater than reported values (Loosli et al., 1954; Creswell and Brooks, 1971). To our knowledge, no data for the SID of AA in CM have been published; however, the SID values obtained for most AA in CM in this experiment are in agreement with SID values reported for copra expellers (Sauvant et al., 2004). The SID values for CP and AA in the 2 sources of PKE and in PKM were greater than previous data for PKE (Février et al., 2001; Sauvant et al., 2004). Specifically, the SID of Lys in PKE-IN, PKE-CR, and PKM were almost twice the values that have been reported (Sauvant et al., 2004).

The reduced digestibility of CP and AA in CM, PKE-IN, and PKM compared with values calculated for SBM was also observed in other experiments (Nwokolo et al., 1976; Février et al., 2001; Kim et al., 2001; Ao et al., 2011). These observations may be due to the greater concentration of dietary fiber in these ingredients compared with SBM. Compared with most other oilseed meals, copra and palm kernel products contain more NDF and ADF and copra and palm kernel ingredients are relatively high in lignin (Göhl, 1981), and NDF negatively affects the AID of CP and AA in pigs (Lenis et al., 1996; Yin et al., 2000; Dilger et al., 2004).

Table 7. Digestible energy and ME in corn, copra meal (CM), palm kernel expellers from Indonesia (PKE-IN), palm kernel expellers from Costa Rica (PKE-CR), palm kernel meal (PKM), and soybean meal (SBM),[1] Exp. 2

	Ingredient						
Item	Corn	CM	PKE-IN	PKE-CR	PKM	SBM	SEM
As-fed basis							
DE, kcal/kg	3,579[a]	3,430[a]	3,000[b]	2,785[b]	2,669[b]	3,753[a]	82
ME, kcal/kg	3,488[a]	3,248[ab]	2,891[bc]	2,681[c]	2,542[c]	3,566[a]	108
DM basis							
DE, kcal/kg	4,021[b]	3,692[b]	3,304[c]	2,994[cd]	2,905[d]	4,275[a]	89
ME, kcal/kg	3,919[ab]	3,496[bc]	3,184[cd]	2,883[d]	2,766[d]	4,062[a]	117

[a–d]Values within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 8 observations for all treatments.

In a recent review, Dégen et al. (2007) calculated that the AID of CP is reduced by 0.3 to 0.8% for every percentage point increase in NDF in the diet, but the negative effect on the digestibility of CP and AA of soluble dietary fibers is greater than of insoluble dietary fibers (Roberfroid, 1993; Zervas and Zijlstra, 2002; Dégen et al., 2007). Copra meal, PKE, and PKM contain relatively high concentrations of soluble dietary fiber, such as β-mannans and glucomannans (Balasubramaniam, 1976; Saittagaroon et al., 1983; Daud and Jarvis, 1992; Dusterhoft et al., 1992), and with the exception of guar gum, PKM has the greatest concentration of β-mannans among all feed ingredients (Göhl, 1981; Dierick, 1989).

In CM, PKM, and PKE-IN, Lys had the least digestibility among all indispensable AA, which may be a result of heat damage that may have taken place during drying or processing of the ingredients (Samson, 1971; Février et al., 2001). Processing of copra is a heat-intensive process, which involves numerous steps that require heat treatment in extended periods of time. Before oil extraction, fresh coconut meat that contain approximately 50% moisture is dried to reduce the moisture content to 6 to 8% (Head et al., 1999). At the oil mill, dried copra is cooked under temperatures ranging from 104 to 110°C for up to 30 min to reduce moisture to 2 to 3%. Palm kernels are also subjected to heat treatment during processing (Ravindran and Blair, 1992). The kernels are cleaned, broken into small pieces, flaked, and steam-conditioned at 104 to 110°C to reduce moisture content to 3% before oil removal. It is, therefore, possible that the heat that is used during processing results in Maillard reactions, which may reduce the digestibility of Lys (Rutherfurd and Moughan, 2007; Pahm et al., 2008).

Energy Measurements, Experiment 2

The DE and ME values for corn that were obtained in this experiment were in close agreement with published values (NRC, 1998; Sauvant et al., 2004; Kim et al., 2009). The DE and ME for SBM were slightly greater than values reported by NRC (1998) and Sauvant et al. (2004), but in agreement with recently published data (Goebel and Stein, 2011). The lack of a difference between the DE and ME of corn and SBM was also observed in other experiments (Baker and Stein, 2009; Goebel and Stein, 2011) and indicates that the DE and ME in SBM may be greater than previously estimated.

The DE value for CM was slightly greater than the value reported by NRC (1998), but a greater difference was observed for ME. In the present experiment, the ME:DE ratio in CM was 95%, which is greater than the ME:DE ratio (85%) in copra meal reported by NRC (1998). However, the ME:DE ratio for copra expeller is 93% (Sauvant et al., 2004), which is close to the value obtained in the present experiment. The reason for the differences in the ME:DE ratio among CM sources is not known; however, the wide variation in protein digestibility among sources of CM may partly contribute to these differences because the digestible protein concentration in the diet affects urinary N excretion and urinary energy loss, which is the main variable that affects the metabolic utilization of DE for ME (Noblet and van Milgen, 2004). The DE and ME of CM obtained in this experiment are within the wide range of values reported for copra expellers (Lekule et al., 1986; Sauvant et al., 2004; PHILSAN, 2010).

To our knowledge, there are no published data for the DE and ME of PKM in pigs. However, the DE and ME for the 2 sources of PKE that were used in this experiment are in agreement with values determined by Agunbiade et al. (1999) but greater than values reported by Sauvant et al. (2004). The ATTD of GE reported by Sauvant et al. (2004) is only 42%, which is much less than the values obtained in the present experiment and in the experiment by Agunbiade et al. (1999), which is likely the reason for the differences in DE and ME values between Sauvant et al. (2004) and the present experiment.

Partial replacement of corn and SBM in swine diets with either copra expellers or PKE resulted in a reduction in energy digestibility of the diets, and consequently, reduced growth performance (O'Doherty and McKeon, 2000; Kim et al., 2001; Ao et al., 2011). This indicates that copra expellers and PKE may contain less DE and ME than corn and SBM, which was also observed in this experiment. The increased concentration of dietary fiber in CM, PKE, and PKM compared with corn and SBM is likely the main reason for this observation because dietary fiber reduces energy digestibility (Noblet and Perez, 1993; Yin et al., 2000; Noblet and Le Goff, 2001).

Conclusions

The SID of most AA is less in CM, PKE, and PKM compared with the SID of AA in SBM. Specifically, the SID of Lys in copra meal and palm kernel ingredients is less than in SBM and also less than the SID of most other indispensable AA in these ingredients, which is likely a consequence of heat damage taking place during the drying or oil extraction process. The concentrations of DE and ME are also less in CM, PKE, and PKM, than in SBM, but CM contains more DE and ME than PKE and PKM. There are no differences in the digestibility of most AA and in the DE and ME between PKE from Indonesia and PKE from Costa Rica.

LITERATURE CITED

Adeola, L. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine Nutrition. CRC Press, Boca Raton, FL. p. 903–916.

Agunbiade, J. A., J. Wiseman, and D. J. A. Cole. 1999. Energy and nutrient use of palm kernels, palm kernel meal and palm kernel oil in diets for growing pigs. Anim. Feed Sci. Technol. 80:165–181.

Ao, X., T. X. Zhou, Q. W. Meng, J. H. Lee, H. D. Jang, J. H. Cho, and I. H. Kim. 2011. Effects of a carbohydrase cocktail supplementation on the growth performance, nutrient digestibility, blood profiles, and meat quality in finishing pigs fed palm kernel meal. Livest. Sci. 137:238–243.

AOAC International. 2007. Official Methods of Analysis.18th ed. W. Howitz and G. W. Latimer Jr., editors. AOAC Int., Gaithersburg, MD.

Babatunde, G. M., B. L. Fetuga, O. Odumosu, and V. A. Oyenuga. 1975. Palm kernel meal as the major protein concentrate in the diets of pigs in the tropics. J. Sci. Food Agric. 26:1279–1291.

Baker, K. M., and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to growing pigs. J. Anim. Sci. 87:2282–2290.

Balasubramaniam, K. 1976. Polysaccharides of the kernel of maturing and matured coconuts. J. Food Sci. 41:1370–1373.

Creswell, D. C., and C. C. Brooks. 1971. Compositions, apparent digestibility and energy evaluation of coconut oil and coconut meal. J. Anim. Sci. 33:366–369.

Daud, M. J., and M. C. Jarvis. 1992. Mannan of oil palm kernel. Phytochemistry 31:463–464.

Dégen, L., V. Halas, and L. Babinszky. 2007. Effect of dietary fiber on protein and fat digestibility and its consequences on diet formulation for growing and fattening pigs: A review. Acta Agric. Scand., Sect. A 57:1–9.

Dierick, N. A. 1989. Biotechnology aids to improve feed and feed digestion: Enzyme and fermentation. Arch. Anim. Nutr. 39:241–246.

Dilger, R. N., J. S. Sands, D. Ragland, and O. Adeola. 2004. Digestibility of nitrogen and amino acids in soybean meal with added soyhulls. J. Anim. Sci. 82:715–724.

Dusterhoft, E. M., M. A. Posthumus, and A. G. J. Voragen. 1992. Nonstarch polysaccharides from sunflower (*Helianthus annuus*) meal and palm kernel (*Elaeis guineensis*) meal preparation of cell wall material and extraction of polysaccharide fractions. J. Sci. Food Agric. 59:151–160.

Ezieshi, E. V., and J. M. Olomu. 2007. Nutritional evaluation of palm kernel meal types: 1. Proximate composition and metabolizable energy values. Afr. J. Biotechnol. 6:2484–2486.

Fan, M. Z., and W. C. Sauer. 1995. Determination of apparent ileal amino acid digestibility in barley and canola meal for pigs with the direct, difference and regression methods. J. Anim. Sci. 73:2364–2374.

Février, C., Y. Lechevestrier, Y. Lebreton, and Y. Jaguelin-Peyraud. 2001. Prediction of the standardized ileal true digestibility of amino acids from the chemical composition of oilseed meals in the growing pig. Anim. Feed Sci. Technol. 90:103–115.

Goebel, K. P., and H. H. Stein. 2011. Phosphorus digestibility and energy concentration of enzyme-treated and conventional soybean meal fed to weanling pigs. J. Anim. Sci. 89:764–772.

Göhl, B. 1981. Tropical feeds: Feed information summaries and nutritive values. FAO Anim. Prod. and Health Ser. No. 12. Food and Agric. Organ. of the U. N., Rome.

Han, Y. K., I. H. Kim, J. W. Wong, O. S. Kwon, S. H. Lee, J. H. Kim, B. J. Min, and W. B. Lee. 2003. Apparent ileal digestibility of nutrients in plant protein feedstuffs for finishing pigs. Asian-Australas. J. Anim. Sci. 16:1020–1024.

Head, S. W., T. A. Swetman, and M. J. Nagler. 1999. Studies on deterioration and aflatoxin contamination in copra during storage, Oleagineux, Corps Gras, Lipids 6:349–359.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. AOAC. 56:1352–1356.

Kim, B. G., J. H. Lee, H. J. Jung, Y. K. Han, K. M. Park, and I. K. Han. 2001. Effect of replacement of soybean meal with palm kernel meal and copra meal on growth performance, nutrient digestibility, and carcass characteristics of finishing pigs. Asian-Australas. J. Anim. Sci. 14:821–830.

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs J. Anim. Sci. 87:4013–4021.

Kim, B. G., and H. H. Stein. 2009. A spreadsheet program for making a balanced Latin square design. Rev. Colomb. Cienc. Pecu. 22:591–596.

Lekule, F. P., T. Homb, and J. A. Kategile. 1986. Digestibility and effect of copra cake on rate of gain, feed efficiency and protein retention of fattening pigs. Trop. Anim. Health Prod. 18:243–247.

Lenis, N. P., P. Bikker, J. van der Meulen, J. T. M. van Diepen, J. G. M. Bakker, and A. W. Jongbloed. 1996. Effect of dietary neutral detergent fiber on ileal digestibility and portal flux of nitrogen and amino acids and on nitrogen utilization in growing pigs. J. Anim. Sci. 74:2687–2699.

Loosli, J. K., J. O. Pena, L. A. Ynalvez, and V. Villegas. 1954. The digestibility by swine of rice bran, copra meal, coconut meat, coconut residue, and two concentrate mixes. Philipp. Agric. 38:191–196.

Noblet, J., and G. Le Goff. 2001. Effect of dietary fiber on the energy value of feeds for pigs. Anim. Feed Sci. Technol. 90:35–52.

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.

Noblet, J., and J. van Milgen. 2004. Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J. Anim. Sci. 82(Suppl.):E229–E238.

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

Nwokolo, E. N., D. B. Bragg, and H. S. Saben. 1976. The availability of amino acids from palm kernel, soybean, cotton seed and rape seed meal for the growing chick. Poult. Sci. 55:2300–2304.

O'Doherty, J. V., and M. P. McKeon. 2000. The use of expeller copra meal in grower and finisher pig diets. Livest. Prod. Sci. 67:55–65.

Pahm, A. A., C. Pedersen, and H. H. Stein. 2008. Application of the reactive lysine procedure to estimate lysine digestibility in distillers dried grains with solubles fed to growing pigs. J. Agric. Food Chem. 56:9441–9446.

PHILSAN, 2010. Feed Reference Standards. 4th ed. Philipp. Soc. Anim. Nutr., Manila, Philippines.

Ramachandran, S., S. K. Singh, C. Larroche,C. R. Soccol, and A. Pandey. 2007. Oil cakes and their biotechnological applications—A review. Bioresour. Technol. 98:2000–2009.

Ravindran, V., and R. Blair. 1992. Feed resources for poultry production in Asia and the Pacific. II. Plant protein sources. World Poult. Sci. J. 48:205–231.

Rhule, S. W. A. 1996. Growth rate and carcass characteristics of pigs fed on diets containing palm kernel cake. Anim. Feed Sci. Technol. 61:167–172. 5.

Roberfroid, M. 1993. Dietary fiber, inulin, and oligofructose: A review comparing their physiological effects. Crit. Rev. Food Sci. 33:103–148.

Rutherfurd, S. M., and P. J. Moughan. 2007. Development of a novel bioassay for determining the available lysine contents of foods and feedstuffs. Nutr. Res. Rev. 20:3–16.

Saittagaroon, S., S. Kawakishi, and M. Namiki. 1983. Characterization of polysaccharides of copra meal. J. Sci. Food Agric. 34:855–860.

Samson, A. S. 1971. Heat treatment of coconut meats and coconut meal. J. Sci. Food Agric. 22:312–316.

Sauvant, D., J. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials. Pigs, poultry, sheep, goats, rabbits, horses, fish. 2nd ed. Wageningen Acad. Publ. Wageningen, the Netherlands.

Stein, H. H., B. Seve, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172–180.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Wachenheim, C. J., P. Novak, E. A. DeVuyst, and D. K. Lambert. 2006. Demand estimation for agricultural processing coproducts. Great Plains Res. 16:85–94.

Widmer, M. R., L. M. McGinnis, and H. H. Stein. 2007. Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs. J. Anim. Sci. 85:2994–3003.

Yin, Y. L., J. D. G. McEvoy, H. Schulze, U. Hennig, W. B. Souffrant, and K. J. McCracken. 2000. Apparent digestibility (ileal and overall) of nutrients and endogenous nitrogen losses in growing pigs fed wheat (var. Soissons) or its byproducts without or with xylanase supplementation. Livest. Prod. Sci. 62:119–132.

Zervas, S., and R. T. Zijlstra. 2002. Effects of dietary protein and fermentable fiber on nitrogen excretion patterns and plasma urea in grower pigs. J. Anim. Sci. 80:3247–3256.