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Nutritional value of dried fermentation biomass, hydrolyzed porcine intestinal mucosa products, and fish meal fed to weanling pigs[1]

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ABSTRACT: Dried fermentation biomass (DFB) and hydrolyzed porcine intestinal mucosa are co-products of L-Lys · HCl production and heparin extraction, respectively. Three experiments were conducted to determine standardized ileal digestibility (SID) of AA (Exp. 1), concentration of DE and ME (Exp. 2), and standardized total tract digestibility (STTD) of P (Exp. 3) in DFB and 2 hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), and compare these values with values for fish meal. In Exp. 1, 12 ileal cannulated barrows (BW = 11.5 ± 1.1 kg) were allotted to a replicated 6 × 6 Latin square design with 6 diets and 6 periods. A N-free diet, diet based on soybean meal (SBM), and 4 diets based on a combination of SBM and DFB, PEP50, PEP2+, or fish meal were formulated. With the exception of Lys, there were no differences in SID of indispensable AA between DFB and fish meal. Except for Thr, no differences in SID of indispensable AA between PEP50 and fish meal were observed, but SID of all indispensable AA, except Lys and Trp, was less ($P < 0.05$) in PEP2+ than in the other ingredients. In Exp. 2, 40 barrows (BW = 12.8 ± 1.4 kg) were allotted to 5 diets with 8 pigs/diet. A basal diet containing 96.4% corn and 4 diets containing corn and DFB, PEP50, PEP2+, or fish meal were formulated. The DE (5,445 kcal/kg DM) and ME (5,236 kcal/kg DM) in DFB were greater ($P < 0.01$) than in PEP50 (4,758 and 4,512 kcal/kg DM for DE and ME, respectively) and fish meal (4,227 and 3,960 kcal/kg DM for DE and ME, respectively). Also, DE in DFB was greater ($P < 0.01$) than in PEP2+ (4,935 kcal/kg DM), but ME in DFB was not different from that in PEP2+ (4,617 kcal/kg DM). Furthermore, DE in PEP50 and PEP2+ were greater ($P < 0.01$) than in fish meal, but ME did not differ from that in fish meal. In Exp. 3, 40 barrows (BW = 12.4 ± 1.3 kg) were randomly allotted to 5 diets with 8 pigs/diet. A P-free diet and 4 diets in which the sole source of P was from DFB, PEP50, PEP2+, or fish meal were formulated. The STTD of P in DFB (96.9%) and PEP2+ (97.6%) were greater ($P < 0.01$) than in PEP50 and fish meal (76.2% and 68.5%, respectively), and STTD of P in PEP50 was greater ($P < 0.01$) than in fish meal. In summary, SID of most indispensable AA did not differ among DFB, PEP50, and fish meal, but DE and ME and STTD of P in DFB were greater than in PEP50 and fish meal.

Key words: amino acids, dried fermentation biomass, energy, hydrolyzed intestinal mucosa, phosphorus, pigs

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INTRODUCTION

Industrial production of L-Lys involves fermentation of dextrose derived from the hydrolysis of corn starch by a lysine-producing bacterium (Wittmann and Becker, 2007). Lysine is then purified from the fermentation broth by ion exchange (Hermann, 2003), mixed with HCl, and sold as L-Lys·HCl. The fermentation biomass that is left after extraction of Lys is dried and a product called dried fermentation biomass (**DFB**) is produced. Dried fermentation biomass might have value as a potential feed ingredient for weanling pigs, but at this point, no data have been reported on the feeding value of this ingredient.

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Table 1. Analyzed nutrient composition (as-fed basis) of soybean meal (SBM), dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), and fish meal[1,2]

	Ingredient				
Item	SBM	DFB	PEP50	PEP2+	Fish meal
DM, %	88.8	92.2	94.7	95.2	92.3
GE, kcal/kg	3,767	5,369	4,630	4,934	4,328
CP (N × 6.25), %	49.51	77.17	53.63	59.54	64.22
Acid-hydrolyzed fat, %	1.77	10.55	7.39	13.14	7.26
ADF, %	4.38	0.03	3.57	1.39	–
NDF, %	6.88	1.27	5.83	2.51	–
Ash, %	6.34	9.66	10.08	12.00	19.98
Total P, %	–	0.88	0.74	0.80	3.25
Indispensable AA, %					
Arg	3.42	4.36	3.13	3.47	3.65
His	1.29	1.69	1.19	1.35	1.43
Ile	2.24	3.57	2.21	2.62	2.60
Leu	3.60	6.02	3.82	4.52	4.34
Lys	2.96	7.94	3.59	4.86	4.76
Met	0.63	1.75	0.80	1.09	1.68
Phe	2.36	2.92	2.23	2.48	2.33
Thr	1.71	3.01	1.81	2.27	2.36
Trp	0.65	1.00	0.47	0.49	0.64
Val	2.39	4.51	2.63	3.22	3.06
Dispensable AA, %					
Ala	1.98	4.84	2.47	3.24	3.80
Asp	5.07	6.83	4.77	5.41	5.31
Cys	0.64	0.52	0.61	0.71	0.46
Glu	8.18	7.71	7.09	7.53	7.62
Gly	1.92	3.30	2.41	3.01	4.33
Pro	2.38	2.35	2.33	2.67	2.88
Ser	1.81	1.99	1.67	1.89	1.93
Tyr	1.67	2.41	1.62	2.01	1.85

[1]Mean of duplicate analyses of each ingredient.

[2]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX. Soybean meal was obtained locally from the University of Illinois Feed Mill, Champaign, IL.

Porcine intestinal mucosa is a rich source of heparin and AA. Heparin is removed using resin beads and then used in the pharmaceutical industry. The deheparinized intestinal mucosa can be hydrolyzed and this product is then co-dried with other ingredients to produce a high-protein product for use in feeding of weanling pigs. The feeding value of dried porcine solubles, which consists of enzymatically hydrolyzed intestinal mucosa produced from a mixture of mucosa from poultry and pigs, has been reported (Lindemann et al., 1998; 2000). Effects of inclusion of hydrolyzed intestinal mucosa co-dried with other protein sources in diets fed to weanling pigs has also been determined (Myers et al., 2011); however, digestibility of AA, energy, and P in hydrolyzed porcine intestinal mucosa that is co-dried with other protein sources has not been reported. Therefore, the objectives of the present experiments were to determine apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA, concentration of DE and ME, and standardized total tract digestibility (**STTD**) of P in DFB and hydrolyzed intestinal porcine mucosa products co-dried with other protein sources when fed to weanling pigs, and to compare these values to those obtained for fish meal.

MATERIALS AND METHODS

Three experiments were conducted and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for each experiment.

Pigs with similar genetic makeup (G-Performer boars × Fertilium 25 females; Genetiporc, Alexandria, MN) were used in the experiments. Dried fermentation biomass (Ajinomoto Heartland, Inc., Chicago, IL) and 2 hydrolyzed porcine intestinal mucosa products (**PEP50** and **PEP2+**; TechMix Inc., Stewart, MN) were obtained from commercial sources (Table 1). Both PEP50 and PEP2+ are hydrolyzed porcine intestinal mucosa mixed and co-dried with vegetable proteins to improve the AA profile of the final product and improve physical and handling characteristics of the products. The difference between PEP50 and PEP2+ is that PEP50 consists of hydrolyzed porcine intestinal mucosa and dehulled soybean meal (**SBM**; 47.5% CP), whereas PEP2+ is produced by mixing hydrolyzed porcine intestinal mucosa with DFB and enzymatically processed, low-antigen SBM (HP 300; Hamlet Protein A/S, Horsens, Denmark). Fish meal (Select Menhaden) was procured from a commercial source (Omega Protein Corp., Houston, TX). The same batch of these ingredients was used in all 3 experiments. Locally sourced conventional SBM was used in 1 experiment and locally grown yellow dent corn was also used in 1 experiment.

Experiment 1: AA Digestibility

Twelve weanling barrows (36 ± 1 d of age; initial BW = 11.5 ± 1.1 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998) and allotted to a replicated 6 × 6 Latin square design with 6 diets and six, 7-d periods in each square. Pigs were allowed 7 d to recover from the surgery before the experiment was initiated. Pigs were housed in individual pens (1.2 m × 1.5 m) in an environmentally controlled room (22°C) with a 12 h light and 12 h dark schedule. Pens had smooth, plastic-coated sides and fully slatted tribar metal floors; a feeder and nipple drinker were installed in each pen. Six diets were prepared (Tables 2 and 3). One diet contained SBM as the sole source of CP and AA, and 4 diets were formulated based

Table 2. Ingredient composition (as-fed basis) of experimental diets containing soybean meal (SBM), dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), or fish meal (Exp. 1)[1]

	Diet					
Item	SBM	DFB	PEP50	PEP2+	Fish meal	N-free
Ingredient, %						
SBM	42.00	21.00	21.00	21.00	21.00	–
DFB	–	13.00	–	–	–	–
PEP50	–	–	19.00	–	–	–
PEP2+	–	–	–	17.00	–	–
Fish meal	–	–	–	–	16.00	–
Soybean oil	3.00	3.00	3.00	3.00	2.00	4.00
Solka-Floc[2]	1.00	2.00	2.00	2.00	2.00	3.00
Dicalcium phosphate	1.30	1.50	1.50	1.50	–	2.00
Limestone	1.00	1.00	1.00	1.00	–	0.80
Sugar	15.00	15.00	15.00	15.00	15.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40
Corn starch	35.60	42.40	36.40	38.40	42.90	68.60
Magnesium oxide	–	–	–	–	–	0.10
Potassium carbonate	–	–	–	–	–	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]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX. Soybean meal was obtained locally from the University of Illinois Feed Mill, Champaign, IL.

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

[3]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin 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 and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu as copper sulfate, 10 mg; Fe as iron sulfate, 125 mg; I as potassium iodate, 1.26 mg; Mn as manganese sulfate, 60 mg; Se as sodium selenite, 0.3 mg; and Zn as zinc oxide, 100 mg.

on a combination of SBM and DFB, PEP50, PEP2+, or fish meal. The last diet was a N-free diet that was used to measure basal endogenous ileal losses of CP and AA. Corn starch, sugar, and soybean oil were included in all diets, and vitamins and minerals were provided to meet or exceed requirement estimates for weanling pigs (NRC, 1998). All diets also contained 0.4% chromic oxide as an indigestible marker. Pigs were fed at a daily level of 2.5 times the maintenance energy requirement of the pigs (106 kcal ME per $kg^{0.75}$; NRC, 1998) and feed was provided daily at 0800 and 1700 h. Animals had free access to water throughout the experiment.

Pig BW measurements were recorded at the beginning of each period and the amount of feed supplied each day was recorded. The initial 5 d of each period were considered an adaptation period to the diet. Ileal digesta samples 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 digesta samples were immediately frozen at –20°C to prevent bacterial degradation of AA in the digesta. At the end of each experimental period, pigs were deprived of feed overnight and a new experimental diet was offered the following morning.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was collected for chemical analyses. A sample of DFB, PEP50, PEP2+, fish meal, and SBM, and of each diet was also collected. Digesta samples were lyophilized and finely ground (Model 4, Thomas-Wiley Laboratory Mill with a 1.0 mm sieve; Thomas Scientific, Philadelphia, PA) before chemical analyses. All samples were analyzed in duplicate. Ingredient samples were analyzed for GE, using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL), and by AOAC (2007) methods for DM (Method 930.15), CP (N × 6.25; Method 990.03), AA [Method 982.30 E (a, b, c)], acid-hydrolyzed ether extract (Method 2003.06), and ash (Method 975.03). Concentrations of ADF (Method 973.18; AOAC, 2007) and NDF (Holst, 1973) were determined in all ingredients except fish meal. The concentration of P was analyzed in all ingredients except SBM, using an AOAC (2007) inductive coupled plasma procedure (Method 985.01 A, B, and C) after wet ash sample preparation [Method 975.03 B(b)]. Diets and ileal digesta samples were also analyzed for DM, CP, and AA, and Cr was

Table 3. Analyzed nutrient composition (as-fed basis) of experimental diets containing soybean meal (SBM), dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), or fish meal (Exp. 1)[1,2]

	Diet				
Item	SBM	DFB	PEP50	PEP2+	Fish meal
DM, %	91.52	92.49	92.68	92.89	91.57
CP (N × 6.25), %	22.88	22.23	20.96	20.87	19.31
Indispensable AA, %					
Arg	1.42	1.19	1.34	1.25	1.02
His	0.53	0.46	0.51	0.47	0.40
Ile	0.91	0.86	0.89	0.88	0.70
Leu	1.52	1.46	1.53	1.49	1.16
Lys	1.24	1.55	1.33	1.40	1.10
Met	0.27	0.33	0.28	0.29	0.31
Phe	0.99	0.83	0.94	0.89	0.70
Thr	0.73	0.73	0.75	0.73	0.59
Trp	0.27	0.25	0.22	0.19	0.19
Val	0.98	1.00	0.99	1.01	0.77
Dispensable AA, %					
Ala	0.85	1.00	0.93	0.97	0.82
Asp	2.15	1.87	2.04	1.94	1.53
Cys	0.26	0.18	0.24	0.23	0.17
Glu	3.51	2.64	3.23	2.98	2.40
Gly	0.83	0.79	0.90	0.91	0.87
Pro	0.95	0.78	0.98	0.92	0.77
Ser	0.81	0.62	0.77	0.69	0.56
Tyr	0.61	0.54	0.61	0.59	0.45

[1]Mean of duplicate analyses of each diet.

[2]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX. Soybean meal was obtained locally from the University of Illinois Feed Mill, Champaign.

analyzed in these samples using an (AOAC, 2007) inductive-coupled plasma atomic emission spectrometric procedure (Method 990.08) after nitric acid-perchloric acid wet ash sample preparation (Method 968.088D).

Values for AID, ileal endogenous losses, and SID of CP and AA in each diet were calculated as previously described (Stein et al., 2007). The AID and SID for CP and AA in the SBM diet also represent AID and SID of CP and AA in SBM because SBM was the sole AA contributing ingredient in this diet. For the other diets, however, AID and SID values represented the combination of AA from SBM and DFB, PEP50, PEP2+, or fish meal, and the AID and SID of AA in DFB, PEP50, PEP2+, and fish meal were, therefore, calculated using the difference procedure (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. Pig was the experimental unit for all calculations and the α level used to determine significance among means was 0.05.

Experiment 2: Energy Measurements

Forty weanling barrows (39 ± 2 d of age; initial BW = 12.8 ± 1.4 kg) were used in a complete randomized design with 5 diets and 8 replicate pigs/diet. Pigs were placed in metabolism cages (152 cm × 81 cm) that were equipped with a feeder and nipple drinker, fully slatted floors, 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 96.40% corn and vitamins and minerals was formulated (Table 4). Four additional diets were formulated by mixing corn with DFB, PEP50, PEP2+, or fish meal. 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 and divided into 2 equal meals. Water was available at all times. The experiment lasted 14 d. The initial 7 d were considered an adaptation period to the diet. Markers were included in the morning meals on d 8 and 13, and fecal collections were initiated at the appearance of the first marker and ceased at the appearance of the second marker, according to the marker–to-marker approach (Adeola, 2001). Urine was collected in urine buckets over a preservative of 50 mL of 6*N* HCL from d 8 in the morning until d 13 in the morning. 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 analyzed for GE (Kim et al., 2009). Fecal samples were dried in a forced-air oven and finely ground (Model 4, Thomas-Wiley Laboratory Mill with a 1.0 mm sieve; Thomas Scientific) before analysis. Fecal and diet samples were analyzed in duplicate for DM and GE. Following analysis, values for apparent total tract digestibility (**ATTD**) of energy and DE and ME were calculated in each diet, using the direct procedure and in each ingredient using the difference procedure, as previously described by Widmer et al. (2007). Data were analyzed as a complete randomized design using the MIXED procedure in SAS.

Experiment 3: Phosphorus Digestibility

Forty growing barrows (37 ± 2 d of age; initial BW = 12.4 ± 1.3 kg) were randomly allotted to 5 dietary treatments with 8 replicate pigs/diet in a complete randomized design. Pigs were placed in metabolism cages as

Table 4. Ingredient composition (as-fed basis) of experimental diets containing corn, dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), or fish meal (Exp. 2)[1]

	Diet				
Item	Corn	DFB	PEP50	PEP2+	Fish meal
Ingredient, %					
Corn	96.40	80.40	73.40	76.40	81.30
DFB	–	16.00	–	–	–
PEP50	–	–	23.00	–	–
PEP2+	–	–	–	20.00	–
Fish meal	–	–	–	–	18.00
Dicalcium phosphate	1.70	1.70	1.70	1.70	–
Limestone	1.20	1.20	1.20	1.20	–
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin-micromineral premix[2]	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition[3]					
DM, %	86.29	85.80	86.89	86.53	85.93
GE, kcal/kg	3,670	3,937	3,899	3,880	3,866

[1]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX. Corn was obtained locally from the University of Illinois Feed Mill, Champaign.

[2]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin 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 and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu as copper sulfate, 10 mg; Fe as iron sulfate, 125 mg; I as potassium iodate, 1.26 mg; Mn as manganese sulfate, 60 mg; Se as sodium selenite, 0.3 mg; and Zn as zinc oxide, 100 mg.

[3]Mean of duplicate analyses of each diet.

explained for Exp. 2, but only feces, and not urine, were collected in this experiment. Four diets were formulated by mixing corn starch and sucrose with DFB, PEP50, PEP2+, or fish meal, and a P-free diet was formulated and used to measure basal endogenous losses of P (Table 5). Vitamins and all minerals, except P, were included in the diets to meet or exceed requirements (NRC, 1998). Feed was provided in a daily amount equivalent to 3 times the maintenance energy requirement and divided into 2 daily meals. Water was available at all times. Pigs were fed their experimental diets for 14 d. The initial 7 d was considered an adaptation period to the diet and fecal samples were collected for 5 d as described for Exp. 2, with markers included in the morning meals on d 8 and 13, according to the marker-to-marker approach (Adeola, 2001). Fecal samples were stored at –20°C, immediately after collection.

At the conclusion of the experiment, fecal samples were dried in a forced-air oven and finely ground (Model 4, Thomas-Wiley Laboratory Mill with a 1.0 mm sieve; Thomas Scientific) before analysis. Fecal samples and diets were analyzed in duplicate for DM and total P. The basal endogenous loss of P was determined from pigs fed the P-free diet and ATTD and STTD of P in each diet were calculated, as described previously (Almeida and Stein, 2010). Because DFB, PEP50, PEP2+, or fish meal was the only P-contributing ingredient in the diets, ATTD and STTD values for each diet also represented ATTD and STTD of P in each ingredient. Data were analyzed as outlined for Exp. 2.

RESULTS

Exp. 1: AA Digestibility

The AID and SID of CP were less ($P < 0.05$) in PEP2+ than in SBM, DFB, and fish meal (Tables 6 and 7), and AID and SID of CP in PEP50 were less ($P < 0.05$) than in SBM and DFB. For indispensable AA, AID and SID of His, Ile, Leu, Met, Phe, Thr, and Val, and SID of Arg were least ($P < 0.05$) in PEP2+, compared with the other ingredients. The AID and SID of Lys were also less ($P < 0.05$) in PEP2+ than in SBM and DFB. The SID of Thr was less ($P < 0.05$) in PEP50 than in fish meal, and AID and SID of His, Met, and Phe, AID of Arg and Ile, and SID of Thr were less ($P < 0.05$) in PEP50 than in SBM. The AID and SID of Lys in DFB were greater ($P < 0.05$) than in fish meal, and AID and SID of Met and Phe, and AID of Arg were less ($P < 0.05$) in DFB than in SBM. The AID and SID of Lys and Met and AID of Arg and His were also less ($P < 0.05$) in fish meal than in SBM.

Experiment 2: Energy Measurements

There were no differences in ATTD of GE among treatments (Table 8). When calculated on a DM basis,

Table 5. Ingredient composition (as-fed basis) of experimental diets containing dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), or fish meal (Exp. 3)[1]

	Diet				
Item	DFB	PEP50	PEP2+	Fish meal	P-free
Ingredient, %					
DFB	20.00	–	–	–	–
PEP50	–	20.00	–	–	–
PEP2+	–	–	20.00	–	–
Fish meal	–	–	–	12.00	–
Gelatin[2]	–	–	–	–	20.00
Soybean oil	4.00	4.00	4.00	3.00	4.00
Solka-Floc[3]	3.00	3.00	3.00	3.00	4.00
Ground limestone	0.80	0.80	0.80	1.60	0.80
Sucrose	15.00	15.00	15.00	15.00	20.00
Corn starch	56.50	56.50	56.50	64.70	49.72
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Vitamin-micromineral premix[4]	0.30	0.30	0.30	0.30	0.30
AA mixture[5]	–	–	–	–	0.78
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition[6]					
DM, %	91.61	92.06	92.41	92.28	91.31
Total P, %	0.21	0.17	0.20	0.39	0.01

[1]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX.

[2]Pork gelatin obtained from Gelita Gelatin USA Inc., Sioux City, IA.

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

[4]The vitamin-micromineral 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, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin 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 and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu as copper sulfate, 10 mg; Fe as iron sulfate, 125 mg; I as potassium iodate, 1.26 mg; Mn as manganese sulfate, 60 mg; Se as sodium selenite, 0.3 mg; and Zn as zinc oxide, 100 mg.

[5]Provided the following quantities (%) of AA: DL-Met, 0.27; L-Thr, 0.08; L-Trp, 0.14; L-His, 0.08; L-Ile, 0.16; and L-Val, 0.05.

[6]Mean of duplicate analyses of each diet.

DE was greater ($P < 0.05$) in DFB than in PEP 2+, PEP50, fish meal, and corn. The DE of PEP2+ and PEP50 were greater ($P < 0.05$) than DE of corn and PEP2+ and PEP50 had greater ($P < 0.05$) DE than fish meal when expressed on a DM basis. There was no difference in DE of fish meal and corn on a DM basis. When calculated on a DM basis, the ME in PEP2+ was greater ($P < 0.05$) than in corn. There were no differences in ME values between PEP50 and PEP2+, and there were also no differences between fish meal and corn.

Table 6. Apparent ileal digestibility (%) of CP and AA in soybean meal (SBM), dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), and fish meal by weanling pigs (Exp. 1)[1, 2]

	Ingredient						
Item	SBM	DFB	PEP50	PEP2+	Fish meal	SEM	*P*-value
CP, %	84.6^{a}	81.7^{ab}	72.7^{cd}	66.7^{d}	77.2^{bc}	2.4	< 0.001
Indispensable AA, %							
Arg	93.0^{a}	88.0^{b}	88.7^{b}	83.7^{c}	85.6^{bc}	1.7	<0.001
His	90.3^{a}	86.5^{ab}	83.4^{b}	76.6^{c}	85.3^{b}	1.5	<0.001
Ile	88.7^{a}	85.6^{ab}	84.6^{b}	79.9^{c}	85.3^{ab}	1.4	0.001
Leu	88.7^{a}	87.1^{a}	85.7^{a}	81.2^{b}	85.9^{a}	1.4	0.003
Lys	89.0^{ab}	92.0^{a}	85.1^{bc}	81.9^{c}	83.9^{c}	1.7	<0.001
Met	90.5^{a}	86.7^{b}	87.2^{b}	82.2^{c}	85.6^{b}	1.2	<0.001
Phe	88.7^{a}	83.3^{b}	84.0^{b}	78.3^{c}	83.9^{b}	1.5	<0.001
Thr	82.2^{a}	81.9^{a}	77.1^{a}	71.2^{b}	80.9^{a}	1.8	<0.001
Trp	90.2	91.2	88.5	87.7	86.3	1.4	0.11
Val	85.9^{a}	84.1^{a}	82.8^{a}	78.4^{b}	82.7^{a}	1.5	0.01
Dispensable AA, %							
Ala	83.2	81.2	82.1	77.4	79.8	1.8	0.13
Asp	87.4^{a}	80.8^{b}	76.9^{bc}	68.3^{d}	75.9^{c}	1.8	<0.001
Cys	79.9^{a}	61.0^{bc}	49.6^{c}	35.1^{d}	71.4^{ab}	4.2	<0.001
Glu	90.2^{a}	82.3^{bc}	75.8^{cd}	73.0^{d}	84.7^{ab}	2.2	<0.001
Gly	76.8^{a}	66.5^{b}	64.6^{b}	59.3^{b}	68.9^{ab}	4.0	0.01
Ser	87.0^{a}	78.3^{b}	80.7^{b}	72.1^{c}	80.0^{b}	1.9	<0.001
Tyr	86.8^{a}	82.3^{bc}	84.8^{ab}	80.1^{c}	84.4^{ab}	1.5	0.02
All AA	85.9^{a}	79.0^{b}	75.7^{b}	71.8^{c}	77.4^{b}	2.3	<0.001

$^{a-d}$Row means that do not have a common superscript letter differ, $P < 0.05$.

[1]Data are least squares means with 12 observations per treatment.

[2]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX.

Exp. 3: Phosphorus Digestibility

The analyzed total P concentration in DFB, PEP2+, and PEP50 were 0.88%, 0.80%, and 0.74%, respectively, whereas fish meal contained 3.25% P (Table 1). Average daily feed intake of pigs fed DFB was less ($P < 0.05$) than for pigs fed the other diets (Table 9). Daily P intake for pigs fed DFB, PEP2+, and PEP50 were less ($P < 0.05$) than for pigs fed fish meal, and pigs fed PEP2+ had greater ($P < 0.05$) daily P intake than pigs fed DFB and PEP50. Daily fecal output was less ($P < 0.05$) from pigs fed PEP2+ than from pigs fed PEP50 or fish meal, but fecal output of pigs fed DFB did not differ from that of pigs fed the other diets. The P concentration in feces and daily P output were less ($P < 0.05$) for pigs fed DFB and PEP2+ than for pigs fed PEP50 or fish meal, and P concentration in feces and daily P output of pigs fed PEP50 was less ($P < 0.05$) than for pigs fed fish meal. Pigs fed fish meal had a greater ($P < 0.05$) daily absorption of P than pigs fed the other diets and pigs fed PEP50 had the least ($P < 0.05$) daily P absorption. Pigs fed PEP2+ also

had greater ($P < 0.05$) absorption of P than pigs fed DFB or PEP50. The ATTD of P was greater ($P < 0.05$) in DFB and PEP2+ than in PEP50 and fish meal, but ATTD of P in PEP50 did not differ from ATTD in fish meal. The basal endogenous loss of P was calculated at 148 mg/kg of DMI in pigs fed the P-free diet. The STTD of P in DFB and PEP2+ was greater ($P < 0.05$) than in PEP50 and fish meal, and STTD of P in PEP50 was greater ($P < 0.05$) than in fish meal.

DISCUSSION

The difference procedure was used to determine digestibility of AA and concentration of DE and ME in DFB, PEP50, PEP2+, and fish meal, and basal diets based on SBM and corn were used in the AA and energy experiments, respectively. A consequence of using the difference procedure is that reliable results for the test ingredients will be obtained only if the results of the ingredients included in the basal diets are accurate. The values obtained for AID and SID of AA in SBM were, however, in good agreement with values reported earlier (NRC, 1998; Cervantes-Pahm and Stein, 2010), which gives confidence that the values obtained for DFB, PEP50, PEP2+, and fish meal are reliable. Likewise, values for DE and ME obtained for corn in the present experiment were in close agreement with previous data (NRC, 1998; Sauvant et al., 2004; Kim et al., 2009; Goebel and Stein, 2011), which indicates that DE and ME in the test ingredients that were calculated are also reliable. The value for the basal endogenous loss of P that was determined in this experiment is also within the range of previously determined values (Petersen and Stein, 2006; Widmer et al., 2007; Almeida and Stein, 2010).

Select Menhaden Fish meal

The composition of AA in fish meal used in this experiment agreed with published values (NRC, 1998; Sauvant et al., 2004; Cervantes-Pahm and Stein, 2010), but the digestibility of indispensable AA was slightly less than previous values. It is, therefore, possible that the quality of

Table 7. Standardized ileal digestibility (%) of CP and AA in soybean meal (SBM), dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), and fish meal by weanling pigs (Exp. 1)[1,2,3]

	Ingredient						
Item	SBM	DFB	PEP50	PEP2+	Fish meal	SEM	*P*-value
CP, %	93.9^{a}	91.8^{a}	84.1^{bc}	78.2^{c}	90.0^{ab}	2.5	<0.001
Indispensable AA, %							
Arg	98.9^{a}	96.6^{a}	95.5^{a}	91.5^{b}	96.6^{a}	1.7	0.007
His	93.6^{a}	91.1^{ab}	87.2^{b}	81.0^{c}	91.1^{ab}	1.5	<0.001
Ile	91.8^{a}	89.0^{a}	87.9^{a}	83.3^{b}	90.3^{a}	1.4	0.001
Leu	91.5^{a}	90.3^{a}	88.6^{a}	84.2^{b}	90.6^{a}	1.4	0.002
Lys	91.7^{ab}	93.8^{a}	87.5^{bc}	84.1^{c}	87.2^{c}	1.7	<0.001
Met	92.5^{a}	88.1^{b}	89.1^{b}	83.9^{c}	87.2^{b}	1.2	<0.001
Phe	91.5^{a}	87.3^{b}	87.1^{b}	81.8^{c}	89.2^{ab}	1.5	<0.001
Thr	88.8^{a}	88.6^{ab}	83.5^{b}	78.1^{c}	90.6^{a}	1.8	<0.001
Trp	93.7	95.3	94.1	95.3	93.2	1.4	0.76
Val	90.3^{a}	88.5^{a}	87.2^{a}	82.8^{b}	89.6^{a}	1.5	0.006
Dispensable AA, %							
Ala	90.7^{a}	86.9^{ab}	88.5^{a}	83.4^{b}	87.7^{ab}	1.8	0.04
Asp	90.6^{a}	85.1^{b}	80.6^{b}	72.4^{c}	82.0^{b}	1.8	<0.001
Cys	86.4^{a}	76.5^{a}	57.5^{b}	43.6^{c}	87.7^{a}	4.2	<0.001
Glu	92.5^{a}	86.8^{a}	78.7^{b}	76.4^{b}	89.6^{a}	2.2	<0.001
Gly	100.3^{a}	92.9^{ab}	85.2^{bc}	79.7^{c}	90.7^{b}	4.0	0.002
Ser	92.7^{a}	88.5^{ab}	87.2^{b}	80.1^{c}	91.3^{ab}	1.9	<0.001
Tyr	90.5^{a}	87.1^{ab}	88.6^{a}	84.2^{b}	91.0^{a}	1.5	0.01
All AA	95.5^{a}	91.4^{ab}	86.7^{bc}	83.6^{c}	93.8^{ab}	2.3	<0.001

$^{a-c}$Row means that do not have a common superscript letter differ, $P < 0.05$.

[1]Data are least squares means with 12 observations per treatment.

[2]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX.

[3]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, 23.35; Arg, 0.91; His, 0.19; Ile, 0.30; Leu, 0.48; Lys, 0.36; Met, 0.06; Phe, 0.30; Thr, 0.53; Trp, 0.10; Val, 0.48; Ala, 0.69; Asp, 0.75; Cys, 0.18; Glu, 0.89; Gly, 2.13; Pro, 9.68; Ser, 0.50; and Tyr, 0.25.

Table 8. Digestibility of energy (ATTD, %) and DE and ME in corn, dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), and fish meal fed to weanling pigs (Exp. 2)[1,2]

	Ingredient						
Item	Corn	DFB	PEP50	PEP2+	Fish meal	SEM	*P*-value
ATTD of GE in diet, %	88.5	88.9	89.0	90.0	90.2	1.0	0.75
GE, kcal/kg DM	4,490	5,894	4,981	5,400	4,698	–	–
DE, kcal/kg DM	4,014^{c}	5,445^{a}	4,758^{b}	4,935^{b}	4,227^{c}	156	<0.001
ME, kcal/kg DM	3,846^{c}	5,236^{a}	4,512^{b}	4,617^{ab}	3,960^{bc}	218	<0.001

$^{a-d}$Row means that do not have a common superscript letter differ, $P < 0.05$.

[1]Data are least squares means with 8 observations per treatment.

[2]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX.

Table 9. Daily intake and fecal output of P and apparent total tract digestibility (ATTD, %) and standardized total tract digestibility (STTD, %) of P in dried fermentation biomass (DFB), hydrolyzed porcine intestinal mucosa products (PEP50 and PEP2+), and fish meal fed to weanling pigs (Exp. 3)[1,2]

	Ingredient					
Item	DFB	PEP50	PEP2+	Fish meal	SEM	*P*-value
Feed intake, g/d	358[b]	458[a]	452[a]	412[a]	17	0.001
P intake, g/d	0.80[c]	0.82[c]	0.96[b]	1.77[a]	0.04	<0.001
Fecal output, g/d	18.8[ab]	24.0[a]	15.6[b]	24.3[a]	2.0	0.01
P output, g/d	0.08[c]	0.27[b]	0.09[c]	0.62[a]	0.03	<0.001
P absorbed, g/d	0.72[c]	0.56[d]	0.87[b]	1.15[a]	0.04	<0.001
ATTD of P, %	90.4[a]	68.0[b]	90.6[a]	65.5[b]	1.8	<0.001
STTD of P,[3] %	96.9[a]	76.2[b]	97.6[a]	68.5[c]	2.2	<0.001

[a–d]Row means that do not have a common superscript letter differ, $P < 0.05$.

[1]Data are least squares means with 8 observations per treatment.

[2]Dried fermentation biomass was obtained from Ajinomoto Heartland Inc., Chicago, IL; PEP50 and PEP2+ were sourced from TechMix, Stewart, MN; and fish meal was a Menhaden Select fish meal that was procured from Omega Protein Corp., Houston, TX.

[3]Values for STTD were calculated by correcting values of ATTD for basal endogenous loss of P. The basal endogenous loss of P was measured from pigs fed the P-free diet at 148 mg/kg of DMI.

fish meal used in this experiment was less than that used in previous experiments; however, DE and ME values for fish meal obtained in the present experiment agree with previous values (NRC, 1998; Sauvant et al., 2004).

The ATTD (65.5%) and STTD (68.5%) of P in fish meal determined in the present experiment agree with recent values from our laboratory (Kim and Stein, 2010), but ATTD of P obtained in this experiment is less than the range of values (77 to 90%) reported from older experiments (Jongbloed and Kemme, 1990; Rodehutscord et al., 1997; Sauvant et al., 2004). These differences in P digestibility could be related to the amount of bone P in the fish meal because P from bone is believed to be less digestible than P from soft tissue (Hua et al., 2005). Bone P accounts for 53 to 79% of total P in fish meal, depending on manufacturing techniques and choice of raw materials used in the production of fish meal (Hua et al., 2005). The high ash concentration in the fish meal used in the present experiment indicates that a high proportion of bone was included in the product, which might explain the relatively low digestibility value for P in fish meal that we determined, compared with previous values.

Dried Fermentation Biomass

The relatively high concentration of protein in DFB and high digestibility of AA resulted in a greater concentration of digestible AA being provided per unit of weight by DFB than by the other protein sources used in this experiment. Specifically, the concentration of digestible Lys is much greater than for any of the other protein sources, which indicates that the biomass that is used to produce DFB retained some Lys after the purification step of L-Lys production. These data agree with other recent data, indicating that fermentation biomass produced from L-Thr production has a greater concentration of digestible Thr than fish meal (Almeida et al., 2011).

The protein fraction of the fermentation biomass mainly originates from bacterium used to synthesize L-Lys. When the bacterium is added to the fermentation broth, Lys accumulates in the aqueous solution, which can then be purified from the broth and separated by ion exchange (Hermann, 2003). The relatively high concentration of other AA in DFB indicates that AA other than Lys accumulate in the fermentation broth. These AA might originate from bacterial protein or the protein fraction of some of the starch sources that were used in the fermentation broth.

The greater DE and ME in DFB, compared with SBM and fish meal, is a result of the greater GE concentration in DFB than the other ingredients. The energy in DFB mainly originates from the feedstock used for fermentation and energy from the microbial biomass that is included in the product. One of the major industrial C sources for Lys production is dextrose, which is obtained from the hydrolysis of corn starch (Ikeda, 2003). Starch undergoes liquefaction after addition of α-amylase, followed by saccharification in the presence of amyloglucosidase to produce a high dextrose equivalent hydrolysate. The bacteria are then grown aerobically in a liquid-nutrient medium, with dextrose as the carbohydrate constituent and ammonia as the N source. Thus, the residual carbohydrate fractions in the fermentation biomass could be mainly monosaccharides and enzymatically, hydrolyzed, short-chain polysaccharides with a very low fiber concentration. Indeed, the concentrations of ADF (0.03%) and NDF (1.27%) in DFB indicate that there is very little fiber in the biomass. Bacteria also contain fat that contributes to the energy value of the fermentation biomass. The fat contribution of bacteria in DFB was not determined, but DFB contained 10.55% acid hydrolyzed fat, which contributed to its high concentration of GE.

Despite the greater digestibility of P in DFB, compared with fish meal, less digestible P is provided from DFB than fish meal because of the decreased concentration of P in DFB, compared with fish meal. The P in the fermentation biomass is composed of P from bacteria and P from corn steep liquor, which is included in the growth medium. The fact that the P in DFB was almost completely digested by the pigs indicates that very little phytic acid is present in DFB.

Hydrolyzed Porcine Intestinal Mucosa Products

Heparin is used as an injectable anticoagulant in the human pharmaceutical industry and it is derived from intestinal mucosal tissues of slaughtered meat animals (Linhardt and Gunay, 1999). Inclusion of dried porcine solubles, which is derived from porcine intestinal mucosa after heparin extraction, in diets fed to weanling pigs improved growth performance, compared with pigs fed select menhaden fish meal (Lindemann et al., 1998; 2000; Jones et al., 2010) or spray-dried animal plasma (DeRouchey et al., 2003). Nonetheless, the PEP50 and PEP2+ products used in the present experiments are different from dried porcine solubles because they are mixtures of hydrolyzed intestinal mucosa and other protein-rich ingredients.

Although the concentration of most AA in PEP2+ was greater than in SBM and fish meal, the concentration of digestible AA was not greater in PEP2+ than in SBM and fish meal as a result of decreased digestibility of AA in PEP2+. Most AA in PEP50 had SID values that were not different from those in SBM and fish meal; however, the concentration of AA was less in PEP50 than in fish meal, and PEP50, therefore, provides fewer digestible AA than fish meal. These observations indicate that greater concentrations of the peptone products than fish meal are required to provide a specific quantity of digestible AA in a given diet. The decreased digestibility of most indispensable AA in PEP2+, compared with PEP50, is likely a result of differences in the proportions of vegetable ingredients included in the products.

The greater DE and ME in PEP50 and PEP2+, compared with corn and fish meal, are largely a result of the greater GE concentrations in these products. Although both PEP50 and PEP2+ contained less digestible AA than fish meal, the greater DE and ME improve their nutritional value. This might explain improved pig growth performance that is observed when PEP50 and PEP2+ were included in diets fed to weanling pigs, compared with select menhaden fish meal (Myers et al., 2011).

The greater digestibility of P in PEP50 and PEP2+, compared with fish meal, is probably a result of differences in the chemical forms of P among these ingredients. Unlike fish meal, in which most of the P is from fishbone, most of the P in PEP50 and PEP2+ is from intestinal mucosa, which is more digestible than P from bone (Hua et al., 2005). Nonetheless, both PEP50 and PEP2+ provide less digestible P than fish meal because of the decreased P concentrations in these ingredients compared with fish meal. Therefore, using PEP50 and PEP2+ to replace fish meal in nursery pig diets would require greater supplementation of P from other sources.

Conclusions

The DFB product that was used in the present experiments has greater nutritional value than fish meal when fed to weanling pigs. Specifically, the SID of most indispensable AA in DFB was similar to the SID of AA in fish meal, but the SID of Lys and Met was greater in DFB than in fish meal. The DE and ME and STTD of P in DFB were also greater than in fish meal. Further research is needed to determine effects of including DFB in diets fed to weanling pigs on growth performance.

The concentration of digestible AA in PEP50 and PEP2+ was less than in fish meal, but both ingredients had DE and ME values that were similar to or greater than fish meal. Likewise, the STTD of P was greater in PEP50 and PEP2+ than fish meal. It is, therefore, likely that both PEP50 and PEP2+ may be used as replacements for fish meal in diets fed to weanling pigs; however, other sources of AA need to be included along with PEP50 or PEP2+ to compensate for the decreased concentration of digestible AA in these ingredients, compared with fish meal.

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