Concentration of digestible and metabolizable energy and digestibility of amino acids in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal mixture, and conventional soybean meal fed to weanling pigs

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Concentration of digestible and metabolizable energy and digestibility of amino acids in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal mixture, and conventional soybean meal fed to weanling pigs[1]

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ABSTRACT: Two experiments were conducted to determine the concentration of DE and ME and the standardized ileal digestibility (SID) of AA in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, and conventional SBM fed to weanling pigs. In Exp. 1, 48 barrows (initial BW: 14.6 ± 2.2 kg) were placed in metabolism cages and allotted to 6 diets with 8 replicate pigs per diet in a randomized complete block design. Six corn-based diets were formulated. The basal diet contained 98.1% corn (as-fed basis) and 5 diets contained corn and 11 to 16% chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, spent hen–SBM mixture, or SBM. All test ingredients were included in their respective diets at levels that were expected to result in similar concentrations of CP among diets. Feces and urine were collected for 5 d. The ME was 3,957, 3,816, 4,586, 4,298, 4,255, and 4,091 kcal/kg DM for corn, chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM, respectively. The ME in poultry byproduct meal was greater ($P < 0.01$) than in corn, chicken meal, the spent hen–SBM mixture, and SBM, and the ME in hydrolyzed porcine intestines and the spent hen–SBM mixture was greater ($P < 0.01$) than in corn and chicken meal, but there was no difference among hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM. In Exp. 2, 12 barrows (initial BW: 12.2 ± 1.5 kg) were equipped with a T-cannula in the ileum and allotted to a replicated 6 × 6 Latin square design. A N-free diet and a cornstarch–SBM based diet were formulated. Four additional diets were formulated by mixing cornstarch, sucrose, and SBM with chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, or the spent hen–SBM mixture. The SID of CP and all AA, except Trp and Pro, was greater ($P < 0.01$) in SBM than in all other ingredients. The SID of CP and all indispensable AA in the spent hen–SBM mixture was also greater ($P < 0.01$) than in chicken meal and hydrolyzed porcine intestines, and with the exception of Arg and Val, SID values of all indispensable AA in the spent hen–SBM mixture were greater than in poultry byproduct meal. However, with the exception of Val and Lys, there were no differences between chicken meal and poultry byproduct meal. In conclusion, the ME in hydrolyzed porcine intestines and the spent hen–SBM mixture is greater than in chicken meal, but not different from the ME of SBM. Poultry by product meal provides more ME than SBM, chicken meal, and the spent hen–SBM mixture, and the SID of most indispensable AA is greater in the spent hen–SBM mixture than in chicken meal, poultry byproduct meal, and hydrolyzed porcine intestines, but less than in SBM.

Key words: amino acid digestibility, animal proteins, chicken meal, energy, pig, poultry byproduct meal

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INTRODUCTION

Chicken meal and poultry byproduct meal are byproducts of the poultry processing industry and both ingredients have a concentration of AA that is similar to that in fish meal (Keegan et al., 2004). Both ingredients have been used in pet food and swine diets to replace fish meal (Yamka et al., 2003; Keegan et al., 2004; Zier et al., 2004). Chicken meal contains mainly skin, flesh, and bones from processed birds whereas feet, legs, beaks, and intestinal contents also may be included in poultry byproduct meal (AAFCO, 2011). It is recognized that some variability among different batches of poultry

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byproduct meal exists (Dong et al., 1993). Other animal proteins such as hydrolyzed porcine intestines and a spent hen–soybean meal (**SBM**) mixture are also available for animal feeding, but for all of these ingredients there is a lack of data on the digestibility of AA and the concentration of DE and ME, which limits the use of these ingredients in diets fed to weanling pigs. Therefore, the objectives of the present experiments were to determine the concentration of DE and ME and the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of AA and CP in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, and the spent hen–SBM mixture when fed to weanling pigs and to compare these values to values obtained for SBM.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois (Urbana, IL) reviewed and approved the protocols for these experiments.

Pigs used in both experiments were the offspring of G-performer boars mated to F-25 gilts (Genetiporc, Alexandria, MN). The ingredients that were used in the experiments included chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–SBM mixture, and SBM (Table 1), and the same batches of these ingredients were used in both experiments. Corn was also used in the DE and ME experiment. All ingredients, except hydrolyzed porcine intestines, were randomly selected commercial products.

The chicken meal and the poultry byproduct meal that were used in the experiments were sourced from a commercial company (The Scoular Company, Minneapolis, MN). The hydrolyzed porcine intestines used were from a noncommercial experimental product that was prepared by enzymatically hydrolyzing porcine intestines collected from pig slaughter facilities (Nutra Flo, Sioux City, IA). The spent hen–SBM mixture that was included in the experiments was prepared by enzymatically hydrolyzing whole spent laying hens and egg albumen, which was then extruded and mixed with a SBM carrier (AV-E Digest; XFE Products, Des Moines, IA). The SBM that was used was sourced locally (Solae, Gibson City, IL) and yellow dent corn was grown locally and obtained from the University of Illinois Feed Mill (Champaign, IL).

Experiment 1: Energy Measurements

Diets, Animals, and Experimental Design. Experiment 1 was designed to determine the apparent total tract digestibility (**ATTD**) of GE and the DE and ME in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM. Forty-eight barrows (initial BW: 14.6 ± 2.2 kg) were placed in metabolism cages that were equipped with a feeder and a nipple drinker and assigned to 6 diets with 8 replicate pigs per diet in a randomized complete block design.

Six corn-based diets were formulated (Table 2). The basal diet contained 98.1% corn (as-fed basis). The chicken meal diet contained 88.3% corn and 11.0% chicken meal (as-fed basis), and the poultry byproduct meal diet contained 87.3% corn and 12.0% poultry byproduct meal (as-fed basis). Two additional diets were formulated by mixing 83.3% corn and 16.0% (as-fed basis) of hydrolyzed porcine intestines or the spent hen–SBM mixture, and the SBM diet contained 82.3% corn and 16.0% SBM (as-fed basis). Vitamins and minerals were included in the diets to meet or exceed the requirements for weanling pigs (NRC, 1998). The only sources of energy in the diets were corn and the test ingredients. All test ingredients were included in their respective diets at levels that were expected to result in similar concentrations of CP among diets.

Feeding and Sample Collection. Feed was supplied in a daily amount of 3 times the maintenance energy requirement [i.e., 106 kcal of ME/kg of metabolic weight ($BW^{0.75}$); NRC, 1998] of the smallest pig in each replicate and divided into 2 equal meals that were fed at 0800 and 1700 h. Water was available at all times. Pigs were fed experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed on d 6 (chromic oxide) and 11 (ferric oxide), and fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at –20°C immediately after collection. Urine was also collected and urine collections started on d 6 at 1700 h and ceased on d 11 at 1700 h. Urine buckets were placed under the metabolism cages to permit total collection. They were emptied in the morning and afternoon and a preservative of 50 mL of 6 *N* HCL was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at –20°C.

Sample Analyses. All samples were analyzed in duplicate. After completing sample collections, urine samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis. Fecal samples were dried at 65°C in a forced-air oven and ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) before analyses. Urine samples were lyophilized and analyzed for energy as previously explained (Kim et al., 2009). Diets and ingredient samples were analyzed for CP by combustion (method 999.03; AOAC International, 2007) using a Rapid N cube (Elementar Americas Inc, Mt. Laurel, NJ), ash (method 975.03; AOAC International, 2007), and acid hydrolyzed ether extraction (**AEE**), which was determined by acid

Table 1. Analyzed nutrient composition (as-fed basis) of chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, SBM, and corn

	Ingredient					
Item	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM	Corn
GE, kcal/kg	4,907	5,226	4,399	4,783	4,216	3,972
DM, %	96.80	94.80	92.89	93.79	89.55	86.86
CP, %	66.04	62.25	51.37	49.48	47.05	6.87
Ash, %	14.19	11.33	22.11	14.57	6.54	1.12
AEE[1], %	11.03	14.29	15.84	15.80	2.11	3.45
NDF, %	–	–	–	–	9.14	7.27
ADF, %	–	–	–	–	6.00	1.95
P, %	2.43	1.87	0.81	1.79	0.59	0.22
Ca, %	4.43	2.69	0.08	3.29	0.38	0.01
Indispensable, AA %						
Arg	4.05	4.05	2.67	3.19	3.42	0.35
His	1.25	1.32	0.97	1.05	1.22	0.20
Ile	2.43	2.35	1.94	2.03	2.30	0.26
Leu	4.27	4.25	3.66	3.49	3.68	0.81
Lys	3.49	3.96	3.54	2.90	3.02	0.24
Met	1.09	1.26	0.86	0.76	0.65	0.15
Phe	2.42	2.41	2.00	2.17	2.38	0.33
Thr	2.27	2.37	1.99	1.76	1.81	0.24
Trp	0.58	0.60	0.51	0.43	0.65	0.06
Val	3.15	2.92	2.48	2.45	2.36	0.32
Dispensable, AA %						
Ala	3.78	3.92	2.73	2.77	2.05	0.50
Asp	4.67	4.84	3.93	4.24	5.24	0.45
Cys	0.96	0.59	0.63	0.75	0.62	0.14
Glu	7.56	7.68	6.16	6.59	8.58	1.26
Gly	5.56	5.63	3.32	3.93	2.03	0.28
Pro	4.06	3.52	2.52	2.98	2.24	0.57
Ser	2.65	2.38	1.77	1.74	2.21	0.31
Tyr	1.92	2.08	1.79	1.69	1.69	0.22
Total AA	56.16	56.13	43.47	44.92	46.14	6.69

[1]AEE = acid hydrolyzed ether extract.

hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06; AOAC International, 2007) on an analyzer (Soxtec 2050 Automated Analyzer; FOSS North America, Eden Prairie, MN). Diets and ingredients were also analyzed for DM (method 930.15; AOAC International, 2007), and P and Ca were analyzed by the inductively coupled plasma spectroscopy procedure (method 985.01 A, B, and C; AOAC International, 2007) after wet ash sample preparation [method 975.03 B(b); AOAC International, 2007]. Diets, ingredients, fecal, and urine samples were analyzed for GE using bomb calorimetry (Model 6300; Parr Instruments, Moline, IL) and all ingredients were analyzed for AA [method 982.30 E (a, b, and c); AOAC International, 2007]. Diets and samples of corn and SBM were also analyzed for ADF (method 973.18; AOAC International, 2007) and NDF (Holst, 1973).

Calculations and Statistical Analysis. Energy values that were determined from the excretion of GE in the feces and urine were subtracted from the intake of GE to calculate DE and ME for each diet (Adeola, 2001). The DE and ME in the corn diet were divided by 0.981 to calculate the DE and ME in corn. The contributions of DE and ME from corn to the diets containing chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, or SBM were then calculated and subtracted from the total DE and ME in these diets. The concentrations of DE and ME in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM were then calculated by difference (Adeola, 2001). The DE and ME in all ingredients were calculated on an as-fed basis as well as on a DM basis. The ATTD of GE was also calculated for all diets and for each ingredient (Adeola, 2001).

Data were analyzed by ANOVA using the Mixed Procedure (SAS Inst. Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure. Outliers were determined as values that deviated from the treatment mean by more than 3.0 times the interquartile range (Devore and Peck,

Table 2. Composition of experimental diets (as-fed basis) containing corn, chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, or SBM, Exp. 1

	Diet					
Item	Corn	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM
Ingredients, %						
Ground corn	98.10	88.30	87.30	83.30	83.30	82.30
Protein source	–	11.00	12.00	16.00	16.00	16.00
Ground limestone	1.20	–	–	–	–	1.00
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed composition						
GE, kcal/kg	3,928	4,064	4,150	4,074	4,085	3,969
DM, %	87.57	87.39	87.93	86.51	87.71	87.01
CP, %	7.37	13.63	13.62	13.57	13.46	13.65
Ash, %	2.79	3.18	2.73	4.94	3.73	3.43
AEE[2], %	2.94	4.05	5.38	6.31	5.23	3.52
P, %	0.25	0.48	0.44	0.31	0.47	0.30
Ca, %	0.52	0.57	0.41	0.06	0.50	0.51
NDF, %	8.39	10.17	9.52	6.13	7.67	8.14
ADF, %	2.06	2.43	2.10	1.76	2.04	2.65

[1]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 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 B_{12}, 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, 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.

[2]AEE = acid hydrolyzed ether extract.

1993), and 1 outlier was detected and removed from the final data analysis (a pig fed the SBM diet). Diet was the fixed effect and pig was the random effect. The least significant means statement was used to calculate treatment means and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and an α level of 0.05 was used to assess significance among means.

Experiment 2: AA Digestibility

Diets, Animals, and Experimental Design. Experiment 2 was designed to determine the AID and the SID of CP and AA in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM fed to weanling pigs. Twelve weanling barrows (initial BW: 12.2 ± 1.5 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were allotted to a replicated 6 × 6 Latin square design with 6 periods and 6 diets in each square. Pigs were housed individually in pens (1.2 by 1.5 m) in an environmentally controlled room. A feeder and a nipple drinker were installed in each pen.

Six diets were prepared (Tables 3 and 4). One diet contained SBM as the sole source of AA, and 4 diets contained SBM and chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, or the spent hen–SBM mixture. The last diet was a N-free diet, which was used to estimate basal endogenous losses of CP and AA. Chromic oxide (0.4%) was included in all diets as an indigestible marker and vitamins and minerals were included to meet or exceed estimated nutrient requirements for weanling pigs (NRC, 1998).

Feeding and Sample Collection. Pigs were fed at a daily level of 2.5 times the estimated maintenance requirement for energy, and the daily allotment of feed was provided at 0700 h each day. Water was available at all times. The BW of each pig was recorded at the beginning of each period and the amount of feed supplied each day was recorded. Each experimental period lasted 7 d. The initial 5 d was an adaptation period to the diet whereas ileal digesta were collected for 8 h on d 6 and 7. A 225-mL plastic bag was attached to the cannula barrel by a zip tie, and digesta that flowed into the bag were collected. Bags were removed whenever they were filled with digesta or at least once every 30 min, and digesta were immediately stored at –20°C to prevent bacterial degradation of AA in the digesta.

Sample Analysis. At the conclusion of the experiment, ileal samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analyses. All ileal digesta samples were lyophilized and finely ground before chemical analyses. All samples of digesta and diets were analyzed in duplicate for DM, CP, and AA as described for Exp. 1 and for chromium (Fenton and Fenton, 1979). All diet samples were also analyzed for ADF, NDF, ash, Ca, P, AEE, and GE as described for Exp. 1.

Table 3. Ingredient composition of experimental diets (as-fed basis) containing chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, or SBM, and in the N-free diet, Exp. 2

	Diet					
Ingredient, %	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM	N-free[1]
Chicken meal	13.00	–	–	–	–	–
Poultry byproduct meal	–	14.00	–	–	–	–
Hydrolyzed intestines	–	–	17.00	–	–	–
Spent hen–SBM mixture	–	–	–	17.00	–	–
SBM	18.00	18.00	18.00	18.00	36.00	–
Soybean oil	1.00	1.00	1.00	1.00	3.00	4.00
Lactose	10.00	10.00	10.00	10.00	10.00	10.00
Solka floc	–	–	–	–	–	4.00
Monocalcium phosphate	–	–	–	–	1.30	2.40
Ground limestone	–	–	–	–	1.30	0.50
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40
Cornstarch	36.90	35.90	32.90	32.90	27.30	57.50
Magnesium oxide	–	–	–	–	–	0.10
Potassium carbonate	–	–	–	–	–	0.40
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30

[1]N-free = nitrogen free diet.

[2]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 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 B_{12}, 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, 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.

Calculations and Statistical Analysis. Values for AID, endogenous losses, and SID of CP and AA were calculated for all diets except the N-free diet (Stein et al., 2007). Data from the SBM diet were used to calculate the contribution of AA from SBM to the other diets, which allowed for calculation of the digestibility of AA in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, and the spent hen–SBM mixture using the difference procedure (Mosenthin et al., 2007). Data were analyzed by ANOVA using the MIXED procedure (SAS) as explained for Exp. 1.

RESULTS

Chemical Characteristics of Ingredients

The GE concentration was 5,226 kcal/kg (as-fed basis) in poultry byproduct meal and 4,907, 4,783, 4,399, 4,216, and 3,972 kcal/kg in chicken meal, the spent hen–SBM mixture, hydrolyzed porcine intestines, SBM, and corn, respectively (Table 1). Crude protein was 66.02, 62.25, 51.37, 49.48, 47.05, and 6.87% (as-fed basis) in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, SBM, and corn, respectively. The concentration of lipids in hydrolyzed porcine intestines, the spent hen–SBM mixture, chicken meal, poultry byproduct meal, corn, and SBM was 15.84 and 15.80, 14.29, 11.03, 3.45, 2.11% (as-fed basis), respectively, and the P and Ca concentrations (as-fed basis) were, respectively, 2.43 and 4.43% in chicken meal, 1.87 and 2.69% in poultry byproduct meal, 0.81 and 0.08% in hydrolyzed porcine intestines, 1.79 and 3.29% in the spent hen–SBM mixture, 0.59 and 0.38% in SBM, and 0.22 and 0.01% in corn.

Experiment 1: Energy Digestibility

Gross energy intake was less ($P < 0.01$) for pigs fed the corn diet than for pigs fed the other diets, but no differences in GE intake were observed among the other diets (Table 5). Fecal excretion of GE was greater ($P < 0.01$) for pigs fed the chicken meal, poultry byproduct meal, and the spent hen–SBM mixture diets than for pigs fed the corn, hydrolyzed porcine intestines, or SBM diets. In contrast, urinary excretion of GE was greater ($P < 0.01$) for pigs fed the hydrolyzed porcine intestines and SBM diets than for pigs fed the corn and the spent hen–SBM mixture diets, but there was no difference among hydrolyzed porcine intestines, SBM, chicken meal, and poultry byproduct meal diets. The ATTD of GE was greater ($P < 0.01$) for the hydrolyzed porcine intestines and SBM diets than for the other diets. The DE (as-fed basis) was greater ($P < 0.01$) in the poultry byproduct meal and the hydrolyzed porcine intestines diets than in the other diets, but the DE in the corn diet was less ($P < 0.05$) than in all other diets. The ME (as-fed basis) was

Table 4. Analyzed nutrient composition of experimental diets, (as-fed basis) containing chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, or SBM, and in the N-free diet, Exp. 2

	Diet					
Item	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM	N-free[1]
GE, kcal/kg	4,054	4,144	4,092	4,025	4,022	3,824
DM, %	92.88	93.33	92.08	93.05	92.84	93.01
CP, %	17.18	17.79	16.64	17.18	15.34	0.45
Ash, %	4.25	3.72	5.74	4.56	5.23	3.62
AEE[2], %	3.11	3.97	4.69	4.50	3.41	4.87
P, %	0.44	0.38	0.25	0.44	0.48	0.52
Ca, %	0.72	0.50	0.14	0.66	0.84	0.62
NDF, %	5.12	4.97	1.13	2.79	2.64	3.16
ADF, %	1.65	1.42	1.13	1.61	2.24	3.26
Indispensable, AA %						
Arg	1.18	1.19	1.04	1.16	1.21	0.01
His	0.39	0.40	0.36	0.40	0.44	–
Ile	0.74	0.75	0.74	0.72	0.80	0.01
Leu	1.28	1.30	1.29	1.27	1.32	0.02
Lys	1.06	1.12	1.13	1.05	1.08	0.01
Met	0.29	0.30	0.27	0.25	0.22	–
Phe	0.75	0.77	0.75	0.77	0.88	0.01
Thr	0.67	0.67	0.65	0.65	0.65	0.01
Trp	0.18	0.19	0.20	0.18	0.24	0.03
Val	0.79	0.86	0.79	0.77	0.83	–
Dispensable, AA %						
Ala	0.94	0.95	0.84	0.88	0.74	0.01
Asp	1.62	1.67	1.58	1.68	1.94	0.02
Cys	0.23	0.20	0.20	0.24	0.24	–
Glu	2.66	2.69	2.56	2.75	3.05	0.04
Gly	1.18	1.18	0.93	1.10	0.72	0.01
Pro	0.97	0.92	0.80	0.95	0.85	0.02
Ser	0.81	0.74	0.68	0.78	0.74	0.01
Tyr	0.50	0.53	0.55	0.51	0.57	0.01
Total AA	16.24	16.43	15.36	16.11	16.52	0.22

[1]N-free = nitrogen free diet.

[2]AEE = acid hydrolyzed ether extract.

greater ($P < 0.01$) for the poultry byproduct meal diet than for all other diets, but there was no difference in ME among diets containing chicken meal, hydrolyzed porcine intestines, the spent hen–SBM mixture, or SBM.

The ATTD of GE was not different among ingredients. The DE (as-fed basis) was greater ($P < 0.01$) in chicken meal, the spent hen–SBM mixture, and SBM than in corn but less ($P < 0.01$) than in poultry byproduct meal and hydrolyzed porcine intestines. The DE calculated on a DM basis was greater ($P < 0.01$) in hydrolyzed intestines than in corn and chicken meal, but no differences among hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM were observed. However, the concentration of DE (DM basis) was greater ($P < 0.01$) in poultry byproduct meal than in all other ingredients except hydrolyzed porcine intestines. The ME concentration (as-fed basis) was greater ($P < 0.01$) in poultry byproduct meal than in the other ingredients, but there was less ($P < 0.01$) DE in chicken meal than in hydrolyzed porcine intestines and the spent hen–SBM mixture. The ME concentration (DM basis) was also greater ($P < 0.01$) in poultry byproduct meal than in all other ingredients except hydrolyzed porcine intestines, but the ME concentration was greater ($P < 0.01$) in the spent hen–SBM mixture than in corn and chicken meal. There was no difference in the ME concentration among hydrolyzed porcine intestines, the spent hen–SBM mixture, and SBM.

Experiment 2: AA Digestibility

The AID of CP and Arg was greater ($P < 0.01$) in SBM than in the spent hen–SBM mixture, poultry byproduct meal, chicken meal, and hydrolyzed porcine intestines (Table 6), but the AID of CP and Arg were not different between the spent hen–SBM mixture and poultry byproduct

Table 5. Concentration of DE and MW, and apparent total tract digestibility (ATTD) of energy in corn, chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, and SBM Exp. 1[1] (as-fed basis)

Item	Corn	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM	Pooled SEM	*P*-value
Diets								
Feed intake, kg/d	0.63[b]	0.72[a]	0.70[a]	0.71[a]	0.73[a]	0.71[a]	0.03	0.04
GE intake, kcal/d	2,447[b]	2,845[a]	2,835[a]	2,799[a]	2,857[a]	2,743[a]	80.9	<0.01
GE in feces, kcal/d	264.7[b]	315.6[a]	311.3[a]	241.4[b]	310.6[a]	262.4[b]	16.9	<0.01
GE in urine, kcal/d	80.9[c]	120.5[ab]	116.9[ab]	128.7[a]	96.2[bc]	135.8[a]	10.7	<0.01
ATTD of GE, %	89.2[b]	88.9[b]	89.1[b]	91.4[a]	89.1[b]	90.5[a]	0.4	<0.01
DE, kcal/kg	3,505[d]	3,613[bc]	3,696[a]	3,725[a]	3,640[b]	3,590[c]	18.2	<0.01
ME, kcal/kg	3,372[b]	3,441[b]	3,522[a]	3,387[b]	3,384[b]	3,370[b]	25.2	<0.01
Ingredients								
ATTD of GE, %	89.2	87.9	89.2	92.6	88.5	93.1	1.9	0.20
DE, kcal/kg	3,573[c]	4,161[b]	4,805[a]	4,563[a]	4,145[b]	4,059[b]	132.3	<0.01
DE, kcal/kg DM	4,114[d]	4,298[cd]	5,069[a]	4,702[ab]	4,419[bcd]	4,533[bc]	142.6	<0.01
ME, kcal/kg	3,437[e]	3,694[d]	4,348[a]	3,992[bc]	3,991[b]	3,661[cde]	113.5	<0.01
ME, kcal/kg DM	3,957[c]	3,816[c]	4,586[a]	4,298[ab]	4,255[b]	4,091[bc]	120.5	<0.01

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

[1]Data are means of 8 observations per treatment, except for the treatment with SBM, which had only 7 observations.

meal. The AID of His and Thr were less ($P < 0.01$) in hydrolyzed porcine intestines than in the other ingredients, but the AID of His and Thr were greater ($P < 0.01$) in SBM than in chicken meal, poultry byproduct meal, and the spent hen–SBM mixture. The AID of Ile, Leu, and Phe were not different among chicken meal, poultry byproduct meal, and hydrolyzed porcine intestines, but the AID of Ile, Leu, and Phe were greater ($P < 0.01$) in SBM and the spent hen–SBM mixture than in chicken meal, poultry byproduct meal, and hydrolyzed porcine intestines. The AID of Lys, Met, and Val was greater ($P < 0.01$) in SBM than in all other ingredients. The AID of Lys was less ($P < 0.01$) in chicken meal than in poultry byproduct meal, the spent hen–SBM mixture, and SBM. Likewise, the AID of Met was less ($P < 0.01$) in hydrolyzed porcine intestines than in poultry byproduct meal, the spent hen–SBM mixture, and SBM. The AID of Trp was greater ($P < 0.01$) in SBM than in the other ingredients but not different from that in the spent hen–SBM mixture. The AID of all dispensable AA, except Ala and Pro, was greater ($P < 0.01$) in SBM than in the other ingredients, and the AID of Ala was greater ($P < 0.01$) in SBM and the spent hen–SBM mixture than in all other ingredients. However, among chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, and the spent hen–SBM mixture, only few differences were observed for AID of dispensable AA.

The SID of CP and all AA except Trp and Pro was greater ($P < 0.01$) in SBM than in all other ingredients (Table 7). The SID of CP and all indispensable AA in the spent hen–SBM mixture was also greater ($P < 0.01$) than in chicken meal and hydrolyzed porcine intestines, and with the exception of Arg and Val, SID values of all indispensable AA in the spent hen–SBM mixture were also greater than in poultry by product meal. However, with the exception of Val and Lys, there were no differences in SID of AA between chicken meal and poultry byproduct meal. The SID of Trp was greater ($P < 0.05$) in hydrolyzed porcine intestines than in chicken meal and poultry byproduct meal and the SID of CP, Arg, and His was less in hydrolyzed porcine intestines than in chicken meal and poultry byproduct meal, but for the remaining indispensable AA, no differences between hydrolyzed porcine intestines and chicken meal were observed. However, the SID of Phe and Thr was less ($P < 0.05$) in hydrolyzed porcine intestines than in poultry byproduct meal. The SID of all dispensable AA except Pro in the spent hen–SBM mixture was greater ($P < 0.01$) than in hydrolyzed porcine intestines. There were no difference in the SID of dispensable AA between chicken meal and poultry byproduct meal, but the SID of all dispensable AA except Ala, Pro, and Tyr was greater ($P < 0.01$) in chicken meal and poultry byproduct meal than in hydrolyzed porcine intestines.

DISCUSSION

Chemical Characteristics of Ingredients

The concentration of DM, CP, P, Ca, and AEE in poultry byproduct meal and SBM were in agreement with values reported by NRC (2012). The high concentration of GE in poultry byproduct meal as well as in chicken meal is due to the high concentration of AEE in these ingredients. The AA concentrations in poultry byproduct meal and SBM were also close to expected values (NRC, 2012). The concentrations of DM, CP, and AA in chicken meal were in close agreement with values reported by Yamka et al. (2003) and Dust et al. (2005), but the P and

Table 6. Apparent ileal digestibility (%) of CP and AA in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, and SBM by weanling pigs, Exp. 2[1]

	Ingredient						
Item	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM	SEM	*P*-value
CP, %	57.5^{c}	62.9^{bc}	50.7^{d}	65.9^{b}	77.3^{a}	4.0	<0.01
Indispensable AA							
Arg	72.9^{c}	75.7^{bc}	63.1^{d}	79.5^{b}	91.4^{a}	2.6	<0.01
His	55.8^{c}	60.8^{c}	44.9^{d}	68.4^{b}	87.1^{a}	4.1	<0.01
Ile	59.0^{c}	61.2^{c}	57.8^{c}	72.5^{b}	83.8^{a}	3.5	<0.01
Leu	59.0^{c}	62.5^{c}	61.2^{c}	73.4^{b}	82.9^{a}	3.4	<0.01
Lys	55.1^{d}	64.0^{c}	61.1^{cd}	71.6^{b}	83.3^{a}	3.9	<0.01
Met	71.8^{cd}	72.1^{c}	68.0^{d}	79.8^{b}	84.9^{a}	1.9	<0.01
Phe	57.3^{c}	61.0^{c}	54.2^{c}	72.6^{b}	84.8^{a}	3.6	<0.01
Thr	53.0^{c}	56.7^{c}	46.7^{d}	65.3^{b}	76.4^{a}	4.0	<0.01
Trp	61.6^{c}	65.5^{c}	78.6^{b}	84.7^{a}	86.9^{a}	3.1	<0.01
Val	54.8^{c}	62.6^{b}	55.5^{c}	65.4^{b}	80.1^{a}	3.8	<0.01
Mean	60.0^{cd}	64.4^{c}	58.4^{d}	71.7^{b}	84.2^{a}	3.4	<0.01
Dispensable AA							
Ala	62.2^{b}	65.9^{b}	61.7^{b}	71.6^{a}	75.8^{a}	3.7	<0.01
Asp	42.9^{c}	45.2^{c}	29.8^{d}	59.0^{b}	83.5^{a}	4.8	<0.01
Cys	42.6^{b}	39.8^{b}	3.8^{c}	37.1^{b}	76.5^{a}	5.8	<0.01
Glu	58.7^{b}	66.2^{b}	45.5^{c}	63.1^{b}	87.7^{a}	5.3	<0.01
Gly	56.5^{b}	59.4^{b}	35.8^{c}	59.1^{b}	71.5^{a}	6.3	<0.01
Pro	53.6^{ab}	53.0^{abc}	42.2^{c}	46.5^{bc}	63.2^{a}	7.4	<0.01
Ser	64.3^{b}	64.8^{b}	52.3^{c}	68.5^{b}	83.5^{a}	3.3	<0.01
Tyr	58.3^{c}	64.9^{b}	65.1^{b}	70.6^{b}	85.5^{a}	3.7	<0.01
Mean	53.9^{b}	56.0^{b}	40.0^{c}	58.5^{b}	81.8^{a}	5.6	<0.01
All AA	54.6^{cd}	60.2^{bc}	49.7^{d}	65.2^{b}	82.7^{a}	4.7	<0.01

$^{a–d}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 12 observations.

Ca concentrations were slightly greater than the values reported by Keegan et al. (2004). The reason for the high concentration of P and Ca in chicken meal and poultry byproduct meal may be that more bones were included in the ingredients used in this experiment compared with the chicken meal used by Keegan et al. (2004). As expected, the greater the ash concentration, the greater the concentration of Ca and P. This was observed in chicken meal that contains more ash, Ca, and P than poultry byproduct meal, and these results agree with Keegan et al. (2004) who reported the concentrations of Ca and P in 2 sources of chicken meal that had different concentrations of ash. This observation indicates that the concentration of bone was greater in chicken meal than in poultry byproduct meal. The concentration of AEE in poultry byproduct meal was slightly greater than the values reported for fat by Zier et al. (2004), but this is likely because the acid hydrolysis procedure was used in this experiment, which results in a greater recovery of fat than if fat is analyzed only by the ether extraction procedure (Palmquist and Jenkins, 2003).

To our knowledge, this is the first time the composition of hydrolyzed porcine intestines and the spent hen–SBM mixture is reported. The spent hen–SBM mixture used in this experiment has approximately the same concentration of DM and CP, but a greater concentration of P, Ca, and fat than a dehydrated broiler mortality product used by Myer et al. (2004). The concentration of GE and most nutrients in the spent hen–SBM mixture was intermediate between poultry byproduct meal and SBM, which was expected because the spent hen–SBM mixture contains both spent laying hens and SBM. However, the concentration of ash in the spent hen–SBM mixture was greater than in both poultry byproduct meal and SBM, which may be a consequence of a greater concentration of bones in the birds used to produce the spent hen–SBM mixture. The greater concentration of AEE in the spent hen–SBM mixture compared with corn and SBM is likely a result of the inclusion of egg albumin in the spent hen–SBM mixture.

Experiment 1: Energy Digestibility

The ATTD of GE in corn and SBM was in close agreement with previously reported values (Baker and Stein, 2009; NRC, 2012). The GE, DE, and ME

Table 7. Standardized ileal digestibility (SID; %) of CP and AA in chicken meal, poultry byproduct meal, hydrolyzed porcine intestines, a spent hen–soybean meal (SBM) mixture, and SBM by weanling pigs, Exp. 2[1,2]

	Ingredient						
Item	Chicken meal	Poultry byproduct meal	Hydrolyzed intestines	Spent hen–SBM mixture	SBM	SEM	*P*-value
CP, %	67.4^{c}	72.1^{bc}	61.1^{d}	75.8^{b}	89.8^{a}	4.0	<0.01
Indispensable AA							
Arg	79.1^{c}	81.8^{bc}	71.1^{d}	86.0^{b}	97.8^{a}	2.7	<0.01
His	62.8^{c}	67.4^{c}	52.9^{d}	75.0^{b}	92.4^{a}	4.1	<0.01
Ile	65.8^{c}	67.9^{c}	64.4^{c}	79.6^{b}	89.5^{a}	3.5	<0.01
Leu	65.2^{c}	68.6^{c}	67.2^{c}	79.7^{b}	88.7^{a}	3.4	<0.01
Lys	60.5^{d}	68.9^{c}	65.8^{cd}	77.1^{b}	88.5^{a}	3.9	<0.01
Met	74.9^{c}	75.2^{c}	71.7^{c}	84.2^{b}	90.6^{a}	1.9	<0.01
Phe	64.7^{cd}	68.0^{c}	61.3^{d}	75.6^{b}	90.1^{a}	3.7	<0.01
Thr	63.3^{cd}	67.1^{c}	57.5^{d}	76.1^{b}	87.4^{a}	4.0	<0.01
Trp	69.7^{c}	72.7^{c}	84.9^{b}	91.2^{a}	91.2^{a}	3.1	<0.01
Val	63.5^{c}	70.0^{b}	64.0^{c}	74.5^{b}	88.4^{a}	3.8	<0.01
Mean	66.8^{cd}	70.9^{c}	65.3^{d}	78.8^{b}	90.4^{a}	3.4	<0.01
Dispensable AA							
Ala	69.7^{c}	73.5^{c}	71.0^{c}	80.2^{b}	87.8^{a}	3.5	<0.01
Asp	48.2^{c}	53.1^{c}	38.3^{d}	66.6^{b}	89.1^{a}	5.2	<0.01
Cys	55.4^{b}	55.6^{b}	11.2^{c}	48.9^{b}	88.4^{a}	6.0	<0.01
Glu	64.9^{b}	72.3^{b}	52.0^{c}	68.8^{b}	92.2^{a}	5.3	<0.01
Gly	67.1^{b}	70.5^{b}	51.6^{c}	71.1^{b}	98.2^{a}	6.5	<0.01
Pro	76.3	89.2	46.1	79.6	108.5	14.4	0.10
Ser	71.1^{b}	73.2^{b}	62.1^{c}	75.9^{b}	91.8^{a}	3.3	<0.01
Tyr	66.3^{c}	72.1^{c}	71.6^{c}	78.3^{b}	91.6^{a}	3.7	<0.01
Mean	68.1^{b}	70.7^{b}	56.9^{c}	72.7^{b}	97.3^{a}	5.9	<0.01
All AA	65.2^{cd}	70.7^{bc}	61.4^{d}	76.1^{b}	93.5^{a}	4.74	<0.01

$^{a–d}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 12 observations.

[2]Values for SID were calculated by correcting the values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of DMI) as CP, 20.75; Arg, 0.76; His, 0.25; Ile, 0.49; Leu, 0.83; Lys, 0.60; Met, 0.13; Phe, 0.50; Thr, 0.77; Trp, 0.11; Val, 0.70; Ala, 0.95; Asp, 1.17; Cys, 0.31; Glu, 1.48; Gly, 1.99; Pro, 6.11; Ser, 0.67; and Tyr, 0.38.

determined in this experiment for corn and SBM also concur with the values reported by Baker and Stein (2009) and by Goebel and Stein (2011).

Crude protein, AEE, and carbohydrates provide the GE in feed ingredients (Stein and Shurson, 2009), but because animal proteins do not contain carbohydrates, the GE in these ingredients is from CP and lipids. The lack of a difference in the ATTD of GE among ingredients included in this experiment indicates that the energy is well digested in all the animal proteins, which is likely a consequence of the relatively high concentration of lipids in these ingredients.

The DE and ME in poultry byproduct meal was greater than the values reported by NRC (2012), which may be due to the greater concentration of lipids in the source of poultry byproduct meal used in this experiment. The concentration of DE and ME in chicken meal is in good agreement with data published by de Blas et al. (2010). The greater concentration of DE and ME in poultry byproduct meal compared with chicken meal is likely a result of the reduced AEE concentration and the greater ash concentration in chicken meal compared with poultry byproduct meal. These data indicate that a relatively large proportion of the chicken meal was chicken bones.

To our knowledge, this is the first time DE and ME values are reported for hydrolyzed porcine intestines and the spent hen–SBM mixture. However, the fact that the values for DE and ME in these ingredients are slightly greater than in SBM indicates that dietary energy concentrations will not be compromised if hydrolyzed porcine intestines or the spent hen–SBM mixture are used in diets fed to pigs.

Experiment 2: AA Digestibility

The AID and SID of AA in SBM that were obtained in this experiment are in agreement with previous values (Kim et al., 2009; NRC, 2012), which is important because the AID and SID of CP and AA in all other ingredients were calculated using the difference procedure. Both the raw materials and the processing methods used to produce chicken meal and poultry byproduct meal are different (Dong et al., 1993), but the fact that the SID

of most AA in poultry byproduct meal was not different from the SID of AA in chicken meal indicates that despite differences in the materials used to produce the 2 ingredients, the AA digestibility is not affected. The greater ash concentration in chicken meal does not seem to affect AA digestibility, which is in agreement with data for poultry (Shirley and Parsons, 2001). It is also apparent that the relatively high ash concentration in the spent hen–SBM mixture did not impair the SID of AA in this ingredient compared with the other products. However, the SID of AA in hydrolyzed porcine intestines was the least among ingredients, and hydrolyzed porcine intestines contain more than 22% ash.

Bone protein is deficient in most indispensable AA and also has a high concentration of collagen, which has a low digestibility (Eastoe and Long, 1960). Animal proteins such as meat and bone meal may contain 50 to 65% of collagen from connective tissue, skin, tendon, and cartilage (Chiba, 2001), and meat and bone meal has a low concentration of Trp because of the high concentration of collagen (Pork Checkoff, 2008). A low concentration of Trp was also observed in all the animal proteins used in this experiment. This observation indicates that there may have been a relatively high concentration of collagen in these ingredients, which may have contributed to the reduced AID and SID of AA in the animal proteins compared with the AID and SID in SBM.

The AID of indispensable AA in chicken meal and poultry byproduct meal that were determined in this experiment are slightly less than values reported by Knabe et al. (1989) and de Blas et al. (2010). This may be a result of differences in the quality of raw materials or in processing procedures. The greater SID of AA in the spent hen–SBM mixture compared with chicken meal, poultry byproduct meal, and hydrolyzed intestines is likely a result of the addition of SBM to the spent hen–SBM mixture.

Conclusions

The ME is greater in poultry byproduct meal than in chicken meal and the spent hen–SBM mixture, and the ME in chicken meal is less than in hydrolyzed porcine intestines and the spent hen–SBM mixture, but not different from that in SBM. The AID and SID of AA in SBM were greater than in all the animal proteins, which may be a result of relatively high concentrations of collagen in the animal proteins. Amino acids in the spent hen–SBM mixture are also well digested by pigs, which indicates that the spent hen–SBM mixture may be used as a source of digestible AA in diets fed to weanling pigs. However, performance experiments need to be conducted to confirm that the spent hen–SBM mixture may replace fish meal in diets fed to weanling pigs. The same is true for the other protein sources used in this experiment.

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