Ileal digestibility of amino acids in selected feed ingredients fed to young growing pigs¹

G. A. Casas,^{*,†} N. W. Jaworski,^{*,2} J. K. Htoo,[‡] and H. H. Stein^{*,§3}

^{*}Department of Animal Sciences, University of Illinois, Urbana 61801, IL; [†]Departamento de Producción Animal, Facultad de Medicina Veterinaria y de Zootecnia, Universidad Nacional de Colombia, Bogotá, Colombia; [‡]Evonik Nutrition & Care GmbH, 63457 Hanau, Germany; and [§]Division of Nutritional Sciences, University of Illinois, Urbana 61801, IL

ABSTRACT: An experiment was conducted to determine the standardized ileal digestibility (SID) of CP and AA in brewers rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), peanut meal, sesame meal, rapeseed meal, rapeseed expellers, soybean expellers, cassava meal, and bakery meal fed to young growing pigs. Twenty-two barrows (initial BW: 14.09 ± 1.48 kg) were surgically fitted with a T-cannula in the distal ileum and randomly allotted to a replicated 11 × 4 incomplete Latin square design with 11 diets and four 7-d periods in each square. Eleven experimental diets were prepared and test ingredients were the sole source of CP and AA in 10 diets and the eleventh diet was a N-free diet used to measure basal ileal endogenous losses of CP and AA. Chromic oxide (0.4%) was included in all diets as an indigestible marker and ileal digesta were collected on day 6 and 7 of each period. Results indicated that the SID of CP and AA was greatest ($P < 0.05$) in brewers rice and sesame meal and least ($P < 0.05$) in cassava meal. The SID of indispensable AA was greater ($P < 0.05$) in sesame meal compared with all other ingredients except brewers rice. Full-fat rice bran had greater ($P < 0.05$) SID of Arg, Ile, Leu, Lys, and Met compared with DFRB.

The SID of CP and most AA was not different among rapeseed meal, rapeseed expellers, and soybean expellers. Bakery meal had the least ($P < 0.05$) SID of most AA compared with all other ingredients, with the exception of cassava meal. The concentration of standardized ileal digestible CP was greater ($P < 0.05$) in sesame meal and peanut meal (482.32 and 452.44 g/kg DM, respectively) than in all other ingredients. Soybean expellers had the greatest ($P < 0.05$) concentration of standardized ileal digestible Lys (22.98 g/kg DM) followed by rapeseed meal (16.11 g/kg DM) and rapeseed expellers (16.17 g/kg DM). Cassava meal and bakery meal had the least ($P < 0.05$) concentration of standardized ileal digestible CP and most AA compared with the other ingredients. Concentrations of standardized ileal digestible CP and AA in brewers rice, FFRB, and DFRB were less ($P < 0.05$) than in rapeseed meal, rapeseed expellers, and soybean expellers. In conclusion, peanut meal and sesame meal have greater concentrations of standardized ileal digestible CP and most AA, with the exception of Lys, than other ingredients. Rapeseed meal, rapeseed expellers, and soybean expellers have the greatest concentrations of standardized ileal digestible Lys.

Key words: amino acid digestibility, pigs, rapeseed, rice coproducts, soybean expellers

© The Author(s) 2018. Published by Oxford University Press on behalf of the American Society of Animal Science. All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.

J. Anim. Sci. 2018.96:2361–2370

doi: 10.1093/jas/sky114

¹Financial support for this research from Evonik Nutrition & Care GmbH, 63457, Hanau, Germany, is greatly appreciated.

²Current address: Trouw Nutrition, Boxmeer, the Netherlands.

³Corresponding author: hstein@illinois.edu

Received October 16, 2017.

Accepted March 17, 2018.

INTRODUCTION

Accurate estimation of the standardized ileal digestibility (SID) of CP and AA is critical for formulating diets for pigs (Stein et al., 2007; Adeola et al., 2016) and a number of factors may affect the SID of CP and AA by young pigs. After weaning, piglets must modify the synthesis of digestive enzymes to adjust to new dietary components (Lindemann et al., 1986). In addition, DM intake, feeding level, and BW also may affect the endogenous losses of AA, and therefore, values for SID of AA (Hess and Sève, 1999; Moter and Stein, 2004). Thus, young pigs may have a limited capacity for digesting nutrients compared with older pigs (Urbaityte et al., 2009; Pedersen et al., 2016).

There are several coproducts from the grain milling and oilseed industries that may be included in diets for weanling pigs. The SID of CP and AA for these feed ingredients have been determined in growing-finishing pigs and are used in practical diet formulations (NRC, 2012). However, lower SID values of CP and AA in some ingredients has been reported in young pigs (<20 kg BW); thus, SID values obtained in older pigs may not always be applicable to younger pigs (Pedersen et al., 2016). Therefore, the objective of this experiment was to determine the apparent ileal digestibility (AID) and the SID of CP and AA in a number of feed ingredients for which limited data have been reported in young growing pigs.

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois at Urbana-Champaign.

Animals, Housing, Experimental Design, and Diets

Twenty-two barrows (PIC, Hendersonville, TN) with an initial BW of 14.09 ± 1.48 kg were used in the experiment. A T-cannula was surgically inserted in the distal ileum of pigs for collection of ileal digesta. Pigs were housed in individual pens (1.2×1.5 m) in an environmentally controlled room. Pens had smooth, plastic-coated sides and fully-slatted tribar metal floors. Each pen contained a feeder and a nipple drinker. Pigs were allowed to recover from surgery for 7 d. Pigs were then randomly allotted to a replicated 11×4 incomplete Latin square design with 11 diets and four 7-d periods in each square (Kim and Kim, 2010).

Brewers rice, full fat rice bran (FFRB), defatted rice bran (DFRB), peanut meal, sesame meal, rapeseed meal, rapeseed expellers, soybean expellers, cassava meal, and bakery meal were used (Table 1). Eleven experimental diets were prepared and test ingredients were the sole source of CP and AA in 10 diets (Tables 2 and 3). The eleventh diet was an N-free diet that was used to determine basal ileal 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 in all diets to meet current requirement estimates (NRC, 2012).

Feeding and Sample Collection

Pigs were fed at a level of 3 times the maintenance energy requirement (i.e., 197 kcal ME per kg BW^{0.60}; NRC, 2012). The initial 5 d of each period was considered an adaptation period to the diets and ileal digesta were collected on day 6 and 7 for 8 h per day. Digesta samples were stored at -20°C immediately after collection. At the conclusion of the experiment, ileal digesta samples were thawed, mixed within animal and diet, and a subsample was collected for chemical analysis. Digesta samples were lyophilized and ground in a coffee grinder before analysis.

Chemical Analysis

Ingredient, diet, and ileal digesta samples were analyzed for DM (method 930.15; AOAC Int., 2007) and CP using the combustion procedure (method 990.03; AOAC Int., 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 $\text{N} \times 6.25$. Amino acids were analyzed in all ingredients, diets, and ileal digesta samples on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc; Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Prior to analysis, samples were hydrolyzed with 6N HCl for 24 h at 110°C (method 982.30 E(a); AOAC Int., 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 982.30 E(b); AOAC Int., 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30 E(c); AOAC Int., 2007). The chromium concentration in diets and ileal digesta samples was determined using the Inductive Coupled

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

Item, %	Brewers rice	FFRB ¹	DFRB ¹	Peanut meal	Sesame meal	Rapeseed meal	Rapeseed expellers	Soybean expellers	Cassava meal	Bakery meal
DM	87.77	94.85	89.32	89.96	96.63	89.31	89.74	92.52	89.08	91.82
AEE ²	1.32	18.61	5.71	1.44	5.37	2.64	13.28	9.14	0.32	9.86
Starch	73.08	24.52	22.07	6.91	0.85	1.72	1.78	1.93	56.80	38.22
TDF ³	1.70	33.3	22.20	17.80	23.70	35.60	37.40	28.00	12.20	18.60
IDF ³	1.70	29.2	22.20	17.80	20.20	35.0	34.60	26.10	9.40	15.5
SDF ³	ND ⁴	4.10	ND	ND	3.50	0.60	2.90	2.00	2.90	3.00
Ash	0.65	9.39	13.02	5.08	7.76	7.91	6.48	5.81	3.87	3.78
Ca	<0.6	0.05	1.54	0.13	0.13	0.77	0.83	0.29	0.26	0.24
P	0.13	1.86	2.20	0.66	1.69	1.16	1.14	0.58	0.14	0.30
CP	6.53	12.74	15.71	48.04	52.57	33.39	29.23	39.36	2.61	11.09
Indispensable AA										
Arg	0.57	1.08	1.30	5.42	6.26	1.99	1.79	2.85	0.24	0.55
His	0.16	0.35	0.43	1.04	1.24	0.84	0.77	1.01	0.05	0.50
Ile	0.27	0.45	0.54	1.54	1.84	1.33	1.17	1.76	0.08	0.44
Leu	0.52	0.88	1.07	2.90	3.31	2.29	2.03	2.92	0.12	0.87
Lys	0.26	0.61	0.72	1.58	1.31	1.79	1.74	2.45	0.10	0.38
Met	0.18	0.26	0.31	0.48	1.58	0.67	0.58	0.54	0.03	0.17
Phe	0.33	0.54	0.65	2.24	2.22	1.31	1.16	1.89	0.07	0.50
Thr	0.23	0.47	0.58	1.22	1.77	1.48	1.27	1.50	0.09	0.38
Trp	0.09	0.162	0.20	0.47	0.79	0.45	0.40	0.52	0.04	0.12
Val	0.40	0.69	0.84	1.87	2.31	1.72	1.49	1.83	0.10	0.51
Dispensable AA										
Ala	0.37	0.78	0.95	1.77	2.32	1.43	1.25	1.64	0.12	0.48
Asp	0.60	1.14	1.35	5.14	3.95	2.43	2.12	4.28	0.19	0.85
Cys	0.16	0.28	0.32	0.59	1.04	0.77	0.72	0.60	0.04	0.20
Glu	1.13	1.77	2.13	8.50	9.33	5.42	4.64	6.81	0.45	2.40
Gly	0.31	0.70	0.85	2.69	2.53	1.69	1.46	1.64	0.09	0.44
Pro	0.31	0.54	0.65	1.91	1.69	1.91	1.73	1.87	0.09	0.81
Ser	0.32	0.58	0.71	2.17	2.22	1.43	1.25	1.94	0.09	0.52
Lys:CP ratio (%) ⁵	3.98	4.79	4.58	3.29	2.49	5.36	5.95	6.22	3.83	3.43

¹FFRB = full-fat rice bran; DFRB = defatted rice bran.

²AEE = acid hydrolyzed ether extract.

³TDF = total dietary fiber; SDF = soluble dietary fiber; IDF = insoluble dietary fiber.

⁴ND = not detectable.

⁵Lys:CP ratio: Calculated by expressing the concentration of Lys in each ingredient as a percentage of the concentration of CP (Stein et al., 2009).

Plasma Atomic Emission Spectrometric method (method 990.08; AOAC Int., 2007). Samples were prepared using nitric acid-perchloric acid (method 968.08D(b); AOAC Int., 2007).

Ingredients were also analyzed for ash (method 942.05; AOAC Int., 2007) and for acid hydrolyzed ether extract (AEE) using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by fat extraction (Ankom XT-15 Extractor, Ankom Technology, Macedon, NY). Starch was analyzed using the glucoamylase procedure (method 979.10; AOAC Int., 2007), and ingredients were also analyzed for insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) according to method 991.43 (AOAC Int., 2007) using the Ankom^{TDF} Dietary

Fiber Analyzer (Ankom Technology, Macedon, NY). Concentrations of Ca and P were also analyzed in all ingredients (method 985.01; AOAC Int., 2007).

Calculations and Statistical Analysis

Total dietary fiber (TDF) was calculated as the sum of SDF and IDF and the Lys:CP ratio was calculated by expressing the concentration of Lys in each ingredient as a percentage of the concentration of CP (Stein et al., 2009). Values for AID, ileal endogenous losses, and SID of CP and AA in each diet were calculated according to Stein et al. (2007). The AID and SID for CP and AA in the diets represent the AID and SID of CP and AA

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

Item, %	Brewers rice	FFRB ¹	DFRB ¹	Peanut meal	Sesame meal	Rapeseed meal	Rapeseed expellers	Soybean expellers	Cassava meal	Bakery meal	N-free
Test ingredient	93.30	40.00	40.00	40.00	40.00	40.00	40.00	40.00	76.75	93.80	-
Lactose	-	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	-	20.00
Cornstarch	-	33.60	34.00	33.75	33.90	34.90	34.25	33.85	-	-	56.70
Sucrose	-	-	-	-	-	-	-	-	-	-	15.00
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	-	3.00	4.00
Limestone	0.55	1.20	1.80	0.35	0.25	-	0.35	0.65	-	0.50	0.40
Dicalcium phosphate	1.95	1.00	-	1.70	1.65	1.20	1.20	1.30	2.05	1.50	2.20
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Chromic oxide	0.40	0.40	0.40	0.40	0.40	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	0.30	0.30	0.30	0.30	0.30
Potassium carbonate	-	-	-	-	-	-	-	-	-	-	0.40
Magnesium oxide	-	-	-	-	-	-	-	-	-	-	0.10

¹FFRB = full fat rice bran; DFRB = defatted rice bran.

²The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D₃ as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B₁₂, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3. Analyzed chemical composition of experimental diets (as-fed basis)

Item, %	Brewers rice	FFRB ¹	DFRB ¹	Peanut meal	Sesame meal	Rapeseed meal	Rapeseed expellers	Soybean expellers	Cassava meal	Bakery meal
DM	87.81	93.34	91.21	91.82	94.34	91.46	91.57	93.02	90.62	91.93
CP	6.40	5.48	6.85	19.88	24.02	15.50	14.34	16.88	1.69	10.88
Indispensable AA										
Arg	0.53	0.45	0.57	2.12	2.70	0.88	0.87	1.20	0.16	0.51
His	0.14	0.15	0.19	0.44	0.57	0.39	0.39	0.44	0.03	0.25
Ile	0.26	0.19	0.24	0.65	0.85	0.62	0.59	0.76	0.05	0.44
Leu	0.52	0.38	0.49	1.24	1.53	1.07	1.03	1.29	0.08	0.86
Lys	0.24	0.27	0.33	0.67	0.60	0.83	0.88	1.07	0.06	0.37
Met	0.16	0.11	0.14	0.19	0.71	0.30	0.29	0.23	0.02	0.16
Phe	0.32	0.23	0.29	0.94	1.02	0.61	0.59	0.83	0.05	0.50
Thr	0.22	0.21	0.26	0.52	0.81	0.69	0.65	0.66	0.05	0.38
Trp	0.08	0.07	0.09	0.19	0.36	0.20	0.19	0.22	0.02	0.12
Val	0.37	0.30	0.38	0.79	1.06	0.79	0.75	0.79	0.06	0.50
Dispensable AA										
Ala	0.34	0.34	0.43	0.77	1.07	0.67	0.64	0.73	0.08	0.48
Asp	0.58	0.49	0.62	2.18	1.84	1.13	1.09	1.89	0.13	0.85
Cys	0.14	0.12	0.14	0.24	0.47	0.33	0.36	0.26	0.02	0.18
Glu	1.07	0.77	0.97	3.58	4.34	2.44	2.42	2.84	0.29	2.33
Gly	0.29	0.31	0.39	1.14	1.15	0.78	0.74	0.72	0.06	0.43
Pro	0.27	0.23	0.31	0.84	0.83	0.90	0.87	0.85	0.06	0.81
Ser	0.32	0.25	0.32	0.93	1.03	0.66	0.63	0.86	0.06	0.51

¹FFRB = full fat rice bran; DFRB = defatted rice bran.

in each test ingredient because the test ingredient was the sole source of CP and AA in the diet. Concentrations of standardized ileal digestible CP and AA (g/kg DM) were calculated for each ingredient by multiplying the concentration of CP and AA by the SID value for CP or each AA (Cervantes-Pahm et al., 2014).

Homogeneity of variances was confirmed using the UNIVARIATE procedure (SAS Inst., Cary, NC). Outliers were tested using the BOXPLOT procedure and 1 outlier was detected as an observation that deviated from the treatment mean by ± 3 times the interquartile range and removed from the data set. Data were analyzed using the MIXED

procedure (SAS Inst. Inc., Cary, NC). The model included ingredient as the fixed effect and pig and period as random effects. Mean values were calculated using the LSMeans statement, and differences among treatments were detected using the PDIF option. The pig was the experimental unit and differences were considered significant if $P < 0.05$.

RESULTS

The AID of CP in sesame meal, peanut meal, rapeseed meal, rapeseed expellers, and soybean expellers was between 64.3% and 79.4% (Table 4). The AID of CP in brewers rice was less ($P < 0.05$) than in sesame meal, but greater ($P < 0.05$) than in FFRB, DFRB, and bakery meal. Except for the AID of Thr, Trp, and Ala, no differences were observed for the AID of AA among brewers rice, sesame meal, and peanut meal. Likewise, there were no differences in AID of AA among rapeseed meal, rapeseed expellers, and soybean expellers. The AID of total AA was greater in sesame meal, brewers rice, and peanut meal compared with FFRB, DFRB, cassava meal, and bakery meal. Cassava

meal had the least ($P < 0.05$) AID of CP and AA followed by bakery meal.

The SID of CP was greater ($P < 0.05$) in brewers rice (93.7%) compared with DFRB (67.6%), cassava meal (30.2%), and bakery meal (65.0%), but no differences were observed among the other ingredients (Table 5). The SID of AA in brewers rice, peanut meal, and sesame meal was not different, with the exception that the SID of Met was less ($P < 0.05$) in peanut meal than in sesame meal and the SID of Trp was less ($P < 0.05$) in peanut meal than in brewers rice. The SID of most AA was greater ($P < 0.05$) in brewers rice than in FFRB, rapeseed meal, rapeseed expellers, and soybean expellers, but no differences were observed in SID of AA among FFRB, rapeseed expellers, and soybean expellers. The SID of Arg and Lys was greater ($P < 0.05$) in DFRB than in bakery meal, but for all other AA, no differences between DFRB and bakery meal were observed. The SID of Arg, Ile, Leu, Lys, Met, Ala, Asp, and Glu was greater ($P < 0.05$) in FFRB than in DFRB. The SID of CP and all indispensable AA was least ($P < 0.05$) in cassava meal compared with the other 9 ingredients, with the exception that the

Table 4. Apparent ileal digestibility (%) of CP and AA in test ingredients¹

Item	Brewers rice	FFRB ²	DFRB ²	Peanut meal	Sesame meal	Rapeseed meal	Rapeseed expellers	Soybean expellers	Cassava meal	Bakery meal	SEM	P - value
CP	61.8 ^b	43.3 ^c	36.6 ^c	73.9 ^{ab}	79.4 ^a	64.3 ^{ab}	64.7 ^{ab}	69.3 ^{ab}	-94.3 ^d	45.3 ^c	7.50	<0.001
Indispensable AA												
Arg	86.2 ^{bc}	78.7 ^{de}	74.7 ^e	90.5 ^{ab}	94.3 ^a	81.3 ^{cd}	82.3 ^{cd}	84.4 ^{bcd}	28.3 ^g	62.3 ^f	2.66	<0.001
His	80.1 ^{ab}	73.1 ^{bc}	66.1 ^c	80.4 ^{ab}	89.0 ^a	81.2 ^{ab}	81.7 ^{ab}	79.6 ^{ab}	-41.3 ^d	63.0 ^e	3.95	<0.001
Ile	78.7 ^{abc}	60.8 ^d	53.1 ^d	82.2 ^{ab}	86.4 ^a	75.0 ^{bc}	71.8 ^c	74.9 ^{bc}	-29.7 ^e	61.2 ^d	3.53	<0.001
Leu	83.4 ^{ab}	65.6 ^{de}	57.6 ^e	84.2 ^{ab}	87.6 ^a	78.0 ^{abc}	74.5 ^{bcd}	75.4 ^{bcd}	-29.7 ^f	68.6 ^{cd}	3.53	<0.001
Lys	75.1 ^{ab}	71.7 ^{bc}	63.1 ^c	78.6 ^{ab}	79.4 ^{ab}	76.5 ^{ab}	79.3 ^{ab}	83.8 ^a	-1.6 ^e	38.7 ^d	3.48	<0.001
Met	86.6 ^{ab}	72.9 ^{de}	62.8 ^f	82.4 ^{bc}	93.3 ^a	84.8 ^{bc}	83.5 ^{bc}	78.4 ^{cd}	4.3 ^g	68.6 ^{ef}	2.5	<0.001
Phe	81.5 ^{abc}	58.3 ^{ef}	49.6 ^f	84.7 ^{ab}	87.7 ^a	76.5 ^{abcd}	71.0 ^{cde}	74.6 ^{bcd}	-67.6 ^g	66.1 ^{de}	4.9	<0.001
Thr	63.6 ^b	45.6 ^c	41.7 ^c	71.5 ^{ab}	78.6 ^a	67.5 ^{ab}	64.5 ^b	68.7 ^{ab}	-86.9 ^d	42.8 ^c	4.91	<0.001
Trp	73.3 ^b	58.3 ^{cd}	52.2 ^{de}	69.7 ^{bc}	85.3 ^a	69.2 ^{bc}	65.4 ^{bc}	66.8 ^{bc}	-27.0 ^f	45.5 ^e	4.26	<0.001
Val	81.3 ^{ab}	64.7 ^{cd}	58.2 ^d	81.5 ^{ab}	85.8 ^a	73.5 ^{bc}	70.3 ^c	72.0 ^{bc}	-32.3 ^e	58.2 ^d	3.81	<0.001
Mean	80.4 ^{abc}	66.4 ^d	59.5 ^d	83.7 ^{ab}	88.2 ^a	76.3 ^{bc}	74.9 ^c	77.0 ^{bc}	-19.0 ^e	59.4 ^d	2.95	<0.001
Dispensable AA												
Ala	72.5 ^b	61.8 ^{cd}	54.9 ^{de}	77.0 ^{ab}	81.7 ^a	70.9 ^b	69.4 ^{bc}	70.7 ^b	-36.5 ^f	47.6 ^e	3.11	<0.001
Asp	77.0 ^{ab}	61.0 ^{cd}	52.7 ^d	80.3 ^a	82.3 ^a	69.6 ^{bc}	71.9 ^{ab}	77.2 ^{ab}	-27.7 ^e	51.8 ^d	3.84	<0.001
Cys	77.9 ^a	57.5 ^{bcd}	47.7 ^{cd}	69.6 ^{ab}	82.1 ^a	69.4 ^{ab}	72.7 ^{ab}	59.5 ^{bc}	-84.4 ^e	42.4 ^d	5.96	<0.001
Glu	84.3 ^{ab}	72.7 ^c	63.6 ^d	83.9 ^{ab}	87.7 ^a	81.8 ^{ab}	83.4 ^{ab}	80.1 ^{bc}	22.4 ^e	74.0 ^e	2.83	<0.001
Gly	31.8 ^{ab}	17.1 ^{ab}	24.4 ^{ab}	59.3 ^{ab}	64.6 ^a	56.5 ^{ab}	52.2 ^{ab}	50.5 ^{ab}	-326.2 ^c	8.3 ^b	21.66	<0.001
Pro	-141.7 ^a	-230.0 ^a	-94.2 ^a	10.5 ^a	-5.4 ^a	53.5 ^a	-8.3 ^a	-9.2 ^a	-988.7 ^b	-46.4 ^a	151.31	<0.001
Ser	74.7 ^{ab}	54.2 ^{de}	50.1 ^e	77.8 ^{ab}	83.9 ^a	67.7 ^{bc}	66.3 ^{bcd}	72.4 ^{ab}	-83.4 ^f	56.3 ^{de}	4.66	<0.001
Mean	55.6 ^{abc}	32.7 ^c	38.4 ^{bc}	71.4 ^{ab}	76.2 ^a	67.9 ^{ab}	62.9 ^{abc}	65.0 ^{abc}	-118.0 ^d	45.4 ^{abc}	14.37	<0.001
Total AA	67.8 ^{abc}	55.0 ^{bc}	56.3 ^{bc}	77.0 ^a	82.2 ^a	71.5 ^{ab}	68.5 ^{abc}	71.0 ^{ab}	-73.1 ^d	51.8 ^c	7.89	<0.001

^{a-h}Values within a row lacking a common superscript letter are different ($P < 0.05$).

¹Data are least squares means of 8 observations for each treatment.

²FFRB = full fat rice bran; DFRB = defatted rice bran.

Table 5. Standardized ileal digestibility (%) of CP and AA in test ingredients^{1,2}

Item	Brewers rice	FFRB ³	DFRB ³	Peanut meal	Sesame meal	Rapeseed meal	Rapeseed expellers	Soybean expellers	Cassava meal	Bakery meal	SEM	P-value
CP	93.7 ^a	82.9 ^{ab}	67.6 ^{bc}	84.6 ^a	88.5 ^a	78.0 ^{abc}	79.6 ^{abc}	82.1 ^{ab}	30.2 ^d	65.0 ^c	7.50	<0.001
Indispensable AA												
Arg	98.6 ^a	94.3 ^{ab}	86.7 ^c	93.7 ^{ab}	96.9 ^a	89.1 ^{bc}	90.1 ^{bc}	90.2 ^{bc}	71.8 ^d	75.7 ^d	2.66	<0.001
His	93.2 ^a	86.4 ^{ab}	76.4 ^{bc}	85.0 ^{ab}	92.6 ^a	86.3 ^{ab}	86.8 ^{ab}	84.2 ^{ab}	29.0 ^d	71.1 ^c	3.95	<0.001
Ile	91.7 ^a	79.2 ^b	67.3 ^d	87.5 ^{ab}	90.6 ^a	80.6 ^b	77.7 ^{bc}	79.6 ^b	40.5 ^e	69.2 ^{cd}	3.53	<0.001
Leu	93.8 ^a	80.6 ^{cd}	69.2 ^e	88.8 ^{abc}	91.4 ^{ab}	83.3 ^{bcd}	80.0 ^{cd}	79.8 ^{cd}	43.9 ^f	75.2 ^{de}	3.53	<0.001
Lys	87.0 ^a	82.9 ^a	72.0 ^b	83.0 ^a	84.5 ^a	80.0 ^{ab}	82.6 ^a	86.6 ^a	43.5 ^e	46.6 ^c	3.48	<0.001
Met	92.1 ^{ab}	81.9 ^c	69.6 ^d	87.3 ^{bc}	94.7 ^a	88.0 ^{abc}	86.8 ^{bc}	82.6 ^c	53.1 ^e	74.5 ^d	2.5	<0.001
Phe	93.6 ^a	76.1 ^{cde}	63.5 ^e	89.0 ^{abc}	91.8 ^{ab}	81.9 ^{abcd}	77.9 ^{cd}	79.5 ^{bcd}	17.2 ^f	74.2 ^{de}	4.85	<0.001
Thr	95.1 ^a	81.7 ^{abc}	69.4 ^{cd}	85.4 ^{ab}	87.8 ^{ab}	78.1 ^{bc}	75.8 ^{bcd}	79.8 ^{bc}	46.3 ^e	62.2 ^d	4.91	<0.001
Trp	92.2 ^a	81.8 ^{abc}	70.4 ^{cd}	78.5 ^{bc}	90.0 ^{ab}	77.3 ^c	73.9 ^c	74.4 ^c	40.7 ^e	59.8 ^d	4.26	<0.001
Val	93.6 ^a	81.1 ^{bcd}	70.9 ^{de}	87.6 ^{abc}	90.4 ^{ab}	79.6 ^{cd}	76.7 ^{de}	78.1 ^{cde}	41.7 ^f	67.7 ^e	3.81	<0.001
Mean	93.7 ^a	83.6 ^b	72.8 ^c	88.9 ^{ab}	92.1 ^a	82.5 ^b	81.2 ^b	82.4 ^b	48.4 ^d	69.1 ^c	2.95	<0.001
Dispensable AA												
Ala	91.2 ^a	82.2 ^b	70.5 ^c	85.8 ^{ab}	88.1 ^{ab}	80.9 ^b	79.9 ^b	80.1 ^b	45.4 ^e	61.6 ^d	3.11	<0.001
Asp	91.1 ^a	78.6 ^b	66.4 ^c	84.2 ^{ab}	87.0 ^{ab}	77.1 ^b	79.7 ^b	81.7 ^{ab}	39.5 ^d	61.8 ^c	3.84	<0.001
Cys	96.5 ^a	80.3 ^{abc}	66.8 ^{cd}	80.7 ^{abc}	87.9 ^{ab}	77.5 ^{bc}	80.1 ^{abc}	70.1 ^{cd}	27.0 ^e	57.4 ^d	5.96	<0.001
Glu	93.3 ^a	86.0 ^{ab}	73.9 ^d	86.7 ^{ab}	90.1 ^{ab}	85.9 ^{ab}	87.5 ^{ab}	83.6 ^{bc}	57.0 ^e	78.3 ^{cd}	2.83	<0.001
Gly	98.3 ^a	84.8 ^a	76.8 ^{ab}	77.2 ^{ab}	82.8 ^a	82.3 ^a	79.5 ^a	79.2 ^a	25.3 ^b	55.1 ^{ab}	21.66	0.300
Pro	116.8 ^a	98.3 ^a	142.8 ^a	97.8 ^a	84.6 ^a	134.7 ^a	75.6 ^a	77.8 ^a	297.6 ^a	43.3 ^a	151.31	1.000
Ser	95.9 ^a	82.4 ^{bcd}	71.6 ^d	85.3 ^{abc}	90.9 ^{ab}	78.2 ^{bcd}	77.3 ^{cd}	80.6 ^{bcd}	35.7 ^e	70.0 ^d	4.66	<0.001
Mean	96.3 ^a	85.0 ^a	78.6 ^a	84.6 ^a	88.4 ^a	86.4 ^a	81.8 ^a	81.0 ^a	66.2 ^a	68.3 ^a	14.37	0.800
Total AA	95.3 ^a	90.2 ^a	83.5 ^{ab}	86.7 ^{ab}	90.4 ^a	84.1 ^{ab}	81.4 ^{ab}	81.9 ^{ab}	57.7 ^c	69.1 ^{bc}	7.89	<0.006

^{a-f}Values within a row lacking a common superscript letter are different ($P < 0.05$).

¹Data are least squares means of 8 observations for each treatment.

²Standardized ileal digestibility values were calculated by correcting values for apparent ileal digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined as (g/kg DMI): CP, 23.23; Arg, 0.74; His, 0.22; Ile, 0.38; Leu, 0.62; Lys, 0.32; Met, 0.10; Phe, 0.44; Thr, 0.79; Trp, 0.18; Val, 0.52; Ala, 0.73; Asp, 0.93; Cys, 0.30; Glu, 1.09; Gly, 2.21; Pro, 7.95; and Ser, 0.76.

³FFRB = full fat rice bran; DFRB = defatted rice bran.

SID of Lys was not different between cassava meal and bakery meal.

The concentration of standardized ileal digestible CP and indispensable AA was greater ($P < 0.05$) in sesame meal than in all other ingredients, except for the concentration of standardized ileal digestible Lys, Phe, and Asp (Table 6). With the exception of Lys, Met, and Thr, peanut meal had greater ($P < 0.05$) concentration of standardized ileal digestible indispensable AA than all other ingredients except sesame meal. Soybean expellers had the greatest ($P < 0.05$) concentration of standardized ileal digestible Lys with 22.98 g/kg DM followed by rapeseed meal (16.17 g/kg DM) and rapeseed expellers (16.11 g/kg DM). Cassava meal and bakery meal had the least ($P < 0.05$) concentration of standardized ileal digestible CP and most AA compared with the other 8 ingredients. The concentration of standardized ileal digestible CP and AA in brewers rice, FFRB, and DFRB were less ($P < 0.05$) compared with rapeseed meal, rapeseed expellers, and soybean expellers. The concentration

of standardized ileal digestible CP and AA in brewers rice was less ($P < 0.05$) than in FFRB and DFRB, but greater ($P < 0.05$) concentrations of standardized ileal digestible Arg, His, Met, Val, Ala, and Ser were observed in FFRB compared with DFRB.

DISCUSSION

Nutrient Composition of Ingredients

The nutrient composition of the rice coproducts used in this experiment agree with previous values (NRC, 2012; Casas et al., 2015). Concentrations of starch and P in peanut meal were in agreement with values reported by Knabe et al. (1989) and Li et al. (2014), but the concentration of Ca, fiber, and AEE in peanut meal was slightly less than reported by Li et al., 2014. Concentrations of fat, starch, and Ca in sesame meal used in this experiment were less than reported values, but the content of NDF and

Table 6. Concentration (g/kg DM) of standardized ileal digestible CP and AA in test ingredients^{1,2}

Item	Brewers rice	FFRB ³	DFRB ³	Peanut meal	Sesame meal	Rapeseed meal	Rapeseed expellers	Soybean expellers	Cassava	Bakery meal	SEM	P-value
CP	73.87 ^a	112.19 ^f	119.50 ^f	452.38 ^b	482.32 ^a	286.64 ^d	262.74 ^e	351.33 ^c	6.93 ^h	76.63 ^g	9.75	<0.001
Indispensable AA												
Arg	6.52 ^h	10.74 ^g	12.56 ^f	56.81 ^b	62.46 ^a	19.77 ^d	18.04 ^e	27.83 ^c	1.89 ^j	4.47 ⁱ	0.35	<0.001
His	1.77 ^h	3.20 ^g	3.72 ^f	9.78 ^b	11.92 ^a	8.12 ^d	7.40 ^e	9.19 ^c	0.11 ⁱ	3.85 ^f	0.13	<0.001
Ile	2.90 ^g	3.78 ^{ef}	4.10 ^e	14.93 ^b	17.30 ^a	12.02 ^c	10.08 ^d	15.13 ^b	0.31 ^h	3.28 ^{fg}	0.2	<0.001
Leu	5.71 ^h	7.50 ^{fg}	8.37 ^f	28.57 ^b	31.35 ^a	21.39 ^d	18.05 ^e	25.20 ^c	0.47 ⁱ	7.05 ^e	0.32	<0.001
Lys	2.71 ^f	5.31 ^e	5.80 ^e	14.55 ^c	11.51 ^d	16.11 ^b	16.17 ^b	22.98 ^a	0.39 ^h	1.77 ^g	0.24	<0.001
Met	1.93 ^g	2.25 ^f	2.43 ^e	4.65 ^d	15.45 ^a	6.61 ^b	5.61 ^c	4.82 ^d	0.15 ⁱ	1.35 ^h	0.07	<0.001
Phe	3.58 ^g	4.33 ^f	4.67 ^f	22.17 ^a	21.12 ^b	12.04 ^d	10.03 ^e	16.27 ^c	0.10 ^h	4.03 ^{fg}	0.26	<0.001
Thr	2.57 ^f	4.05 ^e	4.57 ^e	11.58 ^c	16.10 ^a	12.96 ^b	10.77 ^d	12.91 ^b	0.40 ^g	2.53 ^f	0.22	<0.001
Trp	0.97 ^f	1.40 ^e	1.59 ^e	4.10 ^{bc}	7.36 ^a	3.90 ^c	3.30 ^d	4.18 ^b	0.16 ^g	0.78 ^f	0.08	<0.001
Val	4.36 ^g	5.91 ^f	6.72 ^e	18.18 ^b	21.66 ^a	15.34 ^c	12.70 ^d	15.46 ^c	0.39 ^h	3.72 ^g	0.24	<0.001
Dispensable AA												
Ala	4.02 ^h	6.76 ^g	7.58 ^f	16.85 ^b	21.17 ^a	12.95 ^d	11.11 ^e	14.17 ^c	0.56 ^j	3.12 ⁱ	0.25	<0.001
Asp	6.44 ^g	9.47 ^f	10.11 ^f	47.99 ^a	35.76 ^c	21.00 ^d	18.69 ^e	37.79 ^b	0.68 ^h	5.63 ^g	0.49	<0.001
Cys	1.80 ^f	2.38 ^e	2.42 ^e	5.26 ^c	9.50 ^a	6.70 ^b	6.40 ^b	4.57 ^d	0.07 ^h	1.22 ^g	0.12	<0.001
Glu	12.36 ^h	16.06 ^g	17.77 ^g	81.78 ^b	87.20 ^a	52.28 ^d	45.04 ^e	61.52 ^c	2.62 ⁱ	20.34 ^f	0.93	<0.001
Gly	4.01 ^d	6.28 ^c	7.24 ^c	23.35 ^a	22.00 ^a	14.56 ^b	13.64 ^b	14.53 ^b	0.21 ^e	2.31 ^d	0.81	<0.001
Pro	6.20 ^d	7.82 ^{cd}	7.88 ^{cd}	25.74 ^a	14.94 ^{bc}	15.21 ^{bc}	21.03 ^{ab}	21.35 ^{ab}	3.91 ^d	5.27 ^d	4.49	<0.001
Ser	3.60 ^g	5.04 ^f	5.75 ^e	20.53 ^a	20.95 ^a	12.52 ^c	10.73 ^d	16.91 ^b	0.28 ^h	3.90 ^g	0.24	<0.001

^{a-i}Values within a row lacking a common superscript letter are different ($P < 0.05$).

¹Data are least squares means of 8 observations for each treatment.

²The concentration (g/kg DM) of standardized ileal digestible CP and AA was calculated by multiplying the concentration of CP and AA (DM basis) by the SID of CP and each AA.

³FFRB = full fat rice bran; DFRB = defatted rice bran.

P were greater (Li et al., 2000; NRC, 2012; Aguilera et al., 2015).

Concentrations of AEE and starch in rapeseed meal were within the range of reported values (NRC, 2012; Maison and Stein, 2014; Liu et al., 2016), but concentrations of TDF, ash, Ca, and P were greater than previous values (NRC, 2012; Maison and Stein, 2014; Liu et al., 2016). Rapeseed expellers contained more AEE than the sources used in previous experiments, but concentrations of ash, Ca, and P were within the range of reported values (NRC, 2012; Maison and Stein, 2014; Navarro et al., 2017). The reason for these differences among different sources of rapeseed meal and rapeseed expellers is most likely that the gums from oil purification sometimes is added to the meal or expellers, which will increase the concentration of analyzed AEE, and different efficiencies in oil pressing may also result in different quantities of oil left in rapeseed expellers. In general, concentrations of AEE is more variable in oilseed expellers than in oilseed meals because of differences among crushing plants in the efficiency of mechanically pressing out the oil (Stein et al., 2016).

Concentrations of AEE, starch, ash, Ca, and P in soybean expellers are in agreement with published

values (NRC, 2012). The concentration of ash, Ca, and P in cassava meal and bakery meal were also in agreement with reported values (NRC, 2012), but the concentration of starch was less, whereas the content of AEE and fiber was greater, than in previous reports (Sonaiya and Omole, 1983; NRC, 2012; Casas et al., 2015).

The concentration of CP in brewers rice, FFRB, DFRB, rapeseed meal, rapeseed expellers, soybean expellers, and bakery meal were slightly lower than previous values, but concentrations of AA were within the range of published values (Almeida et al., 2011; Rostagno et al., 2011; NRC, 2012; Maison and Stein, 2014; Casas et al., 2015; Liu et al., 2016). In contrast, concentrations of CP and most AA in peanut meal and sesame meal were greater than values reported by Knabe et al. (1989), Li et al. (2014), and NRC (2012), but in agreement with values reported by Aguilera et al. (2015). These differences are likely due to differences in growing and processing conditions (Li et al., 2014; Aguilera et al., 2015). As expected, cassava meal had the least concentration of CP and AA, but the values are within the range reported previously (Sonaiya and Omole, 1983; NRC, 2012).

Ileal Digestibility of Crude Protein and Amino Acids

Most digestibility values in feed ingredient tables have been determined in growing-finishing pigs between 20 and 100 kg, but as has recently been demonstrated for soybean meal, SID values determined in pigs that are less than 20 kg may be less than values determined in heavier pigs (Pedersen et al., 2016). It is, therefore, possible that diets for young pigs may be more accurately formulated if SID values determined in young pigs are used.

Brewers rice, FFRB, and DFRB are coproducts from the rice milling industry that may be used in diets for pigs (Casas et al., 2015) and combined, these ingredients contribute the 5th largest quantity of ingredients in the global swine feed industry. Positive responses on growth performance of weanling pigs were reported if rice or rice coproducts were included in the diets (Chae and Lee, 2002; Campos et al., 2006; Herfel et al., 2013; Casas and Stein, 2016). Values for SID of CP and AA in brewers rice obtained in this experiment were slightly less than values obtained in growing-finishing pigs (Casas et al., 2015). However, the greater SID of CP and AA observed in brewers rice compared with most other ingredients used in this experiment agree with previous data (Brestenský et al., 2013; Cervantes-Pahm et al., 2014; Casas et al., 2015). The greater SID of CP and AA in brewers rice may be attributed to the low concentration of fiber, which reduces the specific endogenous losses of CP and AA (Souffrant, 2001). Full-fat rice bran and DFRB have a greater concentration of CP and AA compared with brewers rice, but FFRB and DFRB also contain more TDF than brewers rice, which is likely the main reason for the reduced SID of AA in FFRB and DFRB compared with brewers rice. The SID of most AA in FFRB and DFRB were less in this experiment compared with previous data obtained using growing pigs (Kaufmann et al., 2005; Casas et al., 2015). The greater SID of CP and AA in FFRB than in DFRB is also in agreement with Casas et al. (2015) and is likely a consequence of the greater concentration of fat in FFRB compared with DFRB, because increased concentration of oil results in increased digestibility of AA and CP (Cervantes-Pahm and Stein, 2008).

Limited research has been conducted in the United States to determine SID of AA in peanut meal and sesame meal fed to pigs. However, the SID values determined in the current experiment are greater than the average values for 10 Chinese peanut meals fed to growing pigs (Li et al.,

2014) indicating that U.S. peanut meal may have a greater nutritional value than Chinese peanut meal. Processing of peanut meal involves heating and AA in peanut meal, therefore, are susceptible to heat damage (Zhang and Parsons, 1996). However, the SID of Lys in peanut meal used in the current experiment was 83.7%, which is greater than the maximum SID of Lys (80.9%) in peanut meals reported by Li et al. (2014). Also, the peanut meal used in the current experiment had a Lys:CP ratio of 3.3, indicating that the peanut meal used in the current experiment was not heat damaged.

The SID of AA in sesame meal was greater than previous data obtained in young pigs (Aguilera et al., 2015), but due to the limited data base for the SID of AA in sesame meal, it is not possible to determine the reason for this difference. The concentration of standardized ileal digestible Met, Thr, and Trp was greater in sesame meal compared with all other ingredients used in the current experiment, indicating that inclusion of sesame meal in pig diets will contribute to meeting requirements for these AA.

Rapeseed and canola represent approximately 13% of global oilseed meal production (USDA, 2013). Rapeseed meal is produced by a procedure known as prepress solvent extraction, which involves cooking, pressing, and extraction with an organic solvent, usually hexane. As a consequence, the concentration of oil in rapeseed meal is usually less than 3% (Newkirk, 2011). The process to produce rapeseed expellers also involves prepress oil extraction, but solvent extraction is not used to extract residual oil and instead, a second mechanical press is used to remove additional oil. However, the mechanical press process is less efficient in oil removal than solvent extraction, resulting in a greater concentration of residual oil in rapeseed expellers compared with rapeseed meal (Newkirk, 2011). Values for SID of CP and AA observed in this experiment for both rapeseed meal and rapeseed expellers are in agreement with values determined in young pigs by Navarro et al. (2017), but are greater than some values obtained in growing pigs (González-Vega and Stein, 2012; NRC, 2012; Maison and Stein, 2014; Berrocoso et al., 2015). It has been reported that rapeseed expellers have greater SID of AA than rapeseed meal (Maison and Stein, 2014), but in this experiment there were no differences in the SID of CP or AA between rapeseed meal and rapeseed expellers.

The SID of CP and AA in soybean expellers used in the current experiment is in agreement with previous data (Opapeju et al., 2006; NRC, 2012)

and the current data confirm that soybean expellers is an excellent source of standardized ileal digestible CP and AA and because of the greater oil concentration compared with soybean meal, soybean expellers also provide more NE to the diets (Velayudhan et al., 2015).

Bakery meal is a mixture of inedible products from the bakery and confectionary industries and often is included in pig diets as a palatable and highly digestible energy source (Slominski et al., 2004). Variability in digestibility of AA among batches of bakery meal is expected because the raw materials in the mixtures vary depending on which commodities are available (Almeida et al., 2011). The bakery meal used in the current experiment had reduced SID of CP and AA compared with values obtained in growing-finishing pigs (Almeida et al., 2011; Casas et al., 2015). Processing of bakery meal also includes a drying step, which makes AA in bakery meal susceptible to heat damage and, therefore, bakery meal often has a low SID of Lys (Almeida et al., 2011), which was also observed in this experiment. In addition, the SID of Lys in the bakery meal used in this experiment was less than the SID of Thr, which further indicates that this source of bakery meal was heat damaged.

Cassava meal is typically included in swine diets as an energy source because it has a high concentration of starch, whereas the concentration of CP and AA in cassava meal is very low. To our knowledge, this is the first experiment in which the SID of CP and AA in cassava meal fed to young pigs has been reported. The values obtained in this experiment are less than values reported by NRC (2012) and indicate that cassava meal has a very low protein value for pigs.

In conclusion, peanut meal and sesame meal have greater concentrations of standardized ileal digestible CP and most AA, with the exception of Lys, compared with the other ingredients included in this experiment. Rapeseed meal, rapeseed expellers, and soybean expellers are also excellent sources of standardized ileal digestible CP and AA, especially Lys. Full-fat rice bran and DFRB are better sources of standardized ileal digestible CP and AA compared with brewers rice, but although FFRB has greater SID of most AA compared with DFRB, the concentration of standardized ileal digestible AA is not different between FFRB and DFRB. Bakery meal and cassava meal have low concentrations of standardized ileal digestible AA and, therefore, these ingredients mainly provide energy to diets fed to pigs.

Conflict of interest statement. None declared.

LITERATURE CITED

- Adeola, O., P. C. Xue, A. J. Cowieson, and K. M. Ajuwon. 2016. Basal endogenous losses of amino acids in protein nutrition research for swine and poultry. *Anim. Feed Sci. Technol.* 221:274–283. doi:10.1016/j.anifeedsci.2016.06.004
- Aguilera, A., T. C. Reis de Souza, G. Mariscal-Landín, K. Escobar, S. Montaña, and M. G. Bernal. 2015. Standardized ileal digestibility of proteins and amino acids in sesame expeller and soya bean meal in weaning piglets. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 99:728–736. doi:10.1111/jpn.12278
- Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. *J. Anim. Sci.* 89:4109–4115. doi:10.2527/jas.2011-4143
- AOAC Int. 2007. Official methods of analysis of AOAC int. 18th ed. 2nd rev.ed. AOAC Int., Gaithersburg, MD.
- Berrococo, J. D., O. J. Rojas, Y. Liu, J. Shoulders, J. C. Gonzalez-Vega, and H. H. Stein. 2015. Energy concentration and amino acid digestibility in high-protein canola meal, conventional canola meal, and soybean meal fed to growing pigs. *J. Anim. Sci.* 93:2208–2217. doi:10.2527/jas.2014-8528
- Brestenský, M., S. Nitravová, P. Patráš, and J. Heger. 2013. Standardized ileal digestibilities of amino acids and nitrogen in rye, barley, soybean meal, malt sprouts, sorghum, wheat germ and broken rice fed to growing pigs. *Anim. Feed Sci. Technol.* 186:120–124. doi:10.1016/j.anifeedsci.2013.09.006
- de Campos, R. M. L., E. Hierro, J. A. Ordoñez, T. M. Bertol, and L. Hoz. 2006. A note on partial replacement of maize with rice bran in the pig diet on meat and backfat fatty acids. *J. Anim. Feed Sci.* 15:427–433. doi:10.22358/jafs/66913/2006
- Casas, G. A., J. A. S. Almeida, and H. H. Stein. 2015. Amino acid digestibility in rice co-products fed to growing pigs. *Anim. Feed Sci. Technol.* 207:150–158. doi:10.1016/j.anifeedsci.2015.05.024
- Casas, G. A., and H. H. Stein. 2016. Effects of full fat or defatted rice bran on growth performance and blood characteristics of weanling pigs. *J. Anim. Sci.* 94:4179–4187. doi:10.2527/jas.2016-0565
- Cervantes-Pahm, S. K., Y. Liu, and H. H. Stein. 2014. Digestible indispensable amino acid score and digestible amino acids in eight cereal grains. *Br. J. Nutr.* 111:1663–1672. doi:10.1017/S0007114513004273
- Cervantes-Pahm, S. K., and H. H. Stein. 2008. Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs. *J. Anim. Sci.* 86:1841–1849. doi:10.2527/jas.2007-0721
- Chae, B. J., and S. K. Lee. 2002. Rancid rice bran affects growth performance and pork quality in finishing pigs. *Asian-Aust J Anim Sci.* 15:94–101. doi:10.5713/ajas.2002.94
- González-Vega, J. C., and H. H. Stein. 2012. Amino acid digestibility in canola, cottonseed, and sunflower products fed to finishing pigs. *J. Anim. Sci.* 90:4391–4400. doi:10.2527/jas.2011-4631
- Herfel, T., S. Jacobi, X. Lin, E. van Heugten, V. Fellner, and J. Odle. 2013. Stabilized rice bran improves weaning pig performance via a prebiotic mechanism. *J. Anim. Sci.* 91:907–913. doi:10.2527/jas.2012-5287
- Hess, V., and B. Sève. 1999. Effects of body weight and feed intake level on basal ileal endogenous losses in growing

- pigs. *J. Anim. Sci.* 77:3281–3288.
- Kaufmann, C., W. C. Sauer, M. Cervantes, Y. Zhang, J. H. M. Rademacher, and J. K. Htoo. 2005. Amino acid and energy digestibility in different sources of rice bran for growing pigs. *Can. J. Anim. Sci.* 85. doi:10.4141/a04-084
- Kim, B. G., and T. Kim. 2010. A program for making completely balanced Latin Square designs employing a systemic method. *Rev. Colomb. Cienc. Pecu.* 23:277–282.
- Knabe, D. A., D. C. LaRue, E. J. Gregg, G. M. Martinez, and J. T. D. Tanksley. 1989. Apparent digestibility of nitrogen and amino acids in protein feedstuffs by growing pigs. *J. Anim. Sci.* 67:441–458. doi:10.2527/jas1989.672441x
- Li, Q., X. Piao, J. Liu, Z. Zeng, S. Zhang, and X. Lei. 2014. Determination and prediction of the energy content and amino acid digestibility of peanut meals fed to growing pigs. *Arch. Anim. Nutr.* 68:196–210. doi:10.1080/1745039X.2014.910970
- Li, D., S. Y. Qiao, G. F. Yi, J. Y. Jiang, X. X. Xu, X. S. Piao, I. K. Han, and P. Thacker. 2000. Performance of growing-finishing pigs fed sesame meal supplemented diets formulated using amino acid digestibilities determined by the regression technique. *Asian Australas. J. Anim. Sci.* 13:213–219. doi:10.5713/ajas.2000.213
- Lindemann, M. D., S. G. Cornelius, S. M. el Kandelgy, R. L. Moser, and J. E. Pettigrew. 1986. Effect of age, weaning and diet on digestive enzyme levels in the piglet. *J. Anim. Sci.* 62:1298–1307.
- Liu, Y., N. W. Jaworski, O. J. Rojas, and H. H. Stein. 2016. Energy concentration and amino acid digestibility in high protein canola meal, conventional canola meal, and in soybean meal fed to growing pigs. *Anim. Feed Sci. Technol.* 212:52–62. doi:10.1016/j.anifeedsci.2015.11.017
- Maison, T., and H. H. Stein. 2014. Digestibility by growing pigs of amino acids in canola meal from north america and 00-rapeseed meal and 00-rapeseed expellers from europe. *J. Anim. Sci.* 92:3502–3514. doi:10.2527/jas.2014-7748
- Moter, V., and H. H. Stein. 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs. *J. Anim. Sci.* 82:3518–3525. doi:10.2527/2004.82123518x
- Navarro, D. M. D. L., Y. Liu, T. S. Bruun, and H. H. Stein. 2017. Amino acid digestibility by weanling pigs of processed ingredients originating from soybeans, 00-rapeseeds, or a fermented mixture of plant ingredients. *J. Anim. Sci.* 95:2658–2669. doi:10.2527/jas.2016.1356
- Newkirk, R. 2011. Meal nutrient composition. In: J. K. Daun, A. M. Neskin, and D. Hickling, editors, *Canola - chemistry, production, processing and utilization*. AOCS Press, Urbana, IL. p. 229–244.
- NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C.
- Opapeju, F. O., A. Golian, C. M. Nyachoti, and L. D. Campbell. 2006. Amino acid digestibility in dry extruded-expelled soybean meal fed to pigs and poultry. *J. Anim. Sci.* 84:1130–1137. doi:10.2527/2006.8451130x
- Pedersen, C., J. S. Almeida, and H. H. Stein. 2016. Analysis of published data for standardized ileal digestibility of protein and amino acids in soy proteins fed to pigs. *J. Anim. Sci.* 94:340–343. doi:10.2527/jas.2015-9864
- Rostagno, H. S., L. F. T. Albino, J. L. Donzele, P. C. Gomes, R. F. de Oliveira, D. C. Lopes, A. S. Ferreira, S. L. T. Barreto, and R. F. Euclides. 2011. Brazilian tables for poultry and swine. Composition of feedstuffs and nutritional requirements. 3rd ed. Universidade Federal de Viçosa, Viçosa, Brazil.
- Slominski, B. A., D. Boros, L. D. Campbell, W. Guenter, and O. Jones. 2004. Wheat by-products in poultry nutrition. Part I. Chemical and nutritive composition of wheat screenings, bakery by-products and wheat mill run. *Can. J. Anim. Sci.* 84:421–428. doi:10.4141/A03-112
- Sonaiya, E. B., and T. A. Omole. 1983. Cassava meal and cassava peel meal in diets for growing pigs. *Anim. Feed Sci. Technol.* 8:211–220. doi:10.1016/0377-8401(83)90085-8
- Souffrant, W. B. 2001. Effect of dietary fibre on ileal digestibility and endogenous nitrogen losses in the pig. *Anim. Feed Sci. Technol.* 90:93–102. doi:10.1016/S0377-8401(01)00199-7
- Stein, H. H., S. P. Connot, and C. Pedersen. 2009. Energy and nutrient digestibility in four sources of distillers dried grains with solubles produced from corn grown within a narrow geographical area and fed to growing pigs. *Asian-Australas. J. Anim. Sci.* 22:1016–1025. doi:10.5713/ajas.2009.80484
- Stein, H. H., L. V. Lagos, and G. A. Casas. 2016. Nutritional value of feed ingredients of plant origin fed to pigs. *Anim. Feed Sci. Technol.* 218:33–69. doi:10.1016/j.anifeedsci.2016.05.003
- Stein, H. H., B. Sève, 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. doi:10.2527/jas.2005-742
- Urbaityte, R., R. Mosenthin, and M. Eklund. 2009. The concept of standardized ileal amino acid digestibilities: principles and application in feed ingredients for piglets. *Asian-Australas. J. Anim. Sci.* 22:1209–1223. doi:10.5713/ajas.2009.80471
- USDA. 2013. Soybean and oil crops, Canola, <http://www.ers.usda.gov/topics/crops/soybeans-oil-crops> (Accessed 10 August 2017.)
- Velayudhan, D. E., J. M. Heo, and C. M. Nyachoti. 2015. Net energy content of dry extruded-expelled soybean meal fed with or without enzyme supplementation to growing pigs as determined by indirect calorimetry. *J. Anim. Sci.* 93:3402–3409. doi:10.2527/jas.2014-8514.
- Zhang, Y. E., and C. M. Parsons. 1996. Effects of overprocessing on the nutritional quality of peanut meal. *Poult. Sci.* 75:514–518. doi:10.3382/ps.0750514