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Nutrient digestibility of lentil and regular- and low-oligosaccharide, micronized full-fat soybean fed to grower pigs[1]

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ABSTRACT: A study was conducted to determine the standardized ileal digestibility (SID) of AA and calculate the NE value for regular-oligosaccharide, micronized full-fat soybean (R-MFFSB), low-oligosaccharide, micronized full-fat soybean (LO-MFFSB), lentil, and enzymatically hydrolyzed casein (EHC) for growing pigs. Six ileal-cannulated barrows (31.4 kg BW) were fed 6 diets in a 6 × 6 Latin square. Five diets were cornstarch based, containing either soybean meal (SBM), R-MFFSB, LO-MFFSB, or EHC as sole protein source or N free. The sixth diet contained lentil as sole protein and energy source. The SID of AA for diets was calculated using the N-free diet. Digestibility of AA in feedstuffs was determined by the direct method. Energy digestibility in SBM, R-MFFSB, and LO-MFFSB was determined by difference from the N-free diet whereas energy digestibility in lentil was determined by the direct method. On DM basis, SBM, R-MFFSB, LO-MFFSB, and lentil contained 52, 43, 43, and 27% CP, 8, 12, 14, and 16% NDF, and 1.8, 19, 21, and 1.6% ether extract, respectively. The SID of Lys for SBM was greater ($P < 0.05$) than that for R-MFFSB or LO-MFFSB (76 vs. 79 and 79%). The SID of other indispensable AA (except Trp) for SBM was also greater ($P < 0.05$) than that for R-MFFSB or LO-MFFSB. The R-MFFSB and LO-MFFSB were similar in SID of AA. The SID of Lys for lentil (81%) was lower ($P < 0.05$) than that for SBM with a similar trend for SID of other indispensable AA except for Met and Thr whose SID was similar to SBM. The SID of AA for EHC ranged from 98 to 112%. The SBM had a lower ($P < 0.05$) NE value than R-MFFSB or LO-MFFSB (2.63 vs. 2.95 and 3.00 Mcal/kg DM). Lentil and SBM were similar in NE value (2.60 vs. 2.63 Mcal/kg DM). In conclusion, R-MFFSB and LO-MFFSB were similar in energy and AA value for pigs. Lentil had lower SID of AA than SBM. However, lentil and SBM were similar in NE value; therefore, lentil can serve as alternative pulse feedstuff for pigs. The AA in EHC were mostly completely digested indicating that EHC can be fed to estimate ileal endogenous AA losses.

Key words: amino acid, digestibility, energy, full-fat soybean, lentil, pig

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INTRODUCTION

Soybean meal (**SBM**) and full-fat soybean (**FFSB**) are excellent sources of AA for pigs. However, consumption of soybean by nonruminant species can be limited by the presence of oligosaccharides, which can cause flatulency, diarrhea, and reduced nutrient digestibility (Clarke and Wiseman, 2000). Therefore, plant breeders have developed low-oligosaccharide soybean cultivars. However, information on the nutritive value of low-oligosaccharide FFSB for pigs is limited. Specifically, the AA digestibility of low-oligosaccharide FFSB for pigs has been determined

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in one study (Baker et al., 2010) whereas concurrent information on energy digestibility and value of low-oligosaccharide FFSB for pigs is lacking.

Lentil, a pulse seed, is produced mainly for human consumption. Lentil may contain 25% CP and 40% starch (Landero et al., 2012) and thus serves as protein and energy source in pig diets when lentil is not destined for human consumption. Up to 22.5% lentil can be included in diets for nursery pigs without reducing growth performance (Landero et al., 2012). However, the AA digestibility and NE values for lentil fed to pigs have not been reported.

Amino acid availability in swine feedstuffs is better defined using standardized ileal digestibility (**SID**) than apparent ileal digestibility (**AID**; Stein et al., 2007). The SID of AA is derived from AID of AA by correction for basal endogenous AA losses. These losses are typically estimated by feeding an N-free diet or highly digestible protein such as enzymatically hydrolyzed casein (**EHC**). However, whether AA of EHC are completely digested at the terminal ileum is unclear.

The objective of the present study was to determine the NE values and SID of AA of regular-oligosaccharide, micronized FFSB (**R-MFFSB**), low-oligosaccharide, micronized FFSB (**LO-MFFSB**), and lentil. We also determined the SID of AA of EHC fed to grower pigs.

MATERIALS AND METHODS

Experimental procedures were reviewed and approved by the University of Alberta Animal Care and Use Committee for Livestock. Pigs were handled in accordance with the guidelines described by the Canadian Council on Animal Care (CCAC, 2009).

Experimental Animals

Six crossbred barrows (initial BW of 31.4 ± 1.5 kg; Duroc × Large White/Landrace F1; Genex Hybrid, Hypor, Regina, SK, Canada) were surgically fitted with a T-cannula at the distal ileum (Sauer and Ozimek, 1986). Pigs were housed individually in metabolism pens (1.2 by 1.2 m) that allowed freedom of movement in a temperature-controlled room (22 ± 2°C). Pens had plastic-coated expanded metal floor, polyvinyl chloride walls (0.9 m high) fitted with Plexiglas windows (0.3 by 0.3 m), a single-space dry feeder, and a nipple drinker.

Experimental Diets

Diets included cornstarch-based diets with SBM, R-MFFSB, LO-MFFSB, or EHC as the sole source of protein, a lentil-based diet with lentil as the sole source of protein and energy, and a N-free diet (Table 1). The SBM was included as a reference in the study. Diets contained 0.4% Cr_2O_3 as an indigestible marker. The ratio of cornstarch to sugar and canola oil in SBM, R-MFFSB, and LO-MFFSB diets was identical to the N-free diet to allow calculation of energy digestibility of SBM, R-MFFSB, and LO-MFFSB using the difference method (Stein et al., 2006). The EHC diet was formulated to contain 10% EHC similar to other studies feeding an EHC diet to pigs to estimate ileal endogenous AA losses (e.g., Butts et al., 1993; Deglaire et al., 2007). The SBM, R-MFFSB, and LO-MFFSB fed were obtained (Nutreco Canada Inc., Guelph, ON, Canada). The R-MFFSB and LO-MFFSB had been micronized in a custom-built micronizer (Jones Feed Mills Ltd, Linwood, ON, Canada). The micronization involved 3 steps: 1) soaking of soybean to 18 to 20% moisture, 2) cooking of soaked soybean with infrared radiant energy at approximately 105°C for 50 s, and 3) flaking of cooked soybean followed by steeping and cooling. Lentil fed, which was red and feed grade, was obtained (Gowans Feed Consulting, Wainwright, AB, Canada) and not heat treated before use. Both MFFSB and lentil were ground through a 2.8-mm screen in a Jacobson hammer mill (Carter Day International, Minneapolis, MN) before use. The SBM was used as obtained.

Experimental Design and Procedure

The experiment was conducted as a 6 × 6 Latin square design to obtain 6 observations per diet. Each period consisted of 9 d: the first 5 d for adaptation followed subsequently by 2 d of fecal collection and 2 d of ileal digesta collection. Pigs were fed diets at 3 times maintenance energy requirement (3 × 110 kcal of DE/kg of $BW^{0.75}$; NRC, 2012) based on BW at the beginning of each period, which translated to 0.082, 083, 0.083, 0.082, 0.081, and 0.082 kg dietary DM intake per kilogram of $BW^{0.75}$ for SBM-, R-MFFSB-, LO-MFFSB-, lentil-, and EHC-based diets and N-free diet, respectively. Daily feed allowance was offered in 2 equal portions at 0800 and 1500 h. Feces were collected continuously in plastic bags fitted around the anus that were replaced a minimum of 2 times per day (van Kleef et al., 1994). Ileal digesta was collected continuously for 10 h from 0800 to 1800 h daily (Seneviratne et al., 2010). Collected feces and digesta were pooled for each pig and period and stored frozen at –20°C.

Sample Preparation and Chemical Analyses

Digesta and feces for each pig and period were thawed, homogenized, subsampled, and freeze-dried. Diet, feedstuffs (SBM, R-MFFSB, LO-MFFSB, and lentil), lyophilized digesta, and feces were ground in centrifugal mill (Retch model ZMI; Brinkman Instruments, Rexdale, ON, Canada) through a 1-mm screen. The feedstuffs were analyzed for CP (method 984.13A-D), AA

Table 1. Ingredient composition and nutrient content of diets fed in the study[1]

	Diet					
Item	SBM	R-MFFSB	LO-MFFSB	Lentil	N free	EHC
Ingredient, %						
Cornstarch	55.15	47.29	47.29	–	85.50	77.43
Soybean meal	36.50	–	–	–	–	–
R-MFFSB	–	45.00	–	–	–	–
LO-MFFSB	–	–	45.00	–	–	–
Lentil	–	–	–	96.30	–	–
Hydrolyzed casein	–	–	–	–	–	10.00
Sucrose	3.25	2.79	2.79	–	5.00	4.48
Cellulose	–	–	–	–	3.00	3.00
Canola oil	1.30	1.12	1.12	–	2.00	1.79
Limestone	1.20	1.20	1.20	1.10	1.00	0.50
Monodicalcium phosphate	0.80	0.80	0.80	0.80	1.20	0.50
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.50	0.50	0.50	0.50	0.50	0.50
Mineral premix[3]	0.50	0.50	0.50	0.50	0.50	0.50
KCO_3, 56% K	–	–	–	–	0.40	0.40
MgO, 58% Mg	–	–	–	–	0.10	0.10
Analyzed composition						
DM, %	90.7	91.6	92.0	89.2	90.5	90.7
CP, % DM	18.7	19.0	20.2	25.6	0.58	9.84
Indispensable AA, % DM						
Arg	1.24	1.06	1.22	1.20	0.00	0.25
His	0.48	0.44	0.44	0.51	0.00	0.25
Ile	1.20	0.79	0.90	0.85	0.00	0.56
Leu	1.71	1.20	1.39	1.18	0.00	0.91
Lys	1.48	0.98	1.10	1.14	0.00	0.78
Met	0.38	0.31	0.33	0.39	0.00	0.33
Phe	1.23	0.90	0.94	0.93	0.00	0.52
Thr	0.76	0.66	0.70	0.66	0.00	0.29
Trp	0.25	0.28	0.30	0.07	0.28	0.09
Val	1.00	0.93	0.97	0.86	0.00	0.68
Dispensable AA, % DM						
Ala	0.79	0.69	0.71	0.73	0.00	0.26
Asp	2.14	1.97	1.89	1.33	0.00	0.68
Cys	0.22	0.23	0.25	0.20	0.00	0.02
Glu	3.04	2.65	2.45	2.00	0.00	1.90
Gly	0.90	0.83	0.91	0.65	0.00	0.18
Ser	0.88	0.82	0.79	0.75	0.00	0.42
Tyr	0.72	0.39	0.39	0.40	0.00	0.29

[1]SBM = soybean meal; R-MFFSB = regular, micronized full-fat soybean; LO-MFFSB = low-oligosaccharide, micronized full-fat soybean; EHC = enzymatically hydrolyzed casein.

[2]Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 0.2 mg; and vitamin B_{12}, 0.025 mg.

[3]Provided the following per kilogram of diet: Zn, 100 mg (as $ZnSO_4$); Fe, 80 mg (as $FeSO_4$); Cu, 50 mg (as $CuSO_4$); Mn, 25 mg (as $MnSO_4$); I, 0.5 mg [as $Ca(IO_3)_2$]; and Se, 0.1 mg (as Na_2SeO_3).

(method 982.30), ether extract (**EE**; method 920.39A), ADF (method 973.18), crude fiber (method 978.10), ash (method 942.05), Ca (method 968.08), and P (method 946.06) as per AOAC Int. (2006) and NDF (Holst, 1973). Feedstuffs were analyzed for trypsin inhibitor activity (**TIA**; amount of trypsin inhibited per unit weight of sample; method NEN-EN-ISO 14902:2001; NEN, 2001) and total tannin by Folis-Denis method (Kirk and Sawyer, 1998; Nutrilab BV, Giessen, The Netherlands). The SBM, R-MFFSB, and LO-MFFSB were analyzed for sucrose as described by Janauer and Englmaier (1978) at the University of Missouri (Columbia, MO). The R-MFFSB and LO-MFFSB were analyzed for stachyose and raffinose using HPLC (Agilent Technologies, Chesterfield, MO; Dierking and Bilyeu, 2008) at the National Soybean Research Laboratory (Urbana, IL).

Diets, digesta, and feces were analyzed for DM (method 930.15; AOAC Int., 2006) and for Cr_2O_3 by spectrophotometry (model 80-2097-62, KBUltraspec III; Pharmacia, Cambridge, UK) at 440 nm after ashing at 450°C overnight (Fenton and Fenton, 1979). Gross energy of diets, feedstuffs, digesta, and feces was analyzed using an adiabatic bomb calorimeter (model 5003; IKAWerke GmbH & Co. KG, Staufen, Germany); benzoic acid was used as a standard. Diets and digesta were analyzed for CP (method 984.13A-D; AOAC Int., 2006). Diets and digesta were analyzed for AA using a HPLC (Shimadzu, Columbia, MD) coupled with a fluorichrome detector with precolumn derivatization, using fluoraldehyde as the reagent (Sedgwick et al., 1991). For all AA except Cys, Met, and Trp, the samples were hydrolyzed with 6 *M* HCl for 24 h at 110°C before injection. A β-amino-*n*-butyric acid and ethanol amine mixture was used as the internal standard. The Cys content was determined as cysteic acid, and Met content was determined as Met sulfone after oxidation with performic acid before hydrolyzing with 6 *M* HCl. The Trp content was analyzed accordingly (method 982.30E; AOAC Int., 2006).

Calculations

The AID and apparent total tract digestibility (**ATTD**) of the diets were calculated using the indicator method (Eq. [2]; Stein et al., 2007). Each pig fed the N-free diet was used to calculate its basal endogenous AA losses (Eq. [3]; Stein et al., 2007). The SID for the AA in diets was calculated using AID corrected for basal endogenous AA losses from either N-free diet (Eq. [7]; Stein et al., 2007). The AID and SID of AA in feedstuffs was determined by the direct method. The AID and ATTD of energy for SBM, R-MFFSB, and LO-MFFSB were calculated by the difference method (Adeola, 2001) using the N-free diet as the basal diet whereas the AID and ATTD of energy for lentil were calculated by the direct method. The DE values of feedstuffs were calculated by multiplying GE by ATTD. The NE values of feedstuffs (kcal/kg DM) were predicted from the determined DE (kcal/kg of DM) values and analyzed macronutrient content (g/kg of DM) of feedstuffs using the following Eq. [5] that was developed by Noblet et al. (1994) and adopted as Eq. [1] to [18] by NRC (2012):

$$\text{NE} = 0.700 \times \text{DE} + 1.61 \times \text{EE} + 0.48 \times \text{starch} - 0.91 \times \text{CP} - 0.87 \times \text{ADF}$$

Statistical Analyses

Data were subjected to analysis of variance using the MIXED procedure (SAS Inst. Inc., Cary, NC) with pig and period as random terms. Treatment (feedstuff) means were separated by the probability of difference. To test the hypotheses, $P < 0.05$ was considered significant.

Table 2. Analyzed composition (on a DM basis) of feedstuffs

	Feedstuff[1]			
Item	SBM	R-MFFSB	LO-MFFSB	Lentil
DM, %	90.1	92.9	92.8	88.7
GE, Mcal/kg	4.73	5.59	5.59	4.52
CP, %	52.3	43.2	43.4	27.4
Ether extract, %	1.78	19.1	20.6	1.63
NDF, %	7.93	12.1	13.5	15.6
ADF, %	5.26	8.26	9.89	6.72
Crude fiber, %	3.06	4.50	4.78	4.10
Ash, %	6.71	4.96	5.30	2.98
Ca, %	0.27	0.19	0.28	0.10
P, %	0.78	0.58	0.64	0.47
Starch, %	0.19	0.53	0.35	28.6
Indispensable AA, %				
Arg	3.81	3.55	3.05	2.00
His	1.32	1.14	1.06	0.62
Ile	2.33	1.96	1.83	1.08
Leu	3.93	3.30	3.11	1.92
Lys	3.30	2.76	2.64	1.75
Met	0.70	0.57	0.56	0.19
Phe	2.57	2.17	2.02	1.29
Thr	1.93	1.61	1.60	0.93
Trp	0.80	0.54	0.61	0.18
Val	2.48	1.95	2.19	1.21
Dispensable AA, %				
Ala	2.21	1.80	1.71	1.23
Asp	5.78	4.85	4.46	2.92
Cys	0.80	0.68	0.69	0.29
Glu	9.18	7.53	6.91	3.98
Gly	2.15	1.80	1.71	1.08
Pro	2.63	2.28	2.11	1.21
Ser	2.34	1.81	1.86	1.21
Tyr	1.88	1.42	1.38	0.86
Lys, % CP	6.30	6.38	6.08	6.38
Trypsin inhibitor activity, mg/g	6.21	3.23	4.31	2.48
Tannin, %	0.74	0.87	0.81	0.96
Sucrose, %	6.91	5.31	5.81	–
Stachyose, %	–	5.23	1.95	–
Raffinose, %	–	0.57	0.14	–

[1]SBM = soybean meal; R-MFFSB = regular, micronized full-fat soybean; LO-MFFSB = low-oligosaccharide, micronized full-fat soybean.

RESULTS

The R-MFFSB and LO-MFFSB were similar in CP, GE, EE, AA, and tannin contents and Lys to CP ratio (Table 2). As expected, LO-MFFSB contained less oligosaccharides (stachyose and raffinose) than R-MFFSB. However, LO-MFFSB contained more NDF, ADF, TIA, and sucrose than R-MFFSB. The SBM contained more CP, AA, and TIA but less GE, EE, NDF, ADF, and tannin

Table 3. Apparent ileal and total tract digestibility of energy and DE value for diets and apparent ileal digestibility of AA, CP, and energy and apparent total tract digestibility of energy and DE and NE values for feedstuffs[1]

	Feedstuff						
Item	SBM	R-MFFSB	LO-MFFSB	Lentil	EHC	SEM[2]	*P*-value
Diets							
AID of energy, %	78.8[b]	68.4[c]	67.4[c]	69.8[c]	91.3[a]	1.63	<0.001
ATTD of energy, %	94.4[a]	86.6[b]	86.7[b]	83.8[b]	94.8[a]	0.64	<0.001
DE,[3] Mcal/kg of DM	4.05[a]	4.10[a]	4.07[a]	3.71[b]	4.00[a]	0.03	<0.001
Feedstuffs							
AID, %							
Indispensable AA							
Arg	90.7[a]	68.3[c]	71.6[c]	82.0[b]	75.2[bc]	2.71	<0.001
His	89.9[a]	71.9[c]	69.6[c]	82.0[b]	92.5[a]	2.43	<0.001
Ile	89.5[a]	58.2[c]	65.0[c]	76.3[b]	93.1[a]	2.63	<0.001
Leu	87.7[a]	57.9[c]	65.2[c]	74.6[b]	93.4[a]	2.66	<0.001
Lys	90.1[a]	71.7[b]	75.1[b]	76.8[b]	94.2[a]	3.67	0.001
Met	90.0[a]	61.8[c]	71.7[bc]	82.9[ab]	92.5[a]	3.90	<0.001
Phe	88.6[a]	62.9[c]	65.0[c]	77.7[b]	93.6[a]	2.56	<0.001
Thr	77.9[a]	53.5[c]	57.8[c]	69.1[ab]	73.9[a]	3.09	<0.001
Trp	83.6[a]	82.7[a]	78.3[a]	64.0[b]	76.7[a]	3.27	0.005
Val	83.1[b]	59.2[d]	62.6[cd]	70.2[c]	92.2[a]	2.58	<0.001
Dispensable AA							
Ala	82.3[a]	58.2[c]	60.5[c]	70.9[b]	77.2[a]	2.67	<0.001
Asp	84.6[a]	67.5[b]	64.6[b]	65.7[b]	87.7[a]	2.57	<0.001
Cys	73.9[a]	47.4[b]	62.5[ab]	62.9[ab]	16.2[c]	9.00	0.002
Glu	86.7[b]	69.8[c]	65.6[c]	72.7[c]	93.9[a]	2.50	<0.001
Gly	70.6[a]	44.4[b]	56.1[ab]	43.9[b]	7.92[c]	7.21	<0.001
Ser	83.6[a]	59.8[c]	62.2[c]	72.2[b]	85.8[a]	2.88	<0.001
Tyr	89.7[a]	54.4[c]	52.3[c]	69.8[b]	93.2[a]	4.35	<0.001
CP	74.6	65.7	65.4	76.4	80.8	4.22	0.080
Energy	67.1[a]	52.1[b]	50.4[b]	69.8[a]	–	3.58	0.006
ATTD, %							
Energy	94.1[a]	79.5[c]	79.7[c]	86.7[b]	–	1.21	<0.001
DE, Mcal/kg of DM	4.45[a]	4.44[a]	4.45[a]	3.91[b]	–	0.07	<0.001
NE,[4] Mcal/kg of DM	2.63[b]	2.95[a]	3.00[a]	2.60[b]	–	0.05	<0.001

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]AID = apparent ileal digestibility; ATTD = apparent total tract digestibility; SBM = soybean meal; R-MFFSB = regular, micronized full-fat soybean; LO-MFFSB = low-oligosaccharide, micronized full-fat soybean; EHC = enzymatically hydrolyzed casein.

[2]Based on 6 observations per feedstuff.

[3]The DE value for the N-free diet was 3.84 Mcal/kg DM.

[4]Calculated from the DE value and analyzed macronutrient content of feedstuffs using Eq. [5] developed by Noblet et al. (1994) and adopted as Eq. [1] to [18] by NRC (2012).

than R-MFFSB or LO-MFFSB. However, SBM and FFSB products were similar in the Lys to CP ratio.

Soybean meal had greater ($P < 0.05$; Table 3) AID and ATTD of energy than R-MFFSB or LO-MFFSB. Soybean meal, R-MFFSB, and LO-MFFSB were similar in DE value; however, SBM had lower ($P < 0.05$) NE value than R-MFFSB or LO-MFFSB. The R-MFFSB and LO-MFFSB were similar in AID and ATTD of energy and NE values. Lentil and SBM were similar in AID of energy; however, lentil had a lower ($P < 0.05$) ATTD of energy than SBM, resulting in a lower ($P < 0.05$) DE value for lentil than SBM. Lentil and SBM were similar in NE value.

The AID of AA (except Trp, Cys, and Gly) for SBM was greater ($P < 0.05$; Table 3) than that for R-MFFSB or LO-MFFSB, which were similar in AID of AA. The AID of Cys and Gly for SBM was also greater ($P < 0.05$) than that for R-MFFSB. However, SBM and LO-MFFSB were similar in AID of Cys and Gly. Also, SBM and the FFSB products were similar in AID of Trp.

The R-MFFSB and LO-MFFSB were similar in SID of AA (Table 4). The SID of AA (except Trp, Gly, and Cys) for SBM was greater ($P < 0.05$) than that for R-MFFSB or LO-MFFSB. The SBM and FFSB products were similar in SID of Trp Gly, and Cys. The SID of all AA (except Met, Thr, Cys, and Gly) for lentil was lower

Table 4. Standardized ileal digestibility (%) of AA for feedstuffs

Item	Feedstuff[1]					SEM[2]	*P*-value
	SBM	R-MFFSB	LO-MFFSB	Lentil	EHC		
Indispensable AA							
Arg	95.3[a]	73.6[c]	76.2[c]	86.7[b]	97.8[a]	3.09	<0.001
His	94.7[b]	77.1[d]	74.8[d]	86.5[c]	101.7[a]	2.34	<0.001
Ile	92.7[a]	63.1[c]	69.3[c]	80.9[b]	100.0[a]	2.64	<0.001
Leu	91.4[b]	63.1[d]	69.7[d]	80.0[c]	100.4[a]	2.66	<0.001
Lys	93.2[a]	76.4[b]	79.2[b]	80.7[b]	100.0[a]	3.74	<0.001
Met	94.8[a]	67.7[c]	77.2[bc]	87.6[ab]	98.1[a]	2.97	<0.001
Phe	91.7[b]	67.1[d]	69.0[d]	81.8[c]	100.9[a]	2.52	<0.001
Thr	87.9[b]	64.9[d]	68.7[d]	80.5[bc]	100.4[a]	3.18	<0.001
Trp	93.4[ab]	90.8[b]	87.1[b]	72.9[c]	104.8[a]	4.42	0.002
Val	88.6[b]	65.1[d]	68.3[d]	76.7[c]	100.3[a]	2.49	<0.001
Dispensable AA							
Ala	89.4[b]	66.3[d]	68.4[d]	78.7[c]	99.0[a]	2.70	<0.001
Asp	88.9[b]	72.2[c]	69.4[c]	72.6[c]	101.1[a]	2.45	<0.001
Cys	86.3[ab]	59.1[b]	73.7[b]	76.4[b]	112.3[a]	9.19	0.020
Glu	90.0[b]	73.5[cd]	69.7[d]	77.6[c]	99.1[a]	2.45	<0.001
Gly	90.9[b]	66.4[b]	76.0[b]	71.6[b]	111.0[a]	10.7	0.033
Ser	90.8[b]	67.5[d]	70.1[d]	80.5[c]	100.6[a]	2.78	<0.001
Tyr	92.7[b]	60.1[d]	58.0[d]	75.4[c]	100.9[a]	4.29	<0.001

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]SBM = soybean meal; R-MFFSB = regular, micronized full-fat soybean; LO-MFFSB = low-oligosaccharide, micronized full-fat soybean; EHC = enzymatically hydrolyzed casein.

[2]Based on 6 observations per feedstuff.

($P < 0.05$) than that for SBM. The SID of Met, Thr, Cys, and Gly for lentil were similar to those for SBM. The AA in EHC were highly digestible; the SID of AA for EHC ranged from 98 to 112%.

DISCUSSION

Soybean Meal

The nutrient composition, NDF, and Lys to CP ratio of SBM were similar to those reported in NRC (2012) for dehulled, solvent-extracted SBM. However, the TIA for SBM was greater than previous values (Clarke and Wiseman, 2005; Valencia et al., 2008; Frikha et al., 2012) for SBM that ranged from 1.7 to 4.2 mg/g. The ATTD of GE for SBM was close to the 91% calculated based on GE and DE values of SBM reported by Goebel and Stein (2011). The SID of indispensable AA for SBM were similar to those reported by Baker and Stein (2009), Baker et al. (2010), and NRC (2012). Therefore, the greater TIA for SBM fed in the present study did not affect its AA digestibility.

Regular Full-Fat Soybean

The CP, AA, EE, and NDF content and the Lys to CP ratio of R-MFFSB in the present study were similar to earlier values (NRC, 2012) for regular FFSB. The TIA of R-MFFSB in the present study was also within a range of earlier values (1.1 to 4.4 mg/g; Clarke and Wiseman, 2005; Valencia et al., 2008) for regular FFSB. Combined, the R-MFFSB fed in the present study had a composition similar to R-MFFSB or extruded regular FFSB that were fed in other studies. The R-MFFSB contained more NDF and tannin than SBM possibly because of the presence of hulls in FFSB. Soybean hulls contain more fiber (NRC, 2012) and tannin (Egounlety and Aworh, 2003) than cotyledons.

The ATTD of GE for R-MFFSB was close to that reported by Valencia et al. (2008) for regular FFSB fed to pigs. Both the AID and ATTD of GE were lower for R-MFFSB than SBM. Some of the factors that limit digestibility of energy-yielding nutrients in soybean products include TIA, tannins, and fiber. The TIA was greater for SBM than for R-MFFSB; hence, dietary TIA may not have caused the greater energy digestibility for SBM than R-MFFSB. However, SBM contained less tannin and NDF than R-MFFSB and these reductions could have caused the greater energy digestibility for SBM than R-MFFSB. However, the DE content for R-MFFSB was similar to that of SBM because R-MFFSB contained more EE than SBM, similar to the greater NE content for R-MFFSB than for SBM being because of the greater EE content in R-MFFSB. However, whether Eq. [5] developed by Noblet et al. (1994) to predict the NE value from the DE value and analyzed macronutrient content fits for FFSB products or lentil is unclear. Therefore, the reported NE values for the feedstuffs should be interpreted with caution.

The SID of AA for R-MFFSB were lower than those reported for regular FFSB fed to pigs by Baker et al. (2010) or NRC (2012). However, the SID of all AA for R-MFFSB were similar to those reported by Ayoade et al. (2012) for extruded regular FFSB fed to pigs, except the SID of Met and Cys that were greater for R-MFFSB. The SID of indispensable AA for regular FFSB reported by NRC (2012) have a large SD that ranges from 8.1 to 10.5%, implying that AA digestibility of FFSB can vary widely. The SID of most AA for R-MFFSB were lower than those for SBM, possibly due to SBM containing less tannin and NDF than R-MFFSB. Others also reported greater AA digestibility for SBM than for regular FFSB (Marty et al., 1994; Fan et al., 1995).

Low Oligosaccharide Full-Fat Soybean

The CP, AA, and EE contents for LO-MFFSB were similar to those for R-MFFSB whereas the sucrose, NDF, and ADF contents and TIA were greater for LO-MFFSB than for R-MFFSB. Similarly, the CP, AA, and EE contents were similar between extruded low-oligosaccharide FFSB and extruded regular FFSB whereas the sucrose, NDF, and ADF contents and TIA were greater for extruded low-oligosaccharide FFSB than for extruded regular FFSB (Baker et al., 2010). Therefore, breeding of soybean for low-oligosaccharide content produces FFSB that has greater sucrose, NDF, and ADF contents and TIA than regular FFSB.

The AID and ATTD of GE and DE and NE values for LO-MFFSB were similar to those for R-MFFSB, comparable to similar DE values for SBM derived from regular FFSB and low-oligosaccharide FFSB observed previously (Baker and Stein, 2009). The low oligosaccharide FFSB contains slightly more sucrose than regular FFSB; hence, low-oligosaccharide FFSB is expected to have a greater AID of GE than regular FFSB because digestibility of sucrose in the small intestine is greater than that of oligosaccharides. The slight increase in sucrose content in LO-MFFSB in the present study did not affect its energy value, but the lack of a sugar component in Eq. [5] (Noblet et al., 1994) may mask an increased NE value. Regardless, the energy value of FFSB for pigs may not change much because of breeding soybean with less oligosaccharides.

The SID of AA for the LO-MFFSB was similar to those for R-MFFSB. Similarly, extruded low-oligosaccharide FFSB and regular FFSB did not differ in SID of all AA (except Trp) in pigs (Baker et al., 2010). Finally, digestibility of some but not all AA differed marginally between SBM derived from regular FFSB and low-oligosaccharide FFSB (Baker and Stein, 2009). Therefore, like energy value, it appears that the reduction in oligosaccharide content of soybean through breeding has minimal effect on AA digestibility of soybean.

Lentil

The Lys to CP ratio of lentil fed in the present study was similar to that of lentil fed in our previous study (Landero et al., 2012). The contents of starch, NDF, CP, and indispensable AA (except Trp and Val) were lower whereas the EE content was greater for lentil fed in the present study than for lentil fed in this previous study. Notably, the lentil fed in the present study was red and feed grade, and it was green and food grade in the previous study. Therefore, the difference between these 2 lentil samples with regard to starch content might be due to differences in cultivar and quality. Lentil had lower CP and AA and greater NDF and ADF contents compared with SBM. Similarly, other pulses including faba bean and field pea have a lower CP and AA and greater NDF and ADF content than dehulled SBM (NRC, 2012; Woyengo and Nyachoti, 2012). In the present study, lentil contained more tannin and less TIA than dehulled SBM. Antinutritional factor content of lentil was similar to another lentil sample analyzed recently (1.14% tannin and 2.97 mg TIA/g; Landero et al., 2012). The tannin in legume seed, including soybean, are located mostly in the hull (Egounlety and Aworh, 2003), and the tannin detected in the dehulled SBM imply that not the entire soybean hull was removed.

Lentil, like other pulses, can be a good source of energy in swine diets because of its high starch content. Therefore, energy value of lentil requires definition. The ATTD of GE (86.7%) and DE content (3.91 Mcal/kg DM) of lentil in the present study was similar to the 85.7% calculated based on GE and DE content (3.86 Mcal/kg DM), respectively, of field pea reported previously (Stein et al., 2004). The AID of GE for lentil was similar to that for SBM. However, ATTD of GE for lentil was lower than that of SBM. Lentil fiber is more lignified than dehulled SBM fiber. Specifically, lentil contains 1.8% lignin (Khan et al., 2007) whereas dehulled SBM contains 0.5% lignin (NRC, 2001). Fiber fermentation is negatively correlated with fiber lignification. Therefore, the greater ATTD of GE for SBM than for lentil could have been due to the greater hind gut fermentation of fiber in SBM than in lentil.

The DE value for lentil was lower than that of SBM, which was due to the lower ATTD of GE for lentil than for SBM because lentil and SBM were similar in GE values. However, the NE value for lentil was similar to NE value of SBM, which was due to the lower protein and greater starch content in lentil than in SBM. The DE and NE values of lentil were close to the DE (3.91 Mcal/kg DM) and NE (3.03 Mcal/kg DM) values for corn (NRC, 2012). Corn is the most widely used energy source in practical swine diets. Therefore, lentil can be an excellent source of energy in swine diets.

Lentil, like other pulses, can be a good source of AA in swine diets because of its high content of protein. However, AA availability in lentil has not been reported. The SID of AA for lentil fed in the present study were close to previous data for field pea fed to growing pigs (Stein et al., 2004; Friesen et al., 2006). The SID of most AA for lentil were generally lower than those for SBM, which could have been due to the greater fiber and tannin contents for former than for the latter.

Enzymatically Hydrolyzed Casein

Standardized ileal digestibility is a better estimator of AA availability in feedstuffs used for formulating pig diets than AID (Stein et al., 2007). Basal ileal endogenous AA losses, which are used to estimate SID of AA, can be determined by several methods including feeding a N-free diet or a diet whose protein source is assumed to be 100% digestible (Nyachoti et al., 1997). The N-free diet is the most commonly used method for estimating basal endogenous AA losses (NRC, 2012); however, feeding this diet may cause an abnormal physiological function of the gastrointestinal tract (Nyachoti et al., 1997; Stein et al., 2007). Either intact or EHC has been used as protein source that is assumed to be 100% digestible. However, whether or not the casein is completely digested in the small intestine of pigs is unclear. In the present study, the SID of AA for the EHC was at least 98%, implying that AA in EHC were (almost) completely digested in the small intestine. The SID of Cys and Gly for EHC were high (112.3 and 111.0%, respectively), implying that the basal endogenous loss of these AA was greater for pigs were fed the N-free diet than those fed the EHC diet although the reason is unclear. Previously, the endogenous loss of Cys and Gly did not differ between pigs fed the N-free diet or casein-based diet (Butts et al., 1993; Zhang et al., 2002).

In conclusion, R-MFFSB and LO-MFFSB were similar in NE value and SID of most AA. However, the R-MFFSB or LO-MFFSB had greater NE value and lower SID of AA than SBM. Lentil and SBM were similar in NE content. However, lentil had lower SID of AA than SBM. Therefore, results from this study imply that variety of FFSB (regular vs. low oligosaccharide) may not notably affect the NE and SID of AA for micronized FFSB fed to pigs, and the micronized FFSB (regardless of their variety) are a better source of dietary energy but not AA for pigs than SBM. The results also imply that lentil can serve as an alternative feedstuff for pigs. The AA in EHC were (almost) completely digested, implying that EHC can serve to estimate basal ileal endogenous AA losses. Finally, 1 sample per feedstuff was evaluated in the present study, indicating that results may not be applicable to all their samples used in swine feed formulation. Therefore, research is required to determine the variation in the nutritive value among samples of R-MFFSB, LO-MFFSB, and lentil.

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