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Short communication

Amino acid digestibility in conventional, high-protein, or low-oligosaccharide varieties of full-fat soybeans and in soybean meal by weanling pigs

K.M. Baker[a], B.G. Kim[b], H.H. Stein[a,*]

[a] Department of Animal Sciences, University of Illinois, Urbana, IL 61801, USA
[b] Department of Animal Science and Environment, Konkuk University, Seoul 143-701, Republic of Korea

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ABSTRACT

An experiment was conducted to measure the digestibility of crude protein (CP) and amino acids (AA) by weanling pigs in full-fat soybeans (FFSB) produced from conventional (FFSB-CV), high-protein (FFSB-HP), or low-oligosaccharide (FFSB-LO) varieties of soybeans. A source of soybean meal (SBM) that was produced from a conventional variety of soybeans was also used in the experiment. Cornstarch-based diets containing FFSB-CV, FFSB-HP, FFSB-LO, or SBM as the sole source of AA were formulated. A nitrogen-free diet was used to determine basal ileal endogenous losses of AA. The coefficient of ileal standardized digestibility (CISD) of AA in the four ingredients was measured using 10 barrows (initial body weight: 10.1 ± 1.82 kg) that were equipped with a T-cannula in the distal ileum. The CISD of leucine, lysine, and phenylalanine in FFSB-CV was greater ($P<0.05$) than in SBM, but the CISD of AA in FFSB-HP and FFSB-LO were not different ($P>0.05$) from the CISD of AA in SBM. With the exception of methionine, tryptophan, and cysteine, no differences in CISD of AA among the three sources of FFSB were observed ($P>0.05$). It is concluded that the CISD of most AA in FFSB-HP and FFSB-LO are not different from the CISD of AA in FFSB-CV or in SBM, but FFSB-CV has a greater CISD of leucine, lysine, and phenylalanine than SBM if fed to weanling pigs.

1. Introduction

Soybeans can be fed to swine as full-fat soybeans (FFSB) or made into soybean meal (SBM). Full-fat soybeans contain approximately 370 g/kg crude protein (CP) and approximately 180 g/kg oil (Marty and Chavez, 1993). The coefficient of ileal standardized digestibility (CISD) of AA in FFSB-HP is greater than in SBM if fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008), and FFSB is an excellent source of amino acids (AA) and energy in poultry diets (Mateos, 1996). Performance of weanling pigs is also improved if FFSB rather than SBM is used (Kim and Kim, 1997).

Recently, new varieties of FFSB with increased protein concentration (FFSB-HP) or low concentration of oligosaccharide (FFSB-LO) compared with conventional FFSB (FFSB-CV) have been developed. The CISD of AA in FFSB-HP is similar to the

Abbreviations: AA, amino acids; CIAD, coefficient of ileal apparent digestibility; CISD, coefficient of ileal standardized digestibility; CP, crude protein; FFSB, full-fat soybeans; FFSB-CV, full-fat soybeans from a conventional variety of soybeans; FFSB-HP, full-fat soybeans from a high-protein variety of soybeans; FFSB-LO, full-fat soybeans from a low-oligosaccharide variety of soybeans; SBM, soybean meal.

* Corresponding author. Tel.: +1 217 333 0013; fax: +1 217 333 7088.
E-mail address: hstein@illinois.edu (H.H. Stein).

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Table 1
Analyzed energy and nutrient composition of ingredients (g/kg, as-fed basis unless otherwise indicated).

Item	Ingredient[a]			
	FFSB-CV	FFSB-HP	FFSB-LO	SBM
Dry matter	944	939	944	888
Gross energy (MJ/kg)	22.8	22.2	22.1	17.6
Crude protein	368	435	393	487
Ether extract	196	166	177	8
Calcium	3.1	2.8	3.6	4.4
Phosphorus	5.5	6.5	6.0	7.5
Neutral detergent fiber	82	78	103	64
Acid detergent fiber	62	54	75	40
Sucrose	53	48	58	63
Stachyose	37	39	14	47
Raffinose	10	5	1	9
Trypsin inhibitor activity (TIU/mg)	4.5	7.7	7.0	3.6
Indispensable amino acid				
Arginine	28.1	33.8	27.9	36.3
Histidine	10.4	11.5	10.2	13.1
Isoleucine	19.3	20.8	18.8	24.0
Leucine	30.4	33.9	30.1	38.8
Lysine	26.0	28.3	25.6	32.3
Methionine	6.0	6.4	5.6	7.3
Phenylalanine	19.9	22.4	19.6	25.4
Threonine	14.5	16.0	14.4	18.7
Tryptophan	6.4	6.2	6.1	7.2
Valine	20.3	22.1	19.6	25.3
Dispensable amino acid				
Alanine	17.3	18.6	16.6	21.9
Aspartic acid	44.3	50.5	44.5	56.6
Cysteine	6.2	6.6	6.5	7.3
Glutamic acid	68.8	79.3	68.3	88.1
Glycine	17.3	18.9	16.7	21.3
Proline	19.3	20.4	19.2	24.6
Serine	16.0	18.7	16.7	20.9
Tyrosine	13.9	15.4	14.0	17.7

[a] FFSB-CV = full-fat soybeans from a conventional variety of soybeans, FFSB-HP = full-fat soybeans from a high-protein variety of soybeans, FFSB-LO = full-fat soybeans from a low-oligosaccharide variety of soybeans, and SBM = conventional soybean meal.

CISD in FFSB-CV if fed to growing pigs (Cervantes-Pahm and Stein, 2008), but there is no information on the coefficient of ileal apparent digestibility (CIAD) or the CISD of CP and AA in FFSB-HP or FFSB-LO fed to weanling pigs. It was, therefore, the objective of this experiment to measure the ileal digestibility of AA by weanling pigs in FFSB-HP and FFSB-LO and to compare these values to values for FFSB-CV and SBM.

2. Materials and methods

2.1. Ingredients and diets

Three sources of FFSB and one source of SBM were used (Table 1). The FFSB sources were produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans (Schillinger Genetics Inc., Des Moines, IA, USA). The FFSB were extruded using an autogenous extruder (Model 600, Insta-Pro International, Des Moines, IA, USA) with a 0.8 cm die operating at a rate of 182 kg/h. The extruder temperature was between 149 and 157 °C. The SBM was produced from conventional soybeans (Rose Acre Farms Inc., Seymour, IN, USA). The soybeans used for the production of the SBM were de-hulled, but that was not the case for the soybeans used to produce the FFSB.

Five diets were prepared (Tables 2 and 3). Four of the diets contained one source of FFSB or SBM and starch, sugar, and soybean oil. The last diet was a nitrogen-free diet that was used to measure basal endogenous losses of AA and CP. All diets also contained 4 g/kg chromic oxide as an indigestible marker. Solka floc was included in the nitrogen-free diet (40 g/kg) to increase the concentration of crude fiber. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998).

2.2. Animals and experimental design

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Ten barrows with an initial body weight of 10.1 ± 1.82 kg were randomly allotted to a replicated 5 × 5 Latin square design with five diets and five periods balanced for first-order carryover effects (Kim and Stein, 2009). A

Table 2
Ingredient composition of experimental diets (g/kg, as-fed basis).

Ingredient	Diet				
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	Nitrogen-free
FFSB-CV	516.0	–	–	–	–
FFSB-HP	–	436.0	–	–	–
FFSB-LO	–	–	483.0	–	–
SBM	–	–	–	390.0	–
Cornstarch	347.5	426.0	380.5	472.0	680.0
Soybean oil	–	–	–	–	40.0
Sugar	100.0	100.0	100.0	100.0	200.0
Solka floc[a]	–	–	–	–	40.0
Limestone	9.0	9.5	9.5	10.0	12.0
Monocalcium phosphate	16.5	17.5	16.0	17.0	12.0
Magnesium oxide	–	–	–	–	1.0
Potassium carbonate	–	–	–	–	4.0
Chromic oxide	4.0	4.0	4.0	4.0	4.0
NaCl	4.0	4.0	4.0	4.0	4.0
Vitamin–mineral premix[b]	3.0	3.0	3.0	3.0	3.0

FFSB-CV = full-fat soybeans from a conventional variety of soybeans, FFSB-HP = full-fat soybeans from a high-protein variety of soybeans, FFSB-LO = full-fat soybeans from a low-oligosaccharide variety of soybeans, and SBM = conventional soybean meal.

[a] Fiber Sales and Development Corp. (Urbana, OH, USA).

[b] Provided per kg of diet: vitamin A, 11,128 IU; vitamin D_3, 2204 IU; vitamin E, 66 IU; vitamin K, 1.42 mg; thiamin, 0.24 mg; riboflavin, 6.58 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid, 23.5 mg; niacin, 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.

T-cannula was surgically installed in the distal ileum of each pig according to procedures adapted from Stein et al. (1998). Pigs were the offspring of line 337 boars that were mated to C 22 females (Pig Improvement Company, Hendersonville, TN, USA) and they were housed individually in pens (0.9 m × 1.8 m) that had fully slatted concrete floors. A feeder and a nipple drinker were installed in each pen.

2.3. Feeding and sample collection

All pigs were fed once daily at a level of 3.2 times the maintenance energy requirement (*i.e.*, 106 kcal ME/kg $BW^{0.75}$; NRC, 1998) as described by Chastanet et al. (2007) and water was available at all times throughout the experiment. Pig body weights were recorded at the beginning of each 7-d period and feed allowance for each pig was adjusted according to the recorded weights. The initial 5 d of each period were considered an adaptation period to the diet. Ileal digesta samples were

Table 3
Analyzed nutrient composition of experimental diets (g/kg, as-fed basis).

Item	Diet[a]				
	FFSB-CV	FFSB-HP	FFSB-LO	SBM	Nitrogen-free
Dry matter	927	919	926	902	853
Crude protein	202	208	196	216	7
Indispensable amino acid					
Arginine	14.8	15.1	16.4	16.4	0.1
Histidine	5.5	5.2	6.1	6.0	0.1
Isoleucine	10.0	9.3	10.9	10.7	0.1
Leucine	16.4	15.6	18.1	17.9	0.3
Lysine	13.8	12.9	15.2	14.7	0.2
Methionine	3.1	2.8	3.5	3.3	0.0
Phenylalanine	10.6	10.2	11.7	11.6	0.2
Threonine	7.9	7.5	8.8	8.8	0.1
Tryptophan	3.0	2.8	2.8	3.2	<0.4
Valine	10.6	9.9	11.5	11.3	0.2
Dispensable amino acid					
Alanine	9.2	8.6	10.2	10.0	0.2
Aspartic acid	23.7	23.1	26.9	26.1	0.2
Cysteine	3.3	2.9	3.7	3.4	0.0
Glutamic acid	36.7	36.6	41.0	40.7	0.7
Glycine	9.1	8.6	10.1	9.6	0.1
Proline	10.0	9.7	10.7	11.3	0.2
Serine	9.0	8.8	10.3	10.2	0.1
Tyrosine	6.6	6.3	7.4	7.3	0.1

[a] FFSB-CV = full-fat soybeans from a conventional variety of soybeans, FFSB-HP = full-fat soybeans from a high-protein variety of soybeans, FFSB-LO = full-fat soybeans from a low-oligosaccharide variety of soybeans, and SBM = conventional soybean meal.

collected for 8 h on days 6 and 7 as described by Stein et al. (1998). Briefly, a plastic bag was attached to the cannula barrel using a cable tie, and digesta flowing into the bag were collected. Bags were removed whenever they were filled with digesta, or at least once every 30 min. Collected samples were stored at −20 °C to prevent bacterial degradation of AA in the digesta.

2.4. Chemical analysis

The frozen ileal samples were allowed to thaw at room temperature, mixed within animal and diet, and a sub-sample was collected for chemical analysis. Ileal digesta samples were lyophilized and finely ground before chemical analysis. Samples of each source of FFSB, of SBM, and of each diet were collected at the time of mixing. Samples of each source of FFSB and of SBM were analyzed for gross energy using bomb calorimetry (Parr 6300 calorimeter, Parr Instruments Co., Moline, IL, USA), ether extract (method 920.39; AOAC, 2005), calcium (method 978.02; AOAC, 2005), phosphorus (method 946.06; AOAC, 2005), neutral detergent fiber (Holst, 1973), and acid detergent fiber (method 973.18; AOAC, 2005). Sucrose, stachyose, and raffinose were analyzed in these samples using the method described by Janauer and Englmaier (1978), and the concentration of trypsin inhibitors was also analyzed (method Ba 12-75; AOCS, 1998).

All samples of ingredients, diets, and ileal digesta were analyzed for dry matter (method 930.15; AOAC, 2005), CP (method 990.03; AOAC, 2005), and amino acids. Amino acids were analyzed on a Hitachi Amino Acid Analyzer Model L8800 (Hitachi High Technologies America, Inc., Pleasaton, CA, USA) using ninhydrin for post-column derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6N HCl for 24 h at 110 °C (method 982.30 E; AOAC, 2005). Methionine and cysteine were analyzed as methionine sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis. Tryptophan was determined after NaOH hydrolysis for 22 h at 110 °C. The concentrations of chromium in diets and ileal digesta were measured using an Inductive Coupled Plasma Atomic Emission Spectrometric method (method 990.08; AOAC, 2005) after nitric acid–perchloric acid wet ash sample preparation (method 968.088D; AOAC, 2005).

2.5. Calculations

The CIAD for CP and AA in samples obtained from feeding experimental diets were calculated. Because the three sources of FFSB and SBM were the only ingredients contributing CP and AA in each diet, the calculated CIAD values also represented the digestibility coefficients for these ingredients. Values for CIAD were calculated according to the following equation (Stein et al., 2007):

$$\mathrm{CIAD} = 1 - \frac{\mathrm{AA_{ileal}}}{\mathrm{AA_{diet}}} \times \frac{\mathrm{Cr_{diet}}}{\mathrm{Cr_{ileal}}}$$

where CIAD is the CIAD of an AA, AA_{ileal} is the concentration of that AA in the ileal digesta, AA_{diet} is the AA concentration of that AA in the diet, Cr_{diet} is the Cr concentration in the diet, and Cr_{ileal} is the Cr concentration in the ileal digesta. The CIAD of CP was determined using the same equation. All units for CP, AA, and Cr concentrations were expressed as g/kg.

The basal endogenous flow to the distal ileum of each AA was determined based on the flow obtained after feeding the nitrogen-free diet (Stein et al., 2007):

$$\mathrm{IAA_{end}} = \mathrm{AA_{ileal}} \times \frac{\mathrm{Cr_{diet}}}{\mathrm{Cr_{ileal}}}$$

where IAA_{end} is the basal endogenous loss of an AA (g/kg dry matter intake). The basal endogenous loss of CP was determined using the same equation.

The CISD of CP and AA were calculated by correcting the CIAD for the basal endogenous loss of CP and each AA using the following equation (Stein et al., 2007):

$$\mathrm{CISD_{AA}} = \mathrm{CIAD} + \frac{\mathrm{IAA_{end}}}{\mathrm{AA_{diet}}}$$

where $CISD_{AA}$ is the CISD of CP or each AA.

2.6. Statistical analysis

Data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC, USA). The model included diet as the fixed variable, and pig and period as the random variables. Outliers were identified using the UNIVARIATE procedure. Least squares means were calculated and the means were separated using the PDIFF option with Tukey's adjustment. The mean separation output was converted to letter groupings using a macro program (Saxton, 1998). The pig was the experimental unit and an alpha level of 0.05 was used to determine significant differences among means.

Table 4
Coefficient of ileal apparent digestibility of crude protein and amino acids in three sources of full-fat soybeans and conventional soybean meal fed to weanling pigs[a].

Item	Diet[b]				SEM[c]	P-value
	FFSB-CV	FFSB-HP	FFSB-LO	SBM		
Crude protein	0.850a	0.828ab	0.817ab	0.812b	0.0119	0.049
Indispensable amino acid						
Arginine	0.940	0.922	0.930	0.922	0.0066	0.106
Histidine	0.908a	0.883b	0.896ab	0.897ab	0.0067	0.048
Isoleucine	0.899a	0.873b	0.884ab	0.876ab	0.0071	0.035
Leucine	0.896a	0.870b	0.882ab	0.871ab	0.0073	0.034
Lysine	0.909a	0.880ab	0.899ab	0.879b	0.0083	0.023
Methionine	0.909a	0.876b	0.895ab	0.896ab	0.0072	0.013
Phenylalanine	0.905a	0.883ab	0.892ab	0.877b	0.0067	0.016
Threonine	0.834	0.800	0.825	0.825	0.0104	0.090
Tryptophan	0.894a	0.854b	0.841b	0.867ab	0.0078	<0.001
Valine	0.868a	0.835b	0.852ab	0.846ab	0.0087	0.038
Dispensable amino acid						
Alanine	0.854	0.818	0.846	0.825	0.0111	0.044
Aspartic acid	0.894a	0.874ab	0.890ab	0.862b	0.0081	0.022
Cysteine	0.829a	0.753b	0.806ab	0.819a	0.0179	0.010
Glutamic acid	0.912	0.889	0.899	0.877	0.0106	0.099
Glycine	0.779	0.732	0.771	0.739	0.0228	0.136
Proline	0.715	0.584	0.703	0.628	0.0983	0.342
Serine	0.876	0.847	0.865	0.859	0.0090	0.097
Tyrosine	0.897a	0.867b	0.880ab	0.881ab	0.0074	0.042

ab Values within a row lacking a common letter are different ($P < 0.05$).
[a] Data are means of 10 observations.
[b] FFSB-CV = full-fat soybeans from a conventional variety of soybeans, FFSB-HP = full-fat soybeans from a high-protein variety of soybeans, FFSB-LO = full-fat soybeans from a low-oligosaccharide variety of soybeans, and SBM = conventional soybean meal.
[c] SEM = standard error of the means.

3. Results

3.1. Nutrient composition

The concentration of CP and AA were greater in FFSB-HP and SBM compared with FFSB-CV and FFSB-LO (Table 1). Concentrations of ether extract, neutral detergent fiber, and acid detergent fiber were lower in SBM than in the three FFSB. The concentration of sucrose was lower in FFSB-HP compared with all other meals, but the concentration of stachyose and raffinose was lower in FFSB-LO compared with all other ingredients.

Among the FFSB, the concentration of stachyose was greatest in FFSB-HP and the concentration of raffinose was greatest in FFSB-CV. The concentration of ether extract was greatest in FFSB-CV compared with the other FFSB, but the concentration of neutral detergent fiber and acid detergent fiber was greater in FFSB-LO compared with the other 2 FFSB.

3.2. Amino acid digestibility

The CIAD of CP in FFSB-CV was greater ($P<0.05$) than in SBM (Table 4), but the CIAD of CP in FFSB-HP and FFSB-LO were not different from the CIAD of CP in FFSB-CV or in SBM ($P>0.05$). The CIAD of histidine, isoleucine, leucine, methionine, tryptophan, valine, cysteine, and tyrosine were greater in FFSB-CV than in FFSB-HP, but for all other AA, no differences between these 2 ingredients were observed ($P>0.05$).

There were no differences ($P>0.05$) in the CIAD of AA between FFSB-CV and FFSB-LO with the exception that the CIAD of tryptophan was greater ($P<0.05$) in FFSB-CV than in FFSB-LO. The CIAD of AA in FFSB-CV and in SBM were not different ($P>0.05$) with the exception that the CIAD of lysine, phenylalanine, and aspartic acid were greater ($P<0.05$) in FFSB-CV than in SBM. Likewise, no differences ($P>0.05$) in CIAD between FFSB-HP and SBM were observed except that the CIAD of cysteine was less in FFSB-HP than in SBM.

The CISD of CP in FFSB-CV was greater ($P<0.05$) than in SBM, but the CISD of CP in FFSB-HP and FFSB-LO were not different ($P>0.05$) from the CISD in FFSB-CV or SBM (Table 5). There were no differences ($P>0.05$) between FFSB-CV and FFSB-HP in the CISD of AA with the exception that the CISD of methionine, tryptophan, and cysteine were greater ($P<0.05$) in FFSB-CV than in FFSB-HP. The CISD of tryptophan was also greater ($P<0.05$) in FFSB-CV compared with FFSB-LO, but for all other AA, no differences ($P>0.05$) between these 2 ingredients were observed. Likewise, no differences between FFSB-HP and FFSB-LO were observed ($P>0.05$). The CISD of leucine, lysine, phenylalanine, and aspartic acid, but not for any other AA, was greater ($P<0.05$) in FFSB-CV than in SBM, but there were no differences ($P>0.05$) between SBM and FFSB-HP or between SBM and FFSB-LO.

Table 5
Coefficient of ileal standardized digestibility of crude protein and amino acids in three sources of full-fat soybeans and conventional soybean meal fed to weanling pigs[a,b].

Item	Diet[c]				SEM[d]	P-value
	FFSB-CV	FFSB-HP	FFSB-LO	SBM		
Crude protein	0.920a	0.901ab	0.892ab	0.881b	0.0119	0.051
Indispensable amino acid						
Arginine	0.971	0.954	0.959	0.951	0.0066	0.091
Histidine	0.937	0.915	0.922	0.923	0.0067	0.093
Isoleucine	0.928	0.906	0.912	0.904	0.0071	0.054
Leucine	0.924a	0.902ab	0.909ab	0.898b	0.0073	0.041
Lysine	0.943a	0.919ab	0.931ab	0.913b	0.0083	0.038
Methionine	0.933a	0.903b	0.916ab	0.919ab	0.0072	0.034
Phenylalanine	0.932a	0.913ab	0.918ab	0.903b	0.0067	0.015
Threonine	0.897	0.870	0.884	0.884	0.0104	0.264
Tryptophan	0.924a	0.887b	0.873b	0.896ab	0.0078	<0.001
Valine	0.914	0.885	0.895	0.890	0.0087	0.083
Dispensable amino acid						
Alanine	0.910	0.881	0.898	0.879	0.0111	0.094
Aspartic acid	0.923a	0.906ab	0.917ab	0.889b	0.0081	0.023
Cysteine	0.879a	0.812b	0.851ab	0.868ab	0.0179	0.030
Glutamic acid	0.935	0.913	0.920	0.898	0.0106	0.090
Glycine	0.920	0.889	0.902	0.878	0.0228	0.317
Proline	1.050	0.949	1.020	0.939	0.0983	0.422
Serine	0.926	0.900	0.910	0.904	0.0090	0.145
Tyrosine	0.932	0.906	0.913	0.914	0.0074	0.071

ab Values within a row lacking a common superscript letter are different ($P < 0.05$).

[a] Data are means of 10 observations.

[b] Coefficient of ileal standardized digestibility were calculated by correcting coefficient of ileal apparent digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined from pigs fed the nitrogen-free diet as (g/kg dry matter intake): arginine, 0.57; histidine, 0.19; isoleucine, 0.36; leucine, 0.58; lysine, 0.59; methionine, 0.09; phenylalanine, 0.35; threonine, 0.11; tryptophan, 0.14; valine, 0.59; alanine, 0.64; aspartic acid, 0.85; cysteine, 0.20; glutamic acid, 1.02; glycine, 1.59; proline, 4.18; serine, 0.55; and tyrosine, 0.29.

[c] FFSB-CV = full-fat soybeans from a conventional variety of soybeans, FFSB-HP = full-fat soybeans from a high-protein variety of soybeans, FFSB-LO = full-fat soybeans from a low-oligosaccharide variety of soybeans, and SBM = conventional soybean meal.

[d] SEM = standard error of the means.

4. Discussion

4.1. Composition of ingredients

The nutrient composition of SBM concurs with published values (NRC, 1998) and the nutrient composition for FFSB-CV and FFSB-HP is in agreement with previous data (Cervantes-Pahm and Stein, 2008). The concentration of neutral detergent fiber and acid detergent fiber were greater in all the FFSB compared with SBM, because the FFSB were not de-hulled as were the soybeans used to produce the SBM.

The CP and AA concentration in FFSB-HP was greater than in the FFSB-CV and FFSB-LO, which was expected because FFSB-HP has been selected for a greater concentration of CP. The concentration of stachyose and raffinose were lower in FFSB-LO compared with the other FFSB and SBM, which was also expected because this variety was selected for low concentrations of oligosaccharides. The concentration of sucrose was lowest in FFSB-HP compared with the other FFSB and SBM, which is in agreement with previous data (Cervantes-Pahm and Stein, 2008; Baker and Stein, 2009). An adverse relationship between CP and sucrose is often observed in soybeans (Hartwig et al., 1997).

4.2. Amino acid digestibility

The CIAD and CISD for most AA in FFSB-CV were similar to values for FFSB-HP, but because of the increased concentration of AA in FFSB-HP compared with FFSB-CV, greater quantities of digestible AA are provided by FFSB-HP than by FFSB-CV. This observation is in agreement with data obtained for FFSB-HP and FFSB-CV fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008).

The CIAD and CISD of AA in FFSB-CV and FFSB-LO were similar, which indicates that the digestibility of AA was not compromised when varieties with low concentrations of oligosaccharides were selected. This conclusion also agrees with data for extruded-expelled SBM fed to growing-finishing pigs (Baker and Stein, 2009). The greater CISD of some AA in FFSB-CV compared with SBM was expected because the CISD of most AA in FFSB is greater than in SBM fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008). This increase in the CISD of AA in FFSB compared with SBM is due to the greater concentration of ether extract in FFSB than in SBM (Cervantes-Pahm and Stein, 2008). The reason that only a few AA had a greater CISD in FFSB-CV compared with SBM in the present experiment whereas most AA in FFSB-CV had a greater CISD than in SBM in the experiment by Cervantes-Pahm and Stein (2008) is most likely that the source of SBM used in the present experiment was de-hulled, which was not the case for the SBM used by Cervantes-Pahm and Stein (2008). De-hulling causes a reduced concentration of fiber and fiber often reduces the digestibility of AA (Dilger et al., 2004; Stein et al., 2007).

The CIAD of AA for SBM that were measured in this experiment were 0.10–0.15 units greater than the values obtained by Caine et al. (1997) who also fed SBM to weanling pigs. The CIAD obtained in the present experiment are also 0.10–0.15 units greater than the CIAD by weanling pigs for SBM and 0.20–0.25 units greater than the CIAD of AA in FFSB reported by Fan et al. (1995). Likewise, CIAD values for SBM and FFSB that were measured in this experiment are 0.02–0.10 units greater than values obtained in growing pigs by Kim et al. (2000). However, the CISD for SBM and FFSB obtained in the present experiment are in close agreement with digestibility values reported by Marty et al. (1994). The CISD of AA in SBM from the present experiment also concur with the digestibility values from NRC (1998). It is possible that differences among varieties of soybeans, in processing procedures, or in experimental methodologies are responsible for the different results obtained among experiments.

The SBM used in the present experiment was from the same batch as the SBM used by Baker and Stein (2009) and fed to growing-finishing pigs. The values that were measured for CISD for all AA were very similar between the 2 experiments and also similar to CISD values reported for a different batch of conventional SBM that was fed to growing-finishing pigs by Cervantes-Pahm and Stein (2008). Likewise, the CISD obtained for FFSB-CV and FFSB-HP in the present experiment is within 0.02–0.03 of the CISD obtained for different batches of FFSB-CV and FFSB-HP fed to growing-finishing pigs (Cervantes-Pahm and Stein, 2008). These data, therefore, indicate that the digestibility of AA in FFSB-CV, FFSB-HP, and SBM measured in weanling pigs are not different from values measured in growing-finishing pigs.

Values for the basal endogenous losses of CP and AA were measured from pigs fed a nitrogen-free diet and these values were subsequently used to calculate the CISD of AA in the FFSB and SBM. Several procedures are available for determination of basal endogenous losses of CP and AA, but values obtained using the nitrogen-free diet are comparable to values obtained using other procedures (Jansman et al., 2002). However, because of the ease and relatively low cost of using the nitrogen-free diet, this procedure has been recommended for the routine determination of basal endogenous losses of CP and AA (Stein et al., 2007).

5. Conclusion

Results of the present experiment indicate that the CIAD and CISD of most AA in FFSB-HP and FFSB-LO are not different from the CISD of AA in FFSB-CV. This observation confirms that the same digestibility values can be used to calculate the digestibility of AA in these new high-protein and low-oligosaccharide varieties of soybeans as the values used for conventional soybeans.

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