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Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs[1]

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ABSTRACT: An experiment was conducted to measure the effect of adding soybean oil to soybean meal (SBM) and soy protein concentrate (SPC) on apparent (AID) and standardized (SID) ileal digestibility of CP and AA by growing pigs. A second objective was to compare AID and SID of AA in a new high-protein variety of full fat soybeans (FFSB) to values obtained in other soybean products. Commercial sources of FFSB (FFSB-CV), SBM, and SPC, and of a new high-protein variety of FFSB (FFSB-HP) were used in the experiment. Four diets were prepared using each soybean product as the sole source of CP and AA in 1 diet. Two additional diets were formulated by adding soybean oil (7.55 and 7.35%, respectively) to the diets containing SBM and SPC. A nitrogen-free diet was also used to measure basal endogenous losses of CP and AA. The 2 sources of FFSB were extruded at 150°C before being used in the experiment. Seven growing barrows (initial BW = 26.2 kg) were prepared with a T-cannula in the distal ileum and allotted to a 7 × 7 Latin square design. Ileal digesta were collected from the pigs on d 6 and 7 of each period. All digesta samples were lyophilized and analyzed for DM, CP, AA, and chromium, and values for AID and SID of CP and AA were calculated. The addition of oil improved ($P < 0.05$) the SID of most indispensable AA in SBM and SPC. The SID for 6 of the indispensable AA in FFSB-HP were greater ($P < 0.05$) than in FFSB-CV, and the SID for all indispensable AA except Met was greater ($P < 0.05$) in FFSB-HP than in SBM. However, the SID for most AA in FFSB-HP was similar to SBM with oil and SPC, but these values were lower ($P < 0.05$) than in SPC with oil. In conclusion, the addition of oil improved the SID of most AA in SBM and SPC fed to growing pigs, and the SID of AA in FFSB-HP were greater than in SBM and similar to the SID of AA in SBM with oil and in SPC.

Key words: amino acid, digestibility, high protein soybean, oil, pig, soybean meal

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INTRODUCTION

The apparent ileal digestibility (**AID**) of AA by growing pigs is increased if oil is added to the diet (Li and Sauer, 1994; Albin et al., 2001). Standardized ileal digestibility values (**SID**) for CP and AA take into account the AA contributions of endogenous origins, and values for SID are more accurate estimates of the digestibility of AA in a feed ingredient compared with values for AID (Stein et al., 2007). However, there is limited information about the effect of dietary oil on the SID of AA in soybean products fed to pigs. It has been suggested (NRC, 1998) that the digestibility of AA in full-fat soybeans (**FFSB**) is less than in soybean meal (**SBM**) and soy protein concentrate (**SPC**). This is surprising because full-fat soybeans contain more oil than SBM and SPC (Cromwell, 2000; Zarkadas and Wiseman, 2005), and it would, therefore, be expected that the digestibility of AA in FFSB is greater than in defatted soybean products. The digestibility of AA in FFSB may be affected by the variety of the beans and the protein concentration in the beans, and as newer high-protein varieties of soybeans are marketed, it is necessary to investigate the effect of protein concentration on AA concentration and digestibility. Because increased protein concentration in soybeans is often accompanied by a reduced concentration of oil (Yaklich, 2001), the digestibility of AA in high-protein soybean varieties may be different from the digestibility in conventional varieties.

The objective of this experiment was to measure the effect of oil addition to SBM and SPC on AID and SID of CP and AA by growing pigs and to compare these values to the AID and SID for CP and AA in FFSB.

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Table 1. Analyzed nutrient composition of high protein full fat soy beans (FFSB-HP), conventional full fat soybeans (FFSB-CV), soybean meal (SBM), and soy protein concentrate (SPC), as-fed basis

Item	FFSB-HP	FFSB-CV	SBM	SPC
Ingredient				
DM, %	94.91	93.43	89.60	90.55
CP, %	47.64	35.78	42.92	64.15
Ether extract, %	16.40	20.80	1.53	0.11
NDF, %	8.68	9.75	11.26	9.34
Sucrose, %	4.69	7.30	8.14	0.70
Raffinose, %	1.19	0.73	0.99	0.15
Stachyose, %	4.11	4.07	4.51	0.86
Urease activity,[1] pH rise	0.12	0.10	0.18	0.12
Indispensable AA, %				
Arg	3.83	3.00	3.00	4.70
His	1.24	0.98	1.15	1.69
Ile	2.02	1.64	1.83	2.94
Leu	3.43	2.76	3.24	5.00
Lys	2.81	2.35	2.74	4.05
Met	0.64	0.59	0.67	0.94
Phe	2.31	1.84	2.14	3.23
Thr	1.66	1.39	1.69	2.47
Trp	0.33	0.33	0.56	0.81
Val	2.16	1.77	1.97	3.11
Dispensable AA, %				
Ala	1.89	1.57	1.86	2.77
Asp	5.25	4.08	4.8	7.29
Cys	0.66	0.61	0.68	0.92
Glu	8.31	6.39	7.48	11.36
Gly	1.89	1.54	1.8	2.72
Pro	2.17	1.7	2.0	3.04
Ser	2.21	1.74	2.18	3.17
Tyr	1.63	1.33	1.56	2.27
Total AA, %	44.43	35.17	41.35	62.49

[1]Urease activity was measured in the 2 sources of FFSB after extrusion.

The second objective was to compare the digestibility of AA and the concentration of digestible AA in a new high-protein variety of FFSB (**FFSB-HP**) to values obtained in conventional sources of FFSB (**FFSB-CV**), SBM, and SPC.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The animal part of the study was conducted at South Dakota State University, and the experiment was approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Seven growing barrows (initial and final BW = 26.2 ± 2.2 and 52.8 ± 4.3 kg, respectively) originating from the matings of SP-1 boars to line 13 sows (Ausgene Intl. Inc., Gridley, IL) were equipped with a T-cannula in the distal ileum using the method described by Stein et al. (1998). After surgery, pigs were transferred to individual pens (1.2 × 1.8 m) in a temperature-controlled room (22°C) where they were allowed to recover for 14 d. A standard corn-soybean meal diet (16% CP) was provided on an ad libitum basis during this time. Pigs were then allotted to a 7 × 7 Latin square design with pigs and periods comprising the rows and columns, respectively.

Ingredients, Diets, and Feeding

Four soybean products were used in this experiment (Table 1). The 4 sources were FFSB-HP (SSeed. HP 290, Schillinger Seeds, Des Moines, IA), a source of FFSB-CV, conventional SBM, and a commercial source of SPC (Profine E, Central Soya Co. Inc., Fort Wayne, IN). The FFSB-CV and the SBM were commercial sources that were obtained locally. Before the experiment, both sources of FFSB were ground and extruded at 150°C (Model 2500, Insta Pro, Des Moines, IA) and subsequently cooled to 43°C using a tumble drum cooler (Insta Pro).

Seven diets were formulated to contain quantities of AA that were expected to exceed the requirements of the pigs (Tables 2 and 3). Four diets contained each of the soybean products as the only protein and AA source. Two additional diets were formulated by adding soybean oil to the diets containing SBM and SPC, respectively, to bring the total concentration of ether extract in those diets close to the concentrations in the 2 diets containing FFSB. A N-free diet was used to measure

Table 2. Ingredient composition of experimental diets, as-fed basis

	Diet						
Ingredient, %	FFSB-HP[1]	FFSB-CV[1]	SBM[1]	SBM[1] + oil	SPC[1]	SPC[1] + oil	N-free
SSeed. HP 290	45.00	—	—	—	—	—	—
Commercial soybeans	—	45.00	—	—	—	—	—
Soybean meal, 44% CP	—	—	36.50	36.50	—	—	—
Soy protein concentrate	—	—	—	—	25.00	25.00	—
Soybean oil	—	—	—	7.55	—	7.35	4.00
Cornstarch	42.65	42.65	51.15	43.60	58.52	51.17	68.27
Sugar	10.00	10.00	10.00	10.00	10.00	10.00	20.00
Solka floc[2]	—	—	—	—	4.00	4.00	4.00
Limestone	0.75	0.75	0.75	0.75	0.80	0.80	0.60
Monocalcium phosphate	0.62	0.62	0.62	0.62	0.70	0.70	1.65
Magnesium oxide	—	—	—	—	—	—	0.10
Potassium carbonate	—	—	—	—	—	—	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[3]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]FFSB-HP = high protein full fat soybeans; FFSB-CV = conventional full fat soybean; SBM = soybean meal; SPC = soy protein concentrate.

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

[3]Provided the following quantities of vitamins per kilogram of complete diet: Vitamin A, 6,594 IU as vitamin A acetate; vitamin D_3, 989 IU as D-activated animal sterol; vitamin E, 33 IU as α tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; and biotin, 0.1 mg.

[4]Provided the following quantities of minerals per kilogram of complete diet: Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

Table 3. Analyzed nutrient composition of experimental diets, as-fed basis

	Diet						
Item	FFSB-HP[1]	FFSB-CV[1]	SBM[1]	SBM[1] + oil	SPC[1]	SPC[1] + oil	N-free
DM, %	93.44	92.92	91.21	91.63	91.97	91.88	92.76
CP, %	20.72	17.32	15.92	14.60	16.14	16.59	1.0
Ether extract, %	7.35	9.29	0.69	7.50	0.24	6.70	—
Indispensable AA, %							
Arg	1.69	1.17	1.21	1.05	1.25	1.11	—
His	0.56	0.46	0.47	0.41	0.47	0.42	—
Ile	0.91	0.76	0.79	0.70	0.81	0.71	—
Leu	1.56	1.29	1.33	1.17	1.37	1.19	0.01
Lys	1.28	1.11	1.13	0.99	1.12	0.99	0.01
Met	0.31	0.28	0.3	0.26	0.28	0.25	—
Phe	1.04	0.86	0.88	0.77	0.89	0.78	—
Thr	0.75	0.65	0.67	0.58	0.67	0.58	—
Trp	0.27	0.22	0.23	0.23	0.25	0.22	<0.04
Val	0.99	0.82	0.85	0.75	0.86	0.76	0.01
Dispensable AA, %							
Ala	0.86	0.73	0.76	0.67	0.76	0.65	0.01
Asp	2.38	1.90	1.86	1.72	2.00	1.71	0.01
Cys	0.31	0.28	0.29	0.23	0.27	0.23	0.01
Glu	3.76	2.9	3.05	2.68	3.17	2.70	0.03
Gly	0.86	0.72	0.74	0.65	0.74	0.64	—
Pro	0.99	0.80	0.82	0.73	0.84	0.78	0.01
Ser	0.98	0.82	0.83	0.72	0.85	0.74	0.01
Tyr	0.57	0.49	0.52	0.45	0.48	0.41	—
Total AA, %	20.06	16.54	17.01	14.98	17.08	14.88	0.11

[1]FFSB-HP = high protein full fat soybeans; FFSB-CV = conventional full fat soybean; SBM = soybean meal; SPC = soy protein concentrate.

basal ileal endogenous losses of AA. Chromic oxide was included (0.40%) in all diets as an inert marker.

Feed was provided in quantities equal to 3 times the estimated daily maintenance energy requirement of the pigs (106 kcal of ME per $kg^{0.75}$; NRC, 1998). The daily allotment of feed was divided into 2 equal meals that were provided at 0830 and 1600. Water was available at all times.

Data and Sample Collection

Pig BW were recorded at the beginning of the experiment and at the end of each period. Each period lasted 7 d and pigs were allowed to adapt to their diet during the initial 5 d. On d 6 and 7, ileal digesta were collected for 8 h. A 225-mL plastic bag was attached to the cannula barrel using a cable tie and digesta flowing into the bag were collected. Bags were removed every 30 min and replaced with a new bag. Collected digesta were immediately stored at –20°C to prevent bacterial degradation of the AA in the digesta. Ileal samples obtained over the 2-d collection period were thawed, mixed within animal and diet, and a subsample was collected for chemical analysis. A sample of each diet and of each of the protein sources was also collected. Digesta samples were lyophilized and finely ground before chemical analysis.

Chemical Analysis

The soy products were analyzed for urease activity (procedure Ba9–58; AOCS, 1998) and NDF using the procedure of Holst (1973). Sucrose, raffinose, and stachyose were analyzed using the procedure of Janauer and Englmaier (1978). All soy products and diets were also analyzed for ether extract (procedure 4.5.01; AOAC, 2000), DM (procedure 4.1.06; AOAC, 2000), and CP (procedure 4.2.08; AOAC, 2000). Ileal digesta samples were also analyzed for DM and CP. Amino acids were analyzed in all samples on an AA analyzer (Beckman 6300 Amino Acid Analyzer, Beckman Instruments Corp., Palo Alto, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (procedure 4.1.11, alternative 3; AOAC, 1998) before analysis. Methionine and Cys were determined as Met sulfone and cysteic acid, respectively, after cold performic acid oxidation overnight before hydrolysis (procedure 4.1.11, alternative 1; AOAC, 1998). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (procedure 45.4.04; AOAC, 2000). Chromium concentrations of diets and ileal digesta were determined after nitric acid-perchloric acid wet ash sample preparation (procedure 9.2.39; AOAC, 2000).

Calculations and Statistical Analysis

Values for AID, endogenous losses, and SID of CP and AA were calculated as previously outlined (Stein et al., 2007). Concentrations of standardized ileal digestible AA in each protein source were calculated by multiplying the concentration of each AA in an ingredient (DM-basis) by the calculated SID for that AA.

Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC). The UNIVARIATE procedure of SAS was used to confirm homogeneity of the variance. Outliers were determined as values that were more than 3 SD above or below the mean. No outliers were identified and there were no missing values in the analysis. Orthogonal contrasts were used to compare SBM and SPC vs. SBM with oil and SPC with oil, respectively, to determine the effect of oil addition on AA digestibility. An ANOVA was conducted with diet as the fixed effect and pig and period as random effects to compare values for AID and SID among the 6 diets. Whenever differences were detected, treatment means were separated using the least significant difference test of the MIXED procedure. The pig was the experimental unit for all analyses, and an α value of 0.05 was used to assess significance among treatments.

RESULTS

The CP and AA concentrations were greater in FFSB-HP compared with conventional FFSB-CV and SBM (Table 1). However, the concentration of ether extract was decreased in FFSB-HP compared with FFSB-CV. Soybean meal contained more CP and AA than conventional FFSB, but the concentration of CP and AA in SPC was greater than in the other soybean sources. The concentration of NDF was greater in SBM than in the other protein sources. The concentration of sucrose was similar between SBM and FFSB-CV, but these values were greater than in FFSB-HP. The concentration of raffinose was lower in FFSB-CV than in FFSB-HP, but the stachyose concentration was not different for FFSB-CV and FFSB-HP. The urease activity was within the range of 0.05 to 0.20 for all samples.

The AID for CP in FFSB-HP (81.0%) was greater ($P < 0.05$) than the AID obtained for the other ingredients (Table 4). The AID for CP in SBM (68.1%) was less ($P < 0.05$) than the AID for CP in FFSB-CV (76.4%). However, the AID for CP in FFSB-CV was similar to the AID in SPC (75.4%). The AID for SBM with oil (71.5%) was similar to the AID for SBM, but the AID for SPC with oil (81.5%) was greater ($P < 0.05$) than for SPC.

For most AA, no differences in the AID were observed between FFSB-HP and SPC. However, the AID for most AA in SBM was lower ($P < 0.05$) than in FFSB-HP and SPC. The AID for 6 of the 10 indispensable AA (Arg, His, Ile, Leu, Phe, and Val) was greater ($P < 0.05$) in FFSB-HP than in FFSB-CV, but the AID for most AA in FFSB-CV was similar to the AID for SBM. The diet containing SPC had greater ($P < 0.05$) AID for most indispensable AA compared with FFSB-CV, but the AID for most dispensable AA in FFSB-CV was similar to the AID for SPC. Addition of oil to SBM and SPC improved ($P < 0.05$) the AID of most indispensable

Table 4. Apparent ileal digestibility (%) of CP and AA in experimental diets[1]

Item	Diet								Effect of oil[4]	
	FFSB-HP[2]	FFSB-CV[2]	SBM[2]	SBM[2] + oil	SPC[2]	SPC[2] + oil	SEM	*P*-value[3]	SEM	*P*-value
CP, %	81.0^{u}	76.4^{z}	68.1^{x}	71.5^{xy}	75.4y^{z}	81.5^{u}	1.75	<0.001	2.76	0.005
Indispensable AA, %										
Arg	93.1^{z}	88.1^{x}	86.5^{x}	87.1^{x}	89.5^{xy}	92.6^{yz}	1.22	<0.001	2.19	0.122
His	88.5^{y}	85.8^{x}	84.0^{x}	85.0^{x}	88.5^{y}	90.8^{z}	1.00	<0.001	1.51	0.038
Ile	87.6^{z}	83.7^{xy}	82.9^{x}	84.7^{y}	87.6^{z}	88.5^{z}	0.81	<0.001	1.22	0.039
Leu	87.1^{z}	83.1^{xy}	81.9^{x}	83.9^{y}	86.9^{z}	87.9^{z}	0.86	<0.001	1.33	0.038
Lys	88.2^{zu}	87.0^{yz}	82.4^{x}	84.5^{xy}	87.9^{yz}	91.8^{u}	1.62	<0.001	2.54	0.028
Met	88.0^{xyz}	85.7^{x}	86.7^{xy}	88.7^{yz}	89.5^{z}	89.8^{z}	1.18	0.013	1.70	0.180
Phe	89.0^{z}	85.1^{xy}	83.5^{x}	85.2^{y}	89.0^{z}	89.8^{z}	0.77	<0.001	1.19	0.042
Thr	76.7^{yz}	73.9^{xy}	71.7^{x}	72.3^{x}	77.5^{z}	77.3^{z}	1.43	0.002	2.23	0.869
Trp	83.9^{yz}	81.8^{xy}	79.4^{x}	83.0^{y}	86.5^{zu}	88.1^{u}	1.41	<0.001	2.21	0.019
Val	84.0^{y}	79.8^{x}	78.6^{x}	80.6^{x}	84.1^{y}	85.3^{y}	1.10	<0.001	1.67	0.059
Mean	87.5^{y}	83.8^{x}	81.9^{x}	83.6^{x}	86.8^{y}	88.5^{y}	0.98	<0.001	1.53	0.040
Dispensable AA, %										
Ala	81.5^{z}	78.1^{yz}	73.7^{x}	76.5^{xy}	78.2^{yz}	81.60^{z}	1.43	<0.001	2.64	0.025
Asp	86.0^{zu}	83.6^{yzu}	79.4^{x}	80.5^{xy}	84.4^{zu}	86.3^{u}	1.44	<0.001	2.33	0.212
Cys	74.8^{xy}	74.1^{x}	70.3^{x}	73.5^{x}	73.9^{x}	79.8^{y}	2.76	0.048	3.87	0.027
Glu	87.3^{yz}	86.0^{yz}	80.4^{x}	82.6^{xy}	85.6^{y}	90.8^{z}	2.11	0.003	3.37	0.038
Gly	61.8^{z}	51.1^{xy}	41.6^{x}	48.0^{xy}	53.1^{yz}	57.4^{yz}	4.21	0.009	7.07	0.143
Pro	62.8	42.0	18.3	15.1	14.6	14.3	18.4	0.256	33.2	0.917
Ser	83.2^{y}	79.3^{x}	77.2^{x}	79.0^{x}	84.0^{y}	84.6^{y}	1.02	<0.001	1.62	0.146
Tyr	88.4^{z}	85.0^{x}	85.6^{xy}	86.9^{yz}	90.9^{u}	90.7^{u}	0.81	<0.001	1.24	0.358
Mean	81.4^{z}	76.6^{xyz}	70.2^{xy}	72.0^{xy}	75.0^{xyz}	77.6^{yz}	2.55	0.026	4.59	0.344
All AA, %	84.2^{z}	79.9^{yz}	75.6^{x}	77.4^{xy}	80.6^{yz}	82.7^{z}	1.67	0.004	2.98	0.202

$^{u\text{–}z}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are means of 7 observations per treatment.

[2]FFSB-HP = high protein full fat soybeans; FFSB-CV = conventional full fat soybean; SBM = soybean meal; SPC = soy protein concentrate.

[3]*P*-value for the ANOVA comparing all 6 diets.

[4]*P*-value for the effect of adding oil to SBM and SPC.

AA. Among the dispensable AA, only the AID for Ala, Cys, and Glu were improved ($P < 0.05$) by oil addition.

The SID for CP in SBM (84.8%) was lower ($P < 0.05$) than in all other ingredients (Table 5). The SID for most AA in FFSB-HP were similar to the AID for SPC. The SID for Ile, Leu, Phe, Val, Ser, and Tyr in FFSB-HP were greater ($P < 0.05$) than in FFSB-CV, but the SID for the remaining AA where not different between the 2 sources of FFSB. The SID for most of the indispensable AA in FFSB-CV were similar to SBM. The SID of Lys, Phe, and Trp were greater ($P < 0.05$) in FFSB-CV than in SBM, but for the remaining indispensable AA, no differences between these 2 ingredients were observed. The SID for most AA in SPC were greater ($P < 0.05$) than for FFSB-CV and SBM. The addition of oil improved ($P < 0.05$) the SID for most indispensable AA in SBM and SPC, but greater improvements were observed for SBM than for SPC. The SID for all indispensable AA except Phe were similar for SBM plus oil and FFSB-HP, and with the exception of Met, these values were also similar to FFSB-CV. In contrast, SPC with oil had SID values for all indispensable AA that were greater ($P < 0.05$) than in FFSB-CV, and with the exception of Arg, these values were also greater ($P < 0.05$) than in FFSB-HP.

Among all ingredients, FFSB-CV had the lowest ($P < 0.05$) concentration (353 g per kg of DM) of SID CP (Table 6). The concentration of SID CP in FFSB-HP (472 g per kg of DM) was greater ($P < 0.05$) than in SBM (406 g per kg of DM) and SBM with oil (430 g per kg of DM). Soy protein concentrate had a greater ($P < 0.05$) concentration (652 g per kg of DM) of SID CP than FFSB-HP, but SPC with oil (691 g per kg of DM) had the greatest ($P < 0.05$) concentration of SID CP among all treatments.

The concentrations of most of the digestible AA in FFSB-HP were greater ($P < 0.01$) than in FFSB-CV, SBM, and SBM with oil, but the concentration of digestible Lys in FFSB-HP was similar to SBM and SBM with oil. In contrast, the concentration of digestible Met and Trp were lower ($P < 0.05$) in FFSB-HP than in SBM and SBM with oil. The concentration of digestible Thr in FFSB-HP, however, was similar to SBM, but lower ($P < 0.05$) than in SBM with oil. The concentration of digestible AA in FFSB-HP was lower ($P < 0.01$) than in SPC and SPC with oil, but FFSB-CV had the lowest ($P < 0.05$) concentration of digestible AA among all diets. The concentration of digestible Ile, Leu, Met, Trp, and Val was greater ($P < 0.01$) in SBM with oil than in SBM, but for the remaining indispensable AA, no differences between these 2 diets were observed. Soy protein concentrate had a greater ($P < 0.01$) concentration of digestible AA than SBM with oil, and the addition of oil to SPC increased ($P < 0.01$) the concentrations of

Table 5. Standardized ileal digestibility (%) of CP and AA in experimental diets[1,2]

	Diet								Effect of oil[5]	
Item	FFSB-HP[3]	FFSB-CV[3]	SBM[3]	SBM[3] + oil	SPC[3]	SPC[3] + oil	SEM	*P*-value[4]	SEM	*P*-value
CP, %	94.1^{yz}	92.1^{y}	84.8^{x}	89.8^{y}	92.0^{y}	97.6^{z}	1.75	<0.001	2.76	0.006
Indispensable AA, %										
Arg	99.1^{yz}	96.7^{xy}	94.7^{x}	96.6^{xy}	97.4^{xy}	101.4z	1.23	0.005	2.21	0.014
His	93.3^{yz}	91.6^{xy}	89.5^{x}	91.5^{xy}	94.1^{z}	97.1u	1.00	<0.001	1.52	0.004
Ile	93.1^{zu}	90.2^{xy}	89.1^{x}	91.7^{yz}	93.6^{uv}	95.4v	0.81	<0.001	1.22	0.002
Leu	92.5^{z}	89.7^{xy}	88.2^{x}	91.0^{yz}	93.0^{zu}	94.9u	0.86	<0.001	1.33	0.002
Lys	93.0^{y}	92.5^{y}	87.7^{x}	90.6^{xy}	93.2^{y}	97.9z	1.63	<0.001	2.55	0.008
Met	94.0^{xy}	92.2^{x}	92.6^{x}	95.5^{yz}	95.9^{yz}	97.0z	1.18	0.028	1.70	0.028
Phe	93.7^{z}	90.7^{y}	88.9^{x}	91.5^{y}	94.4^{zu}	96.0u	0.77	0.002	1.19	0.002
Thr	87.6^{y}	86.4^{xy}	83.6^{x}	86.1^{xy}	89.4^{yz}	91.2z	1.44	0.071	2.23	0.071
Trp	90.1^{yz}	89.4^{y}	86.1^{x}	90.1^{yz}	93.0^{zu}	95.6u	1.41	0.007	2.21	0.007
Val	91.7^{z}	89.0^{xy}	87.3^{x}	90.6^{yz}	92.7^{zu}	95.2u	1.10	0.002	1.67	0.002
Mean	92.3^{z}	89.7^{xy}	87.5^{x}	90.0^{yv}	92.3^{zv}	94.8u	0.98	<0.001	1.53	0.004
Dispensable AA, %										
Ala	92.7^{yz}	91.1^{y}	86.0^{x}	90.5^{y}	90.5^{y}	96.1z	1.43	<0.001	2.64	<0.001
Asp	91.0^{z}	89.7^{yz}	85.3^{x}	87.3^{xy}	90.2^{yz}	93.1z	1.44	<0.001	2.33	0.046
Cys	84.9^{x}	85.0^{x}	80.6^{x}	85.0^{x}	85.1^{x}	92.8y	2.76	0.006	3.87	0.005
Glu	91.0^{y}	90.7^{y}	84.9^{x}	87.7^{xy}	89.9^{xy}	95.9z	2.11	0.003	3.37	0.015
Gly	93.9^{yz}	89.2^{y}	77.9^{x}	89.6^{yz}	89.6^{yz}	99.7z	4.50	0.008	7.08	0.006
Pro	153.6	153.7	125.2	135.8	119.8	127.6	18.55	0.621	33.26	0.588
Ser	91.1^{zu}	88.6^{y}	86.3^{x}	89.5^{yz}	92.9^{uv}	94.9v	1.02	<0.001	1.62	0.004
Tyr	93.6^{y}	90.9^{x}	91.1^{x}	93.3^{y}	96.9^{z}	97.7z	0.81	<0.001	1.24	0.021
Mean	93.8^{y}	91.7^{y}	84.6^{x}	88.5^{xy}	89.1^{xy}	94.2y	2.56	0.057	4.60	0.064
All AA, %	94.8^{yz}	92.7^{yz}	87.9^{x}	91.4^{xy}	92.6^{yz}	96.7z	1.68	0.008	2.99	0.019

[u–z]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are means of 7 observations per treatment.

[2]Standardized ileal digestibility values were calculated by correcting the AID values for the basal ileal endogenous losses. Basal ileal endogenous losses were determined as (g/kg of DMI): CP, 29.11; Arg, 1.09; His, 0.29; Ile, 0.53; Leu, 0.91; Lys, 0.66; Met, 0.20; Phe, 0.53; Thr, 0.88; Trp, 0.18; Val, 0.81; Ala, 1.02; Asp, 1.27; Cys, 0.33; Glu, 1.50; Gly, 3.95; Pro, 9.62; Ser, 0.82, Tyr, 0.31.

[3]FFSB-HP = high protein full fat soybeans; FFSB-CV = conventional full fat soybean; SBM = soybean meal; SPC = soy protein concentrate.

[4]*P*-value for the ANOVA comparing all 6 diets.

[5]*P*-value for the effect of adding oil to SBM and SPC.

all indispensable AA except Met and Phe. Therefore, SPC with oil had a greater ($P < 0.05$) concentration of digestible AA than all other diets.

DISCUSSION

Composition of Ingredients

To increase the feeding value of soybeans, varieties with increased concentration of CP or reduced concentration of trypsin inhibitors and oligosaccharides have been selected (Palacios et al., 2004). The FFSB-HP variety was selectively bred for greater concentration of CP. The increase in CP was achieved partly at the expense of ether extract that was reduced in FFSB-HP compared with FFSB-CV. The negative correlation of soybean protein to seed oil and yield are the major obstacles that hinder the development of high CP soybeans for commercial use because soybeans are traded on a weight basis and high CP lines often have a decreased yield and contain less oil than conventional lines (Yaklich, 2001). The CP concentration of soybeans is also negatively correlated with the concentration of sucrose but positively correlated with the concentration of stachyose (Hartwig et al., 1997). This inverse relationship between protein and sucrose concentration explains the lower sucrose concentration in FFSB-HP than in FFSB-CV, but the stachyose concentration was similar between the 2 soybean varieties. The stachyose concentration in high-protein soybeans average 4.13% (Hartwig et al., 1997), which is similar to the value obtained in this study for both FFSB-HP and FFSB-CV.

Aqueous alcohol extraction removes the sucrose, raffinose, and stachyose from defatted soy flakes (Eldridge et al., 1979). The concentrations of oligosaccharides in SPC are, therefore, lower than in SBM. The concentration of sucrose, raffinose, and stachyose in SPC and SBM were within the range of values reported in other studies (Eldridge et al., 1979; Bach Knudsen, 1997; Grieshop et al., 2003).

The fiber in soybeans is mainly present in the seed coat and contains approximately 80% polysaccharides, which can be separated into cellulose, hemicellulose, and pectin on the basis of solubility (Stombaugh et al., 2000). Seed coat contribution to the total seed weight is relatively constant. Although the increase in the concentration of CP results in a reduction in ether extract, the combined concentration of CP and ether extract increases and the fiber and carbohydrate components decrease when the soybeans are selected for high protein

Table 6. Concentration of standardized ileal digestible CP and AA (g/kg of DM) in high-protein and conventional full fat soybeans (FFSB-HP and FFSB-CV), in soybean meal (SBM) and SBM with 7.55% soybean oil, and in soy protein concentrate (SPC) and SPC with 7.35% added soybean oil[1]

	Ingredient							
Item	FFSB-HP	FFSB-CV	SBM	SBM + oil	SPC	SPC + oil	SEM	*P*-value
CP, %	472.3^{z}	352.7^{x}	406.2^{y}	430.2^{y}	651.8^{u}	691.4^{v}	9.73	<0.001
Indispensable AA, %								
Arg	40.0^{z}	26.6^{x}	31.7^{y}	32.3^{y}	50.6^{u}	52.6^{v}	0.48	<0.001
His	12.2^{z}	9.9^{x}	11.5^{y}	11.7^{y}	17.6^{u}	18.1^{v}	0.14	<0.001
Ile	19.8^{u}	15.9^{x}	18.2^{y}	18.7^{z}	30.4^{v}	30.9^{w}	0.18	<0.001
Leu	33.4^{z}	26.5^{x}	31.9^{y}	32.9^{z}	51.5^{u}	52.4^{v}	0.33	<0.001
Lys	27.6^{y}	23.3^{x}	26.8^{y}	27.7^{y}	41.7^{z}	43.7^{u}	0.54	<0.001
Met	6.3^{y}	5.8^{x}	7.0^{z}	7.2^{u}	10.0^{v}	10.1^{v}	0.10	<0.001
Phe	22.8^{u}	17.9^{x}	21.2^{yz}	21.9^{z}	33.7^{v}	34.2^{w}	0.19	<0.001
Thr	15.3^{y}	12.9^{x}	15.8^{yz}	16.2^{z}	24.5^{u}	24.9^{u}	0.28	<0.001
Trp	3.1^{x}	3.20^{x}	5.4^{y}	5.6^{z}	8.3^{u}	8.5^{v}	0.08	<0.001
Val	20.9^{u}	16.9^{x}	19.2^{y}	19.9^{z}	31.9^{v}	32.6^{w}	0.26	<0.001
Dispensable AA, %								
Ala	18.4^{yz}	15.3^{x}	17.8^{y}	18.8^{z}	27.7^{u}	29.4^{v}	0.32	<0.001
Asp	50.3^{z}	39.2^{x}	45.7^{y}	47.0^{y}	72.7^{u}	75.9^{u}	0.90	<0.001
Cys	5.9^{xy}	5.5^{x}	6.1^{yz}	6.4^{z}	8.7^{u}	9.4^{v}	0.22	<0.001
Glu	79.9^{z}	62.0^{x}	70.9^{y}	73.3^{y}	112.9^{u}	120.2^{v}	2.12	<0.001
Gly	18.7^{z}	14.7^{x}	15.6^{xy}	18.0^{yz}	26.9^{u}	30.0^{v}	21.43	<0.001
Pro	35.1	28.0	27.8	30.2	39.3	42.5	5.08	0.161
Ser	21.2^{yz}	16.5^{x}	21.0^{y}	21.8^{z}	32.6^{u}	33.2^{u}	0.26	<0.001
Tyr	16.1^{yz}	12.9^{x}	15.8^{y}	16.2^{z}	24.3^{u}	24.5^{u}	0.14	<0.001
All AA, %	443.7^{z}	349.9^{x}	405.2^{y}	421.7^{yz}	639.6^{u}	667.6^{v}	8.99	<0.001

$^{u–z}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data were calculated by multiplying the AA concentration in each ingredient by the measured value for the standardized ileal digestibility; n = 7.

concentration (Hartwig et al., 1997). This may explain the lower concentration of NDF in FFSB-HP than in FFSB-CV. The extraction of fat from the soybean seed results in a greater concentration of NDF in SBM than in FFSB, and the values for NDF obtained in this study are similar to the values reported by Edwards et al. (2000) but lower than the values reported by Grieshop et al. (2003). Genotypic variation may account for the difference in the polysaccharides present in the seed coat (Stombaugh et al., 2000).

The CP and AA concentration in FFSB-CV and SBM used in this study were similar to the values reported by NRC (1998) and from other studies (Kim et al., 2000; Clapper et al., 2001; Grieshop et al., 2003). However, the AA concentration in SPC was slightly lower than the values reported by NRC (1998), but similar to the values reported by Clapper et al. (2001). Differences in processing methods during the production of SPC may result in SPC with different characteristics (Berk, 1992).

Effect of Oil Addition to SBM and SPC

The increased AID and SID of AA when oil was included in the diet may be due to slower gastric emptying, which increases the time that feed proteins are exposed to proteolytic enzymes (Gentilcore et al., 2006). The presence of fat in the small intestine may also reduce the passage rate of the ingested feed (Valaja and Silijander-Rasi, 2001), which may provide a longer time for AA and peptides to be absorbed (Zhao et al., 2000).

Addition of oil to SBM resulted in increased values for AID of most AA (Imbeah and Sauer, 1991; Li and Sauer, 1994; Albin et al., 2001), and the results of this experiment agree with these previous reports. However, results from the present experiment also demonstrated that the SID for AA in SBM is improved by the addition of oil and that dietary oil also increases the digestibility of AA in a highly digestible protein source such as SPC. To our knowledge, this has never been demonstrated before.

Previous studies have shown that the digestibility of AA in FFSB-CV is lower than in SBM with added oil (Marty et al., 1994; Fan et al., 1995; Bruce et al., 2006). The reason for the reduced digestibilities has been attributed to a greater concentration of trypsin inhibitors (Fan et al., 1995) and soy hulls (Bruce et al., 2006) in FFSB-CV than in SBM. It has also been reported that FFSB induce a greater endogenous Lys loss than SBM with added oil (Marty et al., 1994), but oil addition does not influence the endogenous losses of AA (de Lange et al., 1989). In the present experiment, there were no differences in AA digestibility between FFSB-CV and SBM with added oil, which is likely because the soybeans used to produce the SBM used in this experiment were not dehulled and the concentration of hulls was expected to be similar in SBM and FFSB-CV. In addition, both FFSM-CV and SBM were adequately heated as reflected by their urease activity, which was within the range of 0.05 to 0.20, the generally acceptable index for adequate cooking to inactivate trypsin inhibitors (Parsons, 2000). It is, therefore, likely that the reason for the greater digestibility of AA in the 2 sources of FFSB than in SBM is the increased concentration of oil in FFSB. When oil was added to the SBM in a quantity similar to the concentration in FFSB, the digestibility of AA in SBM was similar to the digestibility in FFSB.

Comparison of High Protein Soybeans and Other Soybean Products

The total concentration of AA in FFSB-HP was 25% greater than in FFSB-CV, which indicates that this new variety of soybeans may have a greater feeding value than FFSB-CV. The concentration of Arg and His increased the most among indispensable AA (28%). The concentration of Arg usually increases with increasing CP concentration (Krishnan et al., 2007). In contrast, the concentration of Trp usually decreases with increasing CP concentration (Krishnan et al., 2007), but no difference in Trp concentration was observed between FFSB-HP and FFSB-CV. Among the dispensable AA, Glu followed by Asp had the greatest increase in concentration (30%), and this is consistent with the observation of Zarkadas et al. (1993) who reported that Glu and Asp are the most abundant AA in FFSB composing 26 to 28% of the CP in soybeans regardless of cultivar. The concentration of Met and Cys in FFSB-HP was only 8% greater than in FFSB-CV.

The lack of a difference in AID and SID of most AA between FFSB-HP and FFSB-CV is consistent with the findings of Marty and Chavez (1994) who reported that the AID of AA in 3 soybean cultivars were similar. Although there is no difference in the SID of AA between FFSB-HP and FFSB-CV, the concentration of SID AA in FFSB-HP was greater than in FFSB-CV because of the greater concentration of AA in FFSB-HP compared with FFSB-CV. Using FFSB-HP instead of FFSB-CV will, therefore, increase the contribution of digestible AA to the diet.

In conclusion, the major reason for the increased digestibility of AA in both sources of FFSB compared with SBM was the presence of more oil in FFSB. When oil was added to SBM, the digestibility increased to a level that was similar to the digestibility in FFSB. The protein concentration in FFSB does not influence the digestibility of AA, and the greater AA concentration in high protein soybeans, therefore, translates directly into greater concentrations of digestible AA in these beans.

LITERATURE CITED

Albin, D. M., M. R. Smiricky, J. E. Wubben, and V. M. Gabert. 2001. The effect of dietary level of soybean oil and palm oil on apparent ileal amino acid digestibility and postprandial flow patterns of chromic oxide and amino acids in pigs. Can. J. Anim. Sci. 81:495–503.

AOAC. 1998. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOAC. 2000. Official Methods of Analysis. 17th ed. Assoc. Off. Anal. Chem. Gaithersburg, MD.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS. 5th ed. Am. Oil Chem. Soc., Champaign, IL.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67:319–338.

Berk, Z. 1992. Technology of production of edible flours and protein products from soybean. http://www.fao.org/docrep/t0532e/t0532e00.htm Accessed Nov. 20, 2006.

Bruce, K. J., L. K. Karr-Lilienthal, K. E. Zinn, L. L. Pope, D. C. Mahan, N. D. Fastinger, M. Watts, P. L. Utterback, C. M. Parsons, E. O. Castaneda, M. Ellis, and G. C. Fahey Jr. 2006. Evaluation of the inclusion of soybean oil and soybean processing by-products to soybean meal on nutrient composition and digestibility in swine and poultry . J. Anim. Sci. 84:1403–1414.

Clapper, G. M., C. M. Grieshop, N. R. Merchen, J. C. Russet, J. L. Brent, and G. C. Fahey. 2001. Ileal and total tract digestibilities and fecal characteristics of dogs as affected by soybean protein inclusion in dry, extruded diets. J. Anim. Sci. 79:1523–1532.

Cromwell, G. L. 2000. Utilization of soy products in swine diets. Page 274–280 in Soy in Animal Nutrition. J. K. Drackley, ed. Fed. Anim. Sci. Soc., Savoy, IL.

de Lange, C. F. M., W. C. Sauer, R. Mosenthin, and W. B. Souffrant. 1989. The effect of feeding different protein-free diets on the recovery and amino acid composition of endogenous protein collected from the distal ileum and feces in pigs. J. Anim. Sci. 67:746–754.

Edwards, H. M., M. W. Douglas, C. M. Parsons, and D. H. Baker. 2000. Protein and energy evaluation of soybean meals processed from genetically modified high protein soybeans. Poult. Sci. 79:525–527.

Eldridge, A. C., L. T. Black, and W. J. Wolf. 1979. Carbohydrate composition of soybean flours, protein concentrates, and isolates. J. Agric. Food Chem. 24:799–802.

Fan, M. Z., W. C. Sauer, and C. F. M. de Lange. 1995. Amino acid digestibility in soybean meal, extruded soybean and full-fat canola for early-weaned pigs. Anim. Feed Sci. Technol. 52:189–203.

Gentilcore, D., R. Chaikomin, K. L. Jones, A. Rusco, C. Feinle-Bisset, J. M. Wishart, C. K. Rayner, and M. Horitz. 2006. Effect of fat on gastric emptying of and the glycemic, insulin, and incretin responses to a carbohydrate meal and Type 2 diabetes. J. Clin. Endocrinol. Metab. 91:2062–2067.

Grieshop, C. M., C. T. Kadzere, G. M. Clapper, E. A. Flickinger, L. L. Bauer, R. L. Frazier, and G. C. Fahey. 2003. Nutritional characteristics of United States soybeans and soybean meals. J. Agric. Food Chem. 51:7684–7691.

Hartwig, E. E., T. M. Kuo, and M. M. Kenty. 1997. Seed protein and its relationship to soluble sugars in soybean. Crop Sci. 37:770–778.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. AOAC 56:1352–1356.

Imbeah, M., and W. C. Sauer. 1991. The effect of dietary level of fat on amino acid digestibilities in soybean meal and canola meal and on rate of passage in growing pigs. Livest. Prod. Sci. 29:227–239.

Janauer, G. A., and P. Englmaier. 1978. Multi-step time program for the rapid gas-liquid chromatography of carbohydrates. J. Chromatogr. 153:539–542.

Kim, I. H., J. D. Hancock, R. H. Hines, and T. L. Gugle. 2000. Roasting and extruding affect nutrient utilization from soybeans in 5 and 10 kg nursery pigs. Asian-Aust. J. Anim. Sci. 132:200–206.

Krishnan, H. B., S. S. Natarajan, A. A. Mahmoud, and R. L. Nelson. 2007. Identification of glycinin and β-conglycinin subunits that contribute to the increased protein content of high-protein soybean lines. J. Agric. Food Chem. 55:1839–1845.

Li, S., and W. C. Sauer. 1994. The effect of dietary fat content on amino acid digestibility in young pigs. J. Anim. Sci. 72:1737–1743.

Marty, B. J., and E. R. Chavez. 1994. Apparent digestibility of protein and amino acids at the distal ileum and of protein and energy over the whole tract in several extruded soybean cultivars for pigs. Can. J. Anim. Sci. 74:675–678.

Marty, B. J., E. R. Chavez, and C. F. M. de Lange. 1994. Recovery of amino acids at the distal ileum for determining apparent and true ileal amino acid digestibilities in growing pigs fed various heat-processed full-fat soybean products. J. Anim. Sci. 72:2029–2037.

NRC. 1998. Pages 110–142 in Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Palacios, M. F., R. A. Easter, K. T. Soltwedel, C. M. Parsons, M. W. Douglas, T. Hymowitz, and J. E. Pettigrew. 2004. Effect of soybean variety and processing on growth performance of young chicks and pigs. J. Anim. Sci. 82:1108–1114.

Parsons, C. M. 2000. Assessment of nutritional quality of soy products for animals. Page 90–105 in Soy in Animal Nutrition. J. K. Drackley, ed. Fed. Anim. Sci. Soc., Savoy, IL.

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.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical Note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Stombaugh, S. K., H. G. Jung, J. H. Orf, and D. A. Somers. 2000. Genotypic and environmental variation in soybean seed cell wall polysaccharides. Crop Sci. 40:408–412.

Valaja, J., and H. Silijander-Rasi. 2001. Dietary fat supplementation affects apparent ileal digestibility of amino acids and digesta passage rate of rapeseed meal-based diets. Page 175–177 in Digestive Physiology of Pigs. J. E. Linberg and B. Ogle, ed. CABI Publishing, New York, NY.

Yaklich, R. W. 2001. β-conglycinin and glycinin in high-protein soybean seeds. J. Agric. Food Chem. 49:729–735.

Zarkadas, C. G., Z. Yu, H. D. Voldeng, and A. Minero-Amador. 1993. Assessment of the protein quality of a new high protein soybean cultivar by amino acid analysis. J. Agric. Food Chem. 41:616–623.

Zarkadas, L. N., and J. Wiseman. 2005. Influence of processing of full fat soya beans included in diets for piglets: II. Digestibility and intestinal morphology . Anim. Feed Sci. Technol. 118:121–137.

Zhao, X. T., L. Wang, and H. C. Lin. 2000. Slowing of intestinal transit by fat on –naloxone-blockable afferent, opioid pathway. Am. J. Physiol. Gastrointest. Liver Physiol. 278:G866–G870.