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Amino acid digestibility in canola, cottonseed, and sunflower products fed to finishing pigs[1]

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ABSTRACT: Our objective was to determine the standardized ileal digestibility (SID) of CP and AA in soybean meal (SBM) and canola, cotton, and sunflower products fed to finishing pigs. Each of 8 barrows (average initial BW = 106.6 ± 5.5 kg) were surgically fitted with a T-cannula in the distal ileum. Pigs were allotted to an 8 × 8 Latin square design with 8 diets and 8 periods. The 7 protein ingredients were canola seeds (CS), canola meal (CM), cottonseed meal (CSM), sunflower seeds (SFS), sunflower meal (SFM), dehulled sunflower meal (SFM-DH), and SBM, with each ingredient included as the sole source of AA in the diet. A N-free diet was used to estimate basal endogenous losses of AA. Among tested ingredients, SBM had the greatest ($P < 0.05$) SID of Lys, and CS had the least ($P < 0.05$) SID of Phe, Thr, and Tyr. The SID of all indispensable AA except Trp was less ($P < 0.05$) in CS than SBM, and CM had a greater ($P < 0.05$) SID of all indispensable AA except Arg, His, Lys, and Trp than CS. However, the SID of all indispensable AA except Arg and Trp were less ($P < 0.05$) in CM than in SBM. The SID of all indispensable AA except Arg and Trp also were less ($P < 0.05$) in CSM than in SBM, and the SID of Met was less ($P < 0.05$) in CSM than in all other ingredients. Among sunflower products, the SID of His, Leu, Phe, and Thr were less ($P < 0.05$) in SFM-DH than in SFS and SFM, and the SID of Ile, Met, and Val were less ($P < 0.05$) in SFM-DH than in SFS; however, for CP, Arg, Lys, and Trp, no differences among SFS, SFM, and SFM-DH were observed. The SID of all indispensable AA except Trp were less ($P < 0.05$) in SFM-DH than SBM, and the SID of His, Ile, Lys, Thr, and Val in SFM were also less ($P < 0.05$) than in SBM. Except for Lys, no differences between SBM and SFS were observed. In conclusion, the SID of most AA in CS, CM, CSM, SFM, and SFM-DH are less than in SBM.

Key words: amino acid digestibility, canola, cottonseed, pigs, soybean meal, sunflower

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INTRODUCTION

Soybeans, cottonseeds, canola (rapeseed), and sunflowers are the major oilseeds produced in the world (Salunkhe et al., 1992). Oilseed products are important protein sources that contribute to meeting the demand for plant proteins around the world (Church and Kellems, 1998). Soybean meal (**SBM**) is the premier protein source in diets fed to pigs and poultry because the profile of AA in SBM complements cereal grains to meet the nutritional requirements (Smith, 1986; Harris, 1997; Stein et al., 2008). Because of the global increase in poultry, livestock, and aquaculture production, the demand for SBM is rapidly increasing, and the production of soybeans is therefore increasing faster than any other agricultural crop in the world (Goldsmith, 2008). Even with this increase, demand is greater than supply, and the global stocks of soybeans were at historically low levels at the end of the 2010–2011 crop year (USDA, 2010).

Canola, cotton, and sunflower products are alternative protein sources that usually are less expensive than SBM and can be used in diets fed to pigs and poultry. However, the AA composition of these proteins is less favorable than in SBM (Smith, 1986; Cromwell, 1998), and the apparent ileal digestibility (**AID**) of most AA in canola, cotton, and sunflower products is less than in SBM (Tanksley et al., 1981; Jørgensen et al., 1984; Moon et al., 1994). Although swine diets are most accurately formulated on the basis of values for standardized ileal digestibility (**SID**) of AA (Stein et al., 2007), there is a scarcity of values for the SID of AA for canola, cotton, and sunflower products. There-

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fore, our objective was to determine the AID and the SID of CP and AA in SBM and canola, cotton, and sunflower products fed to finishing pigs.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for the experiment.

Animals and Housing

Eight finishing pigs (Landrace × Large White crossbred barrows; Genetiporc, Alexandria, MN) with an average initial BW of 106.6 ± 5.5 kg were used. Pigs were surgically fitted with a T-cannula in the distal ileum (Stein et al., 1998) when they had a BW of approximately 25 kg, and all pigs had been used in another experiment before being assigned to this experiment. Animals were allotted to an 8 × 8 Latin square design with 8 diets and 8 periods. A spreadsheet-based program was used to balance for potential residual effects in the Latin square (Kim and Stein, 2009). Pigs were housed individually in 2.33 m × 2.74 m pens with concrete slatted floors. A feeder and a nipple drinker were installed in each pen, and the environment of the room was automatically controlled between 20 and 24°C and with a dark-light cycle of 12 and 12 h.

Diets and Feeding

Seven protein-containing ingredients were used (Table 1). Canola products included canola seeds (**CS;** Specialty commodities, Burnsville, MN) and canola meal (**CM;** CP Feeds LLC., Valders, WI). Cottonseed meal (**CSM;** Delta Oil Mill, Jonestown, MS) was also used, and sunflower seeds (**SFS;** Anderson Seed Company, Mentor, MN), sunflower meal (**SFM;** ADM Milling Co, Kansas City, MO), and dehulled sunflower meal (**SFM-DH;** ADM Northern Sun Division, Enderlin, ND) were the sunflower products that were used. Dehulled soybean meal (**SBM;** Solae LLC., Gibson City, IL) was also included in the experiment.

Eight diets were prepared (Tables 2 and 3); 7 diets contained 1 of the 7 protein-containing ingredients as the sole source of AA. The last diet was a N-free diet that was used to estimate basal ileal endogenous losses of CP and AA in the pigs. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). All diets contained 0.4% chromic oxide as an indigestible marker. The N-free diet also contained 4% of a fiber source (Solka floc; Fiber Sales and Development Corp., Urbana, OH) to increase the concentration of crude fiber, and magnesium oxide and potassium carbonate were included in the N-free diet because the ingredients that were included in this diet did not contain Mg and K.

Pigs were fed once daily at a level of 3 times the maintenance energy requirement (106 kcal ME/kg BW 0.75; NRC, 1998). At the beginning of each period, the BW of each pig was recorded, and the feed allowance for each pig was adjusted. Animals had free access to water throughout the experiment.

Sample Collection

Each period of the Latin square lasted 6 d. The initial 4 d were for adaptation to the diet, and on d 5 and 6, ileal digesta samples were collected for 8 h. For collection of samples, cannulas were opened, a plastic bag was attached to the cannula barrel using a cable tie, and the digesta flowing into the bag were collected. When bags were filled with digesta, or at least once every 30 min, they were removed, and a new bag was attached to the cannula. Digesta samples were stored at −20°C to prevent bacterial degradation of AA.

Chemical Analyses

At the conclusion of each period, ileal samples were thawed at room temperature and mixed within animal and diet, and a subsample was collected. All samples were lyophilized and finely ground before chemical analyses.

Two samples of each of the protein-containing ingredients were collected and analyzed. Samples of each ingredient, a sample of each diet, and samples of ileal digesta were analyzed for DM (method 930.15; AOAC International, 2007), for CP (N × 6.25) by combustion using an apparatus (Elementar Rapid N-Cube Protein/Nitrogen Apparatus; Elementar Americas Inc., Mount Laurel, NJ; method 990.03; AOAC International, 2007), and for AA with an analyzer (Hitachi Amino Acid Analyzer Model L8800; Hitachi High Technologies America, Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard [method 982.30 E(a, b, c); AOAC International, 2007]. Ingredient and diet samples also were analyzed for dry ash (method 942.05; AOAC International, 2007). The Cr concentration of diets and ileal digesta were measured using an inductive coupled plasma atomic emission spectrometric method (method 990.08; AOAC International, 2007) after nitric acid–perchloric acid wet ash sample preparation [method 968.088 D(b); AOAC International, 2007]. The protein-containing ingredients were analyzed for acid-hydrolyzed ether extract (**AEE**) by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.06; AOAC International, 2007) on an au-

Table 1. Analyzed composition of canola seeds (CS), canola meal (CM), cottonseed meal (CSM), sunflower seeds (SFS), sunflower meal (SFM), dehulled sunflower meal (SFM-DH), and soybean meal (SBM), as-fed basis[1]

Item	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	SEM	P-value
GE, kcal/kg	6,415[b]	4,291[cd]	4,307[c]	7,196[a]	4,194[e]	4,218[de]	4,266[cde]	40	<0.001
DM, %	93.5[b]	89.6[d]	89.3[d]	95.8[a]	89.9[cd]	91.1[c]	89.2[d]	0.4	<0.001
CP, %	24.6[f]	39.0[c]	42.3[b]	22.1[g]	29.4[e]	37.3[d]	49.8[a]	0.5	<0.001
Ash, %	3.4[d]	7.6[a]	8.1[a]	3.1[d]	6.3[b]	7.6[a]	5.8[c]	0.1	<0.001
AEE,[2] %	41.2[b]	4.1[c]	3.8[cd]	54.5[a]	1.6[cd]	2.1[cd]	1.3[d]	0.8	<0.001
ADF, %	16.6[c]	18.6[bc]	17.1[bc]	7.6[d]	29.2[a]	21.9[b]	5.4[d]	1.5	<0.001
NDF, %	21.3[c]	32.2[ab]	24.6[bc]	8.1[d]	39.3[a]	30.3[abc]	9.1[d]	2.8	<0.001
GLS,[3] μmol/g	21.0	1.7	ND[4]	ND	ND	ND	ND	2.7	0.037
Indispensable AA, %									
Arg	1.42[e]	2.12[d]	4.25[a]	1.84[d]	2.08[d]	2.69[c]	3.48[b]	0.09	<0.001
His	0.63[de]	1.01[b]	1.07[b]	0.58[e]	0.68[d]	0.90[c]	1.29[a]	0.03	<0.001
Ile	0.96[e]	1.47[b]	1.29[c]	0.97[e]	1.15[d]	1.47[b]	2.26[a]	0.03	<0.001
Leu	1.61[d]	2.57[b]	2.31[c]	1.41[e]	1.74[d]	2.26[c]	3.70[a]	0.04	<0.001
Lys	1.40[d]	1.89[b]	1.71[c]	0.79[g]	1.01[f]	1.25[e]	2.97[a]	0.05	<0.001
Met	0.47[e]	0.69[b]	0.63[cd]	0.48[e]	0.58[d]	0.76[a]	0.65[bc]	0.02	<0.001
Phe	0.92[f]	1.43[d]	2.09[b]	1.04[f]	1.23[e]	1.60[c]	2.43[a]	0.04	<0.001
Thr	0.90[d]	1.44[b]	1.21[c]	0.74[e]	0.92[d]	1.23[c]	1.77[a]	0.04	<0.001
Trp	0.31[c]	0.44[b]	0.33[c]	0.25[d]	0.32[c]	0.43[b]	0.65[a]	0.04	<0.001
Val	1.21[e]	1.94[b]	1.79[c]	1.18[e]	1.43[d]	1.82[c]	2.43[a]	0.04	<0.001
Total	9.80[e]	14.99[c]	16.66[b]	9.25[e]	11.12[d]	14.38[c]	21.62[a]	0.32	<0.001
Dispensable AA, %									
Ala	0.99[d]	1.58[b]	1.57[b]	0.92[d]	1.17[c]	1.50[b]	2.06[a]	0.05	<0.001
Asp	1.56[f]	2.45[d]	3.49[b]	1.88[e]	2.37[d]	3.01[c]	5.28[a]	0.09	<0.001
Cys	0.59[c]	0.83[a]	0.65[b]	0.34[e]	0.44[d]	0.55[c]	0.65[b]	0.02	<0.001
Glu	3.81[e]	5.74[c]	7.30[b]	3.86[e]	4.79[d]	6.23[c]	8.35[a]	0.27	<0.001
Gly	1.13[e]	1.79[bc]	1.64[cd]	1.17[e]	1.49[d]	1.91[ab]	2.03[a]	0.05	<0.001
Pro	1.35[c]	2.09[b]	1.36[c]	0.86[e]	1.08[d]	1.42[c]	2.34[a]	0.04	<0.001
Ser	0.77[de]	1.18[c]	1.40[b]	0.72[e]	0.88[d]	1.18[c]	1.97[a]	0.06	<0.001
Tyr	0.64[e]	0.97[c]	1.11[b]	0.59[e]	0.62[e]	0.85[d]	1.73[a]	0.03	<0.001
Total	10.82[e]	16.60[c]	18.50[b]	10.32[e]	12.82[d]	16.62[c]	24.40[a]	0.58	<0.001

[a–e]Means in a row that do not have a common superscript differ, $P < 0.05$.

[1]Means are the average of 2 analyzed samples of each ingredient.

[2]AEE = acid-hydrolyzed ether extract.

[3]GLS = glucosinolates.

[4]ND = not determined.

tomated analyzer (Soxtec 2050; FOSS North America, Eden Prairie, MN). These samples also were analyzed for GE using an adiabatic bomb calorimeter (model 6300; Parr Instruments, Moline, IL) and for ADF (method 973.18; AOAC International, 2007) and NDF (Holst, 1973). Canola meal and canola seeds were analyzed for glucosinolates using a HPLC with a diode array detector (Agilent 1100; Santa Clara, CA; method 9167-1; International Organization for Standardization, 1992).

Calculations and Statistical Analyses

Values for AID and SID of CP and AA in each ingredient were calculated as described previously (Stein et al., 2007). Data were analyzed using the MIXED procedure (SAS Inst., Inc., Cary, NC; Saxton, 1998) with pig as the experimental unit. The model included the fixed effect of diet, whereas period and animal were random effects. Means were calculated using the LSMEANS statement, and when significant F-tests for treatment were observed, means were separated using the PDIFF option. An α value of 0.05 was used to assess differences among means.

RESULTS

Composition of Ingredients

Among all ingredients, the concentrations of DM, GE, and AEE were greatest ($P < 0.01$; Table 1) in SFS, but SFS had the least ($P < 0.01$) concentration of CP. The concentration of CP was greatest ($P < 0.01$) in SBM, and the concentration of ADF was greatest ($P < 0.01$) in SFM.

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

	Diet[1]							
Ingredient, %	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	N free
Protein source	50.0	45.0	42.0	50.0	50.0	45.0	34.0	—
Cornstarch	37.3	39.3	42.3	37.3	34.3	39.3	50.3	73.1
Sucrose	10.0	10.0	10.0	10.0	10.0	10.0	10.0	15.0
Soybean oil	—	3.0	3.0	—	3.0	3.0	3.0	4.0
Solka floc[2]	—	—	—	—	—	—	—	4.0
Limestone	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Monocalcium phosphate	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.5
Chromic oxide	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sodium chloride	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Vitamin-micromineral premix[3]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Potassium carbonate	—	—	—	—	—	—	—	0.4
Magnesium oxide	—	—	—	—	—	—	—	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1]CS = canola seeds; CM = canola meal; CSM = cottonseed meal; SFS = sunflower seeds; SFM = sunflower meal; SFM-DH = dehulled sunflower meal; and SBM = soybean meal.

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

[3]The vitamin-micromineral premix provided the following quantities of vitamins and minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D3 as cholecalciferol, 2,204 IU; vitamin E as dl-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; d-pantothenic acid as d-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

The concentration of total indispensable AA was greatest ($P < 0.01$) in SBM, the concentration of Met was greatest ($P < 0.01$) in SFM-DH, and the concentration of Arg was greatest ($P < 0.01$) in CSM. The concentrations of Leu, Lys, Thr, and Trp were least ($P < 0.01$) in SFS. Soybean meal also had the greatest ($P < 0.01$) concentration of all dispensable AA except for Cys, which was present at the greatest ($P < 0.01$) concentration in CM.

Among canola products, the concentration of GE, DM, and AEE in CS was greater ($P < 0.01$) than in CM, but the concentrations of CP, ash, NDF, and all indispensable and dispensable AA were greater ($P < 0.01$) in CM than in CS. The concentration of glucosinolates was greater ($P < 0.05$) in CS than in CM (21.0 and 1.7 μmol/g, respectively). The concentration of most AA was greater ($P < 0.01$) in SBM than in CSM, but no differences were observed in Met and Cys concentration between CSM and SBM.

Among sunflower products, the concentrations of CP, ash, and all AA were greater ($P < 0.01$) in SFM-DH than in SFS and SFM; however, no differences ($P < 0.01$) in the concentrations of GE, DM, AEE, and NDF between SFM-DH and SFM were observed. The concentrations of CP, ash, ADF, NDF, and all AA except Arg and Tyr were greater ($P < 0.01$) in SFM than in SFS, but the concentrations of GE, DM, and AEE were greater ($P < 0.01$) in SFS than in SFM and SFM-DH. The concentrations of most AA were greater ($P < 0.01$) in SBM than in the sunflower products.

AID and SID of CP and AA

Among all ingredients, SBM had the greatest ($P < 0.05$) AID of Lys, Ser, and Tyr and the greatest ($P < 0.05$) SID of Lys (Tables 4 and 5). Cottonseed meal had the least ($P < 0.05$) AID and SID of Met, and CS had the least ($P < 0.05$) AID of CP, Arg, Phe, Thr, Val, Asp, Glu, Ser, and Tyr, as well as the least ($P < 0.05$) SID of Phe, Thr, and Tyr. Soybean meal had greater ($P < 0.05$) AID and SID of all indispensable AA, except Trp, than CS, and SBM had greater ($P < 0.05$) AID of all indispensable AA, except Met and Trp, and greater ($P < 0.05$) SID of all indispensable AA, except Arg and Trp, than CM. Among canola products, CM had greater ($P < 0.05$) AID of all indispensable AA, except Trp, and greater ($P < 0.05$) SID of all indispensable AA, except Arg, His, Lys, and Trp, than CS. The AID and SID of all indispensable AA, except Arg and Trp, were greater ($P < 0.05$) in SBM than in CSM. The AID and SID of Lys were greater ($P < 0.05$) in SBM than in SFS, but for all other indispensable AA, no differences between SBM and SFS were observed. The AID of Leu and the AID and SID of His, Ile, Lys, Thr, and Val were greater ($P < 0.05$) in SBM than in SFM, but for all other indispensable AA, no differences between SBM and SFM were observed. The AID of all indispensable AA except Met and Trp and the SID of all indispensable AA except Trp were greater ($P < 0.05$) in SBM than in SFM-DH. Among sunflower products, the AID of Lys and Phe and the SID of His, Leu, Phe, and Thr were less ($P < 0.05$) in SFM-DH than in SFS and SFM. In addition, the AID of

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

Item	Diet[1]							
	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	N free
DM, %	92.8	90.5	89.8	94.1	90.9	91.4	90.6	90.2
Ash, %	4.8	5.6	5.4	3.9	5.3	5.6	4.5	2.4
CP, %	10.5	17.0	15.8	15.2	15.1	15.4	15.8	0.3
Indispensable AA, %								
Arg	0.67	1.00	1.71	1.32	1.13	1.15	1.18	0.03
His	0.30	0.46	0.44	0.40	0.35	0.37	0.43	0.01
Ile	0.45	0.70	0.53	0.69	0.61	0.65	0.77	0.02
Leu	0.77	1.23	0.96	1.02	0.93	0.97	1.27	0.04
Lys	0.63	0.88	0.69	0.57	0.52	0.51	0.99	0.03
Met	0.21	0.32	0.24	0.36	0.30	0.31	0.22	—
Phe	0.44	0.71	0.86	0.76	0.67	0.70	0.83	0.03
Thr	0.42	0.69	0.50	0.54	0.50	0.51	0.59	0.02
Trp	0.15	0.21	0.15	0.17	0.18	0.19	0.23	<0.04
Val	0.59	0.91	0.75	0.83	0.75	0.80	0.83	0.05
Total	4.63	7.11	6.83	6.65	5.94	6.16	7.34	0.23
Dispensable AA, %								
Ala	0.47	0.76	0.64	0.66	0.63	0.65	0.71	0.03
Asp	0.76	1.21	1.43	1.40	1.30	1.33	1.83	0.05
Cys	0.26	0.39	0.25	0.25	0.23	0.24	0.22	0.01
Glu	1.92	2.79	2.99	2.90	2.62	2.73	2.88	0.14
Gly	0.53	0.86	0.67	0.86	0.80	0.83	0.70	0.03
Pro	0.65	0.99	0.57	0.63	0.56	0.62	0.80	0.03
Ser	0.38	0.57	0.57	0.55	0.50	0.50	0.65	0.03
Tyr	0.28	0.45	0.43	0.39	0.34	0.34	0.52	—
Total	0.47	0.76	0.64	0.66	0.63	0.65	0.71	0.32

[1]CS = canola seeds; CM = canola meal; CSM = cottonseed meal; SFS = sunflower seeds; SFM = sunflower meal; SFM-DH = dehulled sunflower meal; and SBM = soybean meal.

His, Ile, Leu, Met, Thr, and Val and the SID of Ile, Met, and Val were less ($P < 0.05$) in SFM-DH than in SFS; however, for the AID and SID of CP, Arg, and Trp and the SID of Lys, no differences among SFS, SFM, and SFM-DH were observed.

DISCUSSION

Composition of Ingredients

The concentrations of CP, AEE, ash, ADF, and NDF observed in the SBM used in this experiment agree with values reported by Harris (1997), and the concentrations of GE, CP, and all AA agree with values reported by Baker and Stein (2009). Aside from soybeans, the most abundant oilseeds produced in the world are cottonseeds, canola seeds, and sunflower seeds (Salunkhe et al., 1992), and the production of canola has increased in recent years (Newkirk, 2009). The de-oiled meals from these oilseeds may be used, but the full-fat seeds of canola and sunflowers also are valuable ingredients in swine diets (Aherne and Bell, 1990) because of their high energy concentration and ease of handling in feed mills (Thacker, 1998).

Canola represents varieties of rapeseed that are low in glucosinolates and erucic acid, which have antinutritional properties in diets fed to pigs (Aherne and Bell, 1990). The concentrations of CP and AEE in the CS used in this experiment agree with values reported by Aherne and Bell (1990) and by Pritchard (1991), but the concentrations of CP and most AA were greater than values reported by Sauvant et al. (2004) for full-fat rapeseed. Canola meal is a coproduct of canola oil production that can replace SBM in swine diets (Thacker, 1990). Although there is variability in the concentration of nutrients among sources of CM, the concentrations of indispensable AA in the source of CM used in this experiment are within the range of values reported by NRC (1998) and Sauvant et al. (2004). The concentration of glucosinolates in CS was within the range of values reported by Daun (1986), but the concentration of glucosinolates in CM that we observed was less than previously reported values (Bonnardeaux, 2007).

Cottonseed is the second largest source of plant protein produced in the United States, and CSM is the de-oiled meal of cottonseeds. The concentrations of CP and all AA in the CSM used in the present experiment agree with values reported by NRC (1998) and by Sauvant et al. (2004), but the concentrations of CP and Lys in CSM were greater than previously reported values [Fundación Española para el Desarrollo de la Nutrición Animal (**FEDNA**), 2003].

Sunflower seeds are mainly produced for oil extrac-

Table 4. Apparent ileal digestibility of CP and AA in canola seeds (CS), canola meal (CM), cottonseed meal (CSM), sunflower seeds (SFS), sunflower meal (SFM), dehulled sunflower meal (SFM-DH), and soybean meal (SBM)[1]

	Ingredient								
Item	CS	CM	CSM	SFS	SFM	SFM-DH	SBM	SEM	*P*-value
CP, %	41.7[c]	57.8[b]	57.3[b]	63.1[ab]	61.8[ab]	56.3[b]	71.1[a]	3.9	<0.001
Indispensable AA, %									
Arg	63.9[c]	76.5[b]	81.1[ab]	81.7[ab]	82.1[ab]	77.1[b]	85.3[a]	2.9	<0.001
His	65.7[e]	74.6[bc]	71.0[cde]	79.2[ab]	74.2[bcd]	68.1[de]	84.6[a]	2.3	<0.001
Ile	58.3[d]	71.2[c]	59.8[d]	80.2[ab]	74.9[bc]	69.8[c]	83.6[a]	2.2	<0.001
Leu	60.8[e]	73.4[bc]	62.7[de]	79.1[ab]	75.3[bc]	68.9[cd]	83.2[a]	2.3	<0.001
Lys	47.3[d]	59.6[bc]	46.6[d]	62.2[b]	62.1[b]	52.8[cd]	81.5[a]	3.3	<0.001
Met	69.2[c]	80.5[b]	61.8[d]	86.9[a]	84.7[ab]	80.2[b]	84.5[ab]	1.9	<0.001
Phe	60.8[d]	73.1[bc]	74.7[bc]	82.3[a]	78.5[ab]	71.7[c]	84.1[a]	2.3	<0.001
Thr	45.7[e]	62.4[cd]	55.7[d]	70.8[ab]	65.4[bc]	58.3[cd]	75.5[a]	2.7	<0.001
Trp	76.5	80.9	81.3	79.6	81.6	81.1	85.9	2.0	0.054
Val	57.1[e]	68.9[cd]	63.9[d]	77.9[ab]	72.6[bc]	68.4[cd]	81.0[a]	2.3	<0.001
Mean	58.5[e]	70.9[cd]	67.5[d]	78.3[ab]	75.2[bc]	69.5[cd]	82.8[a]	2.3	<0.001
Dispensable AA, %									
Ala	48.9[c]	64.3[ab]	53.7[c]	64.1[ab]	64.3[ab]	57.4[bc]	73.2[a]	3.6	<0.001
Asp	55.7[d]	62.4[c]	66.7[bc]	78.4[a]	71.6[b]	63.4[c]	81.4[a]	2.3	<0.001
Cys	62.5[cd]	67.7[bc]	64.4[cd]	76.1[a]	64.5[cd]	60.0[d]	72.8[ab]	2.4	<0.001
Glu	72.9[d]	79.7[bc]	79.2[bc]	85.5[a]	83.1[ab]	78.3[c]	83.9[ab]	1.8	<0.001
Gly	28.5	45.6	38.1	43.4	36.9	28.2	50.2	7.8	0.167
Pro	−53.3[ab]	−7.1[a]	−98.9[bc]	−153.5[c]	-81.8[abc]	−91.3[bc]	-21.6[ab]	43.4	0.020
Ser	50.5[e]	62.7[cd]	65.4[c]	73.3[b]	66.5[c]	58.6[d]	80.5[a]	2.5	<0.001
Tyr	51.5[d]	69.4[bc]	69.3[bc]	75.3[b]	75.4[b]	67.8[c]	83.2[a]	2.6	<0.001
Mean[2]	58.8[d]	68.2[bc]	68.1[c]	75.1[ab]	70.8[bc]	64.3[cd]	78.5[a]	2.6	<0.001

[a–e]Means in a row that do not have a common superscript letter differ, $P < 0.05$.

[1]Least squares means; n = 8/treatment.

[2]Values for Pro were not included in the calculated mean for dispensable AA.

tion; however, as a result of the high concentration of energy, SFS is also a potential ingredient for inclusion in swine diets. Sunflower products are free of most antinutritional factors (Wahlstrom, 1990; Chiba, 2001), but inclusion of SFS in swine diets is limited by the high fiber concentration (Wahlstrom, 1990). The concentrations of CP and AEE in the SFS used in this experiment agree with values reported by Salunkhe et al. (1992).

Dehulled sunflower meal is produced after oil is extracted from dehulled SFS. The nutrient concentration in SFM-DH varies depending on the method used for oil extraction and the amount of hulls removed (Harris, 1997). The concentration of CP in SFM-DH is typically around 40%, but partially dehulled meals can contain only 30% to 35% CP (Dinusson, 1990). The concentrations of most indispensable and dispensable AA in the SFM-DH used in this experiment agree with previous values (NRC, 1998; FEDNA, 2003), and the CP concentration indicates that most of the hulls had been removed.

Sunflower meal is produced after oil has been extracted from SFS. Sunflower meal is deficient in Lys (Chiba, 2001), but the exact concentration of nutrients in SFM depends on the extraction process and the amount of residual oil left after oil extraction (Dinusson, 1990). The concentration of AEE in the SFM used in the present experiment was low, indicating that most of the oil had been extracted, and the concentrations of AA in the SFM agree with reported values (NRC, 1998; Sauvant et al., 2004). The NDF and ADF values in the SFM also agree with the values reported by Jondreville et al. (2000). The Association of American Feed Control Officials (**AAFCO**, 2011) notes that "solvent extracted sunflower meal is obtained by grinding the residue remaining after extraction of most of the oil from whole sunflower seed by a solvent extraction process." Therefore, it was expected that the concentration of nutrients in SFM would increase proportionally to the amount of oil extracted from the SFS. Sunflower seeds contained 54.5% AEE, and SFM contained only 1.6% AEE. As a consequence, more than a 2-fold increase in the concentration of all other nutrients was expected in SFM compared with SFS. Nonetheless, the concentration of CP in SFM increased by only 33%, whereas the concentration of NDF increased by more than 380% relative to the concentration of CP and NDF in SFS. The reason for these discrepancies is not clear, but it is possible that hulls removed from sunflowers to produce SFM-DH are added to SFM, which would explain why the concentration of NDF in SFM was much greater than expected.

Table 5. Standardized ileal digestibility of CP and AA in canola seeds (CS), canola meal (CM), cottonseed meal (CSM), sunflower seeds (SFS), sunflower meal (SFM), de-hulled sunflower meal (SFM-DH), and soybean meal (SBM)[1,2]

Item	Ingredient							SEM	*P*-value
	CS	CM	CSM	SFS	SFM	SFM-DH	SBM		
CP, %	68.1[c]	73.7[bc]	74.3[bc]	81.6[ab]	79.8[ab]	74.1[bc]	88.2[a]	3.9	0.004
Indispensable AA, %									
Arg	81.5[c]	88.0[abc]	87.8[abc]	90.7[ab]	92.3[ab]	87.2[bc]	95.1[a]	2.9	0.019
His	73.5[d]	79.6[bcd]	76.2[cd]	85.2[ab]	80.8[bc]	74.3[d]	90.0[a]	2.3	<0.001
Ile	66.6[d]	76.4[c]	66.7[d]	85.7[ab]	80.9[bc]	75.4[c]	88.3[a]	2.2	<0.001
Leu	68.5[e]	78.1[bc]	68.6[de]	85.0[a]	81.5[ab]	75.0[cd]	87.8[a]	2.3	<0.001
Lys	58.8[cd]	67.7[bc]	56.8[d]	75.3[b]	75.8[b]	66.7[bc]	88.6[a]	3.3	<0.001
Met	74.4[c]	83.9[b]	66.3[d]	90.0[a]	88.3[ab]	83.6[b]	89.3[a]	1.9	<0.001
Phe	68.9[d]	78.0[bc]	78.7[bc]	87.1[a]	83.7[ab]	76.7[c]	88.3[a]	2.3	<0.001
Thr	59.2[e]	70.5[cd]	66.7[d]	81.5[ab]	76.5[bc]	69.3[d]	84.9[a]	2.7	<0.001
Trp	83.5	85.8	88.1	85.8	87.3	86.5	90.3	2.0	0.263
Val	65.4[e]	74.1[cd]	70.3[de]	83.9[ab]	79.0[bc]	74.4[cd]	86.8[a]	2.3	<0.001
Mean	68.7[d]	77.4[bc]	74.2[cd]	85.5[a]	83.0[ab]	77.0[bc]	89.1[a]	2.3	<0.001
Dispensable AA, %									
Ala	68.1[c]	75.9[bc]	67.3[c]	78.0[ab]	78.3[ab]	71.1[bc]	85.5[a]	3.6	<0.001
Asp	68.4[c]	70.1[c]	73.2[bc]	85.3[a]	78.8[b]	70.5[c]	86.5[a]	2.3	<0.001
Cys	70.7[b]	73.0[b]	72.7[b]	84.8[a]	73.6[b]	68.7[b]	82.3[a]	2.4	<0.001
Glu	79.0[d]	83.8[bcd]	83.0[cd]	89.6[a]	87.5[abc]	82.5[d]	87.9[ab]	1.8	<0.001
Gly	78.7	75.8	76.6	74.8	69.5	59.8	87.3	7.8	0.157
Pro	137.1	115.0	112.0	46.0	135.1	105.5	129.4	43.4	0.353
Ser	64.8[e]	72.0[cd]	74.6[cd]	83.3[ab]	77.1[bc]	69.3[de]	88.7[a]	2.5	<0.001
Tyr	61.9[d]	75.7[c]	75.9[bc]	83.0[ab]	83.7[a]	76.2[bc]	88.7[a]	2.6	<0.001
Mean[3]	73.4[c]	77.5[bc]	77.5[bc]	84.8[a]	81.1[ab]	74.3[bc]	87.2[a]	2.6	0.001

[a–e]Means in a row that do not have a common superscript letter differ, $P < 0.05$.

[1]Least squares means; n = 8/treatment.

[2]Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses. Basal endogenous losses were determined, using pigs fed the N-free diet, as (g/kg DMI) CP, 29.93; Arg, 1.27; His, 0.25; Ile, 0.40; Leu, 0.64; Lys, 0.78; Met, 0.12; Phe, 0.39; Thr, 0.61; Trp, 0.11; Val, 0.53; Ala, 0.97; Asp, 1.03; Cys, 0.23; Glu, 1.27; Gly, 2.87; Pro, 13.35; Ser, 0.58; and Tyr, 0.31.

[3]Values for Pro were not included in the calculated mean for dispensable AA.

AA Digestibility

The SID values for AA in SBM that we observed agree with previous reports (NRC, 1998; Cervantes-Pahm and Stein, 2008; Baker and Stein, 2009). The fact that the SID of AA in CM and SFM-DH were less than in SBM might be a result of the greater concentration of ADF and NDF in CM and SFM-DH than in SBM because increased concentrations of ADF and NDF have a depressive effect on values for AA digestibility (Sauer et al., 1980; Lenis et al., 1996). Values for the AID of AA in CM agree with previous reports (Fan and Sauer, 1995; Fan et al., 1996), and values for the SID of most AA in CM are in agreement with values reported previously (Stein et al., 2001, 2005). In contrast, the AID and SID of Lys obtained for CM in this experiment are less than values in most previous reports, and the Lys:CP ratio in the CM used in this experiment was less than the value that can be calculated from NRC (1998). This observation may be a result of overheating of the canola meal during the desolventizer-toasting phase, which may negatively affect Lys concentration and digestibility (Newkirk et al., 2003). The most likely reason for this effect is that overheating results in Maillard reactions, which decrease the concentration and the digestibility of Lys (Pahm et al., 2008; González-Vega et al., 2011).

Most antinutritional factors in feed ingredients have a negative effect on AA digestibility (Gilani et al., 2005);

however, glucosinolates in concentrations of up to 10 mmol/g have not influenced the digestibility of DM, CP, and AA in pigs or rats (Sauer et al., 1982; Aumaitre et al., 1989). Thus, it is likely that the SID of AA in CM were not affected by the concentration of glucosinolates. Conversely, the concentration of glucosinolates in CS was 21 mmol/g, which might have contributed to the decreased SID of AA in CS compared with CM.

The values for the AID and SID of most AA in CSM that were determined in this experiment are within the range of previous values (Batterham et al., 1990; NRC, 1998; Sauvant et al., 2004; Rostagno et al., 2005), with the exception that the AID and SID of Lys and the SID of Met are less than previously reported. The low digestibility of Lys in CSM may be a result of heat damage because cottonseed is heated to inactivate the gossypol that is present in the seeds, and during this process, a gossypol-lysine complex can form (Conkerton et al., 1957; Batterham et al., 1990; Church and Kellems, 1998). In addition, if heat is applied to a feed ingredient for an extended period, it can decrease the AID and SID of Lys because of formation of Maillard products (Pahm et al., 2008; González-Vega et al., 2011).

The values for the SID of all AA in SFM obtained in this experiment agree with values reported by Jondreville et al. (2000); however, the values for the SID of all AA in SFM-DH were less than values previously reported (NRC, 1998; Sauvant et al., 2004). The reason for the decreased SID of AA is not clear because NDF values and CP values in the SFM-DH used in this experiment were within the range of values previously reported (NRC, 1998; Sauvant et al., 2004). It is possible that differences among varieties of sunflowers results in different digestibility values, which may have affected the results.

The reason for the greater SID of AA in SFS than in SFM and SFM-DH may be that the concentration of fiber in SFS is less than in SFM and SFM-DH. The high concentration of oil in SFS also may contribute to an increased AA digestibility because dietary oil has a positive influence on AA digestibility (Li and Sauer, 1994; Cervantes-Pahm and Stein, 2008). When fed to broilers, the digestibility of AA in SFS was also greater than in SFM (San Juan and Villamide, 2001).

The negative values that were observed for the AID of Pro in this experiment are a consequence of secretion of endogenous Pro into the intestinal tract of pigs (Stein et al., 1999). Proline is usually the AA that is present in endogenous losses in the greatest concentrations (Stein et al., 1999; Moter and Stein, 2004), which also was observed in the present experiment. It is therefore generally accepted that values for the AID and SID of Pro that are determined using the procedures employed in this experiment are not always reliable (Stein et al., 1999).

In conclusion, SBM had greater AID and SID of AA compared with the AID and SID of AA in canola, cottonseed, and sunflower products, with the exception that the AID and SID of most AA in SFS were not different from those in SBM. As a consequence, greater concentrations of the defatted meals of canola, cotton, and sunflowers need to be included in diets fed to pigs to reach a certain concentration of digestible AA. Canola seeds had the least AID and SID of most AA, but CM had a relatively high concentration of digestible AA. Full-fat SFS had a high energy concentration and a relatively high AA digestibility; thus, SFS may be used as a source of energy as well as of digestible AA in diets fed to pigs.

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