Chemical composition, energy, and amino acid digestibility in 7 cottonseed co-products fed to growing pigs

D. L. Ma,¹ X. K. Ma,¹ L. Liu, and S. Zhang²

State Key Laboratory of Animal Nutrition, Ministry of Agriculture Feed Industry Centre, China Agricultural University, Beijing 100193, China

ABSTRACT: The objective of this study was to determine the chemical composition, DE and ME contents, and apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of AA in 7 cottonseed co-products fed to growing pigs. The 7 cottonseed co-products were: cottonseed meals (solvent extracted) with CP level of 46%, 50%, and 55% (**46CSM**, **50CSM**, and **55CSM**), cottonseed protein with CP level of 50% and 55% (**50CSP** and **55CSP**), fermented cottonseed meal (**CSMF**), and expelled cottonseed meal (**CSME**). The DE and ME contents of the 7 test ingredients were measured using 48 crossbreed barrows (BW: 44.1 ± 4.2 kg) and 8 diets (including a corn-soybean meal basal diet) in a completely randomized design. The AID and SID of AA of the 7 test ingredients were determined using 7 crossbreed barrows (initial BW: 67.4 ± 8.5 kg) in a 6×8 Youden square design with 6 periods and 8 diets (including one N-free diet). The DE and

ME values of the 7 cottonseed co-products varied from 12.72 to 15.63 MJ/kg and 12.24 to 14.83 MJ/kg, respectively. Among the 7 cottonseed co-products, 55CSP and CSME had the greatest ($P < 0.05$) ME and DE values compared to the other cottonseed co-products. In addition, 55CSP had the greatest ($P < 0.05$) AID and SID of all the AA tested except for Gly and Pro. In contrast, 46CSM or 55CSM had the lowest ($P < 0.05$) AID and SID of all the AA tested except for Gly and Pro. The 55CSP also had the greatest ($P < 0.05$) concentrations of standardized ileal digestible CP and all the AA tested except for Gly and Pro. In conclusion, the chemical composition, energy, and AA digestibility of cottonseed co-products with different processing techniques varied widely. Based on the energy and AA digestibility, cottonseed protein with CP level of 55% is a better dietary ingredient for growing pigs compared with the other cottonseed co-products.

Key words: amino acid digestibility, cottonseed meal, cottonseed protein, energy, pigs

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

J. Anim. Sci. 2018.96:1338–1349

doi: 10.1093/jas/sky042

INTRODUCTION

Cottonseeds are one of the major oilseeds around the world that can provide abundant protein to meet the requirements of plant protein for animals (Church and Kellems, 1998). In recent years, the demand for soybean meal, the most common protein source in swine diet, is increasing

rapidly as the development of the livestock production (Stein et al., 2008), resulting in increased cost of the feed. Therefore, the feed industry is searching for alternative protein sources for soybean meal to achieve high growth performance and low cost. Cottonseed co-products such as cottonseed meal (CSM) and cottonseed protein (CSP) are promising plant protein replacer for soybean meal.

China is one of the largest cottonseed producers in the world, with the cottonseed production of 9.6 million tons in 2016 (USDA, 2017). After extracting oil and removing lint and hull,

¹These authors contributed equally to this work.

²Corresponding author: zhangshuai16@cau.edu.cn

Received November 7, 2017.

Accepted February 19, 2018.

approximately 45% of the initial cottonseed product remains and is used as CSM, containing 22% to 56% CP (Nagalakshmi et al., 2007; Stein et al., 2016). The major limitation to use CSM in pig diets is the concentration of the anti-nutritional factor free gossypol, which may be present up to 5% or more in CSM and is toxic to pigs (Stein et al., 2016). Heating processing can reduce the concentration of free gossypol, but gossypol also binds to lysine in this process, resulting in low digestibility of lysine (Yu et al., 1996). Microbial fermentation could decrease free gossypol in CSM, which is believed to be one of the most promising techniques to improve the protein quality of CSM (Zhang et al., 2006; Sun et al., 2013).

Swine diets can be accurately formulated based on the values of the ME and standardized ileal digestibility (SID) of AA (Stein et al., 2007). However, few studies have focused on the energy contents as well as the AA digestibility of cottonseed co-products. The nutritional value of cottonseed co-products may vary widely as they are produced by different processing techniques. Therefore, our objective was to determine the chemical composition, DE and ME contents, and apparent ileal digestibility (AID) and SID of CP and AA in cottonseed co-products from different sources, including solvent extracted CSM and CSP with different CP levels, expelled CSM, and fermented CSM, fed to growing pigs.

MATERIALS AND METHODS

General

All protocols in this study were approved by the Institutional Animal Care and Use Committee of China Agricultural University (Beijing, China). Two experiments were conducted in Fengning Animal Experimental Base of China Agricultural University (Hebei, China). Seven cottonseed co-products were tested in this study, which include: CSM (solvent extracted) with CP level of 46%, 50%, and 55% (**46CSM**, **50CSM**, and **55CSM**), CSP with CP level of 50% and 55% (**50CSP** and **55CSP**), fermented CSM (**CSMF**), and expelled CSM (**CSME**). All the samples were provided by the Tycoon Group (Xinjiang, China). The chemical compositions and AA contents of the 7 cottonseed co-products are shown in Table 1. In both experiments, pigs used were crossbred (Duroc × Landrace × Yorkshire) barrows obtained from Fengning Animal Experimental Base. They were individually placed in stainless-steel metabolism crates (1.4 m ×

0.45 m × 0.6 m) in a temperature-controlled room (22 ± 2 °C). Feeds were supplied each day at a level of 4% of their BW (Adeola, 2001; Li et al., 2015) determined at the beginning of the experiment and were divided into 2 equal-sized meals at 0800 and 1700 h. All pigs had free access to water.

Experiment 1: Energy Contents

This experiment was conducted to determine the DE and ME values and the apparent total tract digestibility (ATTD) of GE in 7 cottonseed co-products fed to growing pigs. Forty-eight barrows (initial BW: 44.1 ± 4.2 kg) were randomly allotted to 8 experiment diets in a completely randomized design with 6 pigs per treatment diet. The 8 experimental diets included 1 corn-soybean meal basal diet and 7 test diets. The test diets were formulated to contain 24.35% cottonseed co-products which replaced 25% of the energy supplied part by corn and soybean meal in the basal diet (Table 2). The chemical composition of the experimental diets used in Experiment 1 is presented in Table 3.

Experiment 1 lasted for 19 d, with 7 d for cage adaptation, 7 d for diet adaptation, and the last 5 d for total feces and urine collection. During the 5 d collection period, all feces were immediately collected into plastic bags once produced and stored at -20 °C. At the end of the experiment, the 5 d fecal production from each pig were pooled and weighed and a 350 g sample was taken and dried in a forced-draft oven at 65 °C for 72 h. After drying and grinding through a 1-mm screen, subsamples were stored at -20 °C for further chemical analysis. Total urine was collected into plastic buckets attached to funnels located under the metabolism cages at the same time as the fecal collection. Approximately 50 mL of 6 N HCl were added to the buckets to limit microbial growth and reduce loss of ammonia. Urine volume was recorded daily and a subsample of 10% of the urine excreted from each pig was collected and stored at -20 °C. At the end of the collection period, urine samples were pooled for each pig and a subsample (about 45 mL) was saved for further analysis.

Experiment 2: AA Digestibility

This experiment was conducted to determine the AID and SID of CP and AA in 7 cottonseed co-products fed to growing pigs. Sixteen cross-bred barrows (initial BW: 67.4 ± 8.5 kg) fitted with a T-cannula in the distal ileum were allotted to a 6 × 8 Youden square experiment with 6 periods

Table 1. Analyzed composition of the 7 cottonseed co-products (% , as-fed basis)

Items	Cottonseed co-products ^b						
	46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME
DM	90.0	90.6	92.5	93.0	92.0	92.8	93.2
GE, MJ/kg	17.9	17.6	18.3	18.0	17.9	17.8	19.6
CP	45.6	52.8	55.8	51.7	54.9	49.7	47.1
EE	2.9	1.6	1.6	2.0	1.6	1.4	9.0
AEE	2.6	1.2	1.1	1.6	1.8	1.3	8.6
CF	10.3	9.1	6.0	9.0	6.5	10.8	7.6
NDF	30.2	16.4	14.5	19.3	15.6	25.4	20.0
ADF	13.5	9.3	7.4	11.6	8.3	12.8	9.3
Ash	6.15	6.44	6.39	6.37	7.00	6.75	6.18
Total phosphorus	1.00	0.93	1.13	1.08	1.22	1.00	1.09
Calcium	0.26	0.24	0.28	0.39	0.29	0.28	0.28
Free gossypol, µg/g	347.7	292.6	291.0	162.9	217.4	301.2	393.9
Indispensable AA							
Arg	5.80	6.15	6.79	6.08	6.30	4.54	5.32
His	1.50	1.60	1.74	1.60	1.64	1.41	1.43
Ile	1.43	1.51	1.67	1.52	1.57	1.35	1.43
Leu	2.72	2.94	3.19	2.90	2.98	2.61	2.72
Lys	2.17	2.31	2.44	2.39	2.43	1.92	2.09
Met	0.57	0.55	0.41	0.61	0.67	0.58	0.65
Phe	2.54	2.79	2.96	2.70	2.77	2.33	2.41
Thr	1.63	1.77	1.91	1.74	1.79	1.57	1.63
Trp	0.57	0.64	0.69	0.63	0.67	0.52	0.55
Val	1.99	2.14	2.34	2.14	2.20	1.90	1.97
Dispensable AA							
Ala	1.86	2.02	2.17	1.97	2.02	1.91	1.86
Asp	4.56	4.91	5.31	4.83	4.94	4.31	4.28
Cys	0.67	0.75	0.85	0.79	0.81	0.69	0.74
Glu	9.31	10.13	11.04	9.99	10.31	8.85	8.97
Gly	1.94	2.12	2.27	2.08	2.14	1.87	1.94
Pro	2.22	2.35	2.57	2.34	2.43	2.23	2.26
Ser	2.03	2.20	2.36	2.15	2.23	1.90	1.96
Tyr	1.26	1.38	1.51	1.36	1.41	1.20	1.27

^aAnalysis conducted in duplicates.

^b46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSMF: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

and 8 diets. The procedures for equipping pigs with a simple T-cannula near the distal ileum were as described by [Stein et al. \(1998\)](#). Eight diets that were prepared included one N-free diet which contained 733.5 g/kg cornstarch and 150 g/kg sucrose and 7 test diets which were formulated to contain 400 g/kg of one of the cottonseed co-products, 400 g/kg cornstarch and 150 g/kg sucrose ([Table 2](#)). In the test diets, cottonseed co-product was the only source of CP and AA. The N-free diet was used to determine the endogenous losses of nitrogen. Chromic oxide (3 g/kg) was used as an indigestible marker in all diets to determine AA digestibility using the indicator method. The analyzed composition of the experimental diets used in Experiment 2 is presented in [Table 4](#).

Each test period in Experiment 2 lasted 7 d, with a 5 d adaption to the diets followed by a 2 d collection of ileal digesta from 0800 to 1700 h using the procedures described by [Stein et al. \(1998\)](#). The digesta was collected in a plastic bag and then stored at -20 °C. Ileal digesta samples were thawed, mixed within animal and diet, and a subsample was taken, then the digesta subsamples were lyophilized in a vacuum-freeze dryer (Tofflon Freezing Drying Systems, Minhang District, Shanghai, China) and ground through a 1-mm screen for further chemical analysis.

Chemical Analysis

All cottonseed co-products used in this study were analyzed for DM (procedure 930.15; [AOAC](#)

Table 2. Ingredient composition of the experimental diets (as-fed basis, %)

Ingredients	Exp. 1		Exp. 2	
	Basal diet	Test diet	Cottonseed co-products diets	N-free diet
Corn	79.90	59.93	–	–
Soybean meal	17.50	13.12	–	–
Cottonseed co-products	–	24.35	40.00	–
Cornstarch	–	–	40.00	73.35
Soybean oil	–	–	2.00	3.00
Sucrose	–	–	15.00	15.00
Cellulose acetate ^a	–	–	–	4.00
Dicalcium phosphate	0.90	0.90	1.50	2.50
Limestone	0.90	0.90	0.40	0.50
Salt	0.30	0.30	0.30	0.45
Chromic oxide	–	–	0.30	0.30
Potassium carbonate	–	–	–	0.30
Magnesium oxide	–	–	–	0.10
Mineral and vitamin premix ^b	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00

^aMade by Chemical Reagents Company (Beijing, China).

^bPremix provided the following quantities of vitamins and microminerals per kilogram of the diet for pigs: vitamin A, 5,600 IU; vitamin D₃, 2,200 IU; vitamin E, 21.6 IU; vitamin K₃, 1.8 mg; B₁₂, 12 µg; thiamine, 0.88 mg; riboflavin, 4 mg; pantothenic acid, 10 mg; niacin, 20 mg; cholinechloride, 0.32 g; folacin, 0.4 mg; pyridoxine, 1.8 mg; biotin, 40 µg; Fe, 88 mg; Cu, 120 mg; Zn, 96 mg; Mn, 16 mg; I, 0.24 mg; and Se, 0.4 mg.

2006), CP (procedure 984.13; AOAC 2006), ether extract (EE; Thiex et al., 2003), acid-hydrolyzed ether extract (AEE; Sanderson, 1986), crude fiber (CF; procedure 978.10; AOAC 2006), crude ash (procedure, 942.05; AOAC 2006), calcium (procedure 968.08; AOAC 2006), and phosphorus (procedure 946.06; AOAC 2006). The modified procedures of Van Soest et al. (1991) were followed to determine NDF and ADF. The concentration of NDF was analyzed using heat stable α -amylase and sodium sulfite without correction for insoluble ash as using a fiber bay system (Ankom Technology, Macedon, NY, USA). The ADF fraction was analyzed in a separate sample. The free

gossypol concentration was determined by the standard method (method Ba 7b-96; AOCS 2009). The GE of cottonseed co-products was analyzed using an adiabatic oxygen bomb calorimeter (Parr Instruments Co., Moline, IL, USA). Diets used in Experiment 1 were analyzed for DM, CP, EE, CF, NDF, ADF, ash, calcium, phosphorus, and GE. Diets used in Experiment 2 were analyzed for DM, CP, and EE.

Samples of cottonseed co-products, diets used in Experiment 2, and ileal digesta were analyzed for their AA contents by the standard method (AOAC, 2006). With the exception of Met, Cys, and Trp, the AA contents were determined after hydrolysis with

Table 3. Analyzed composition of the experimental diets used in Exp. 1 (% as-fed basis)

Item ^a	Basal diet	Cottonseed co-products diets ^b						
		46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME
DM	88.6	88.7	89.3	89.4	89.6	89.8	89.6	89.9
CP	17.2	25.5	26.4	28.2	27.3	27.3	26.0	25.6
EE	2.24	2.59	2.12	1.64	2.17	1.90	1.51	3.37
CF	3.04	4.86	4.36	3.07	4.19	3.76	4.88	3.80
NDF	14.1	22.6	20.8	17.8	20.2	19.5	20.5	20.0
ADF	3.61	7.36	6.72	5.22	6.28	6.02	6.90	6.21
Ash	4.38	5.42	5.63	5.61	5.65	5.62	5.41	5.48
Calcium	0.70	0.65	0.69	0.80	0.72	0.74	0.62	0.64
Total phosphorus	0.43	0.64	0.71	0.68	0.72	0.71	0.64	0.65
GE, MJ/kg	18.21	18.56	18.47	18.53	18.36	18.41	18.34	18.73

^aAnalysis conducted in duplicates.

^b46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSMF: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

Table 4. Analyzed composition of the experimental diets used in Exp. 2 (% , as-fed basis)

Item ^a	Cottonseed co-products diets ^b							N-free diet
	46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME	
DM	91.8	91.5	93.2	91.9	92.4	92.4	92.6	92.8
CP	19.5	20.8	22.3	21.6	19.9	19.9	19.8	0.5
EE	3.4	3.1	3.0	2.8	2.8	2.4	6.2	2.6
Indispensable AA								
Arg	2.14	2.10	2.63	2.55	2.57	1.84	2.30	0.01
His	0.60	0.60	0.73	0.70	0.72	0.60	0.63	0.02
Ile	0.54	0.56	0.65	0.63	0.65	0.55	0.59	0.01
Leu	1.03	1.06	1.26	1.21	1.24	1.05	1.14	0.04
Lys	0.82	0.83	0.96	0.99	1.04	0.80	0.84	0.04
Met	0.21	0.23	0.28	0.23	0.21	0.20	0.23	–
Phe	0.93	0.95	1.17	1.11	1.13	0.94	1.00	0.01
Thr	0.62	0.65	0.76	0.76	0.73	0.65	0.69	0.03
Trp	0.22	0.23	0.28	0.26	0.26	0.21	0.23	–
Val	0.74	0.77	0.91	0.89	0.90	0.77	0.82	0.02
Dispensable AA								
Ala	0.68	0.71	0.86	0.81	0.81	0.75	0.76	0.03
Asp	1.71	1.74	2.12	2.04	2.03	1.74	1.86	0.04
Cys	0.23	0.26	0.33	0.26	0.26	0.22	0.29	0.03
Glu	3.53	3.63	4.41	4.29	4.30	3.62	3.83	0.08
Gly	0.73	0.76	0.90	0.88	0.88	0.75	0.81	0.02
Pro	0.90	0.93	1.10	1.07	1.07	0.96	0.98	0.04
Ser	0.76	0.78	0.92	0.91	0.91	0.76	0.82	0.02
Tyr	0.48	0.49	0.58	0.60	0.59	0.50	0.52	–

^aAnalysis conducted in duplicates.

^b46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSMF: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

6 N HCl at 110 °C for 24 h using an AA analyzer (Hitachi L-8900, Tokyo, Japan). Methionine and Cys were determined as methionine sulphone and cysteic acid using an AA analyzer (Hitachi L-8900, Tokyo, Japan) after cold performic acid oxidation overnight and hydrolyzing with 7.5 N HCl at 110 °C for 24 h. Tryptophan was determined using High Performance Liquid Chromatography (Agilent 1200 Series, Santa Clara, CA, USA) after LiOH hydrolysis for 22 h at 110 °C. The chromium concentration in diets used in Experiment 2 and ileal digesta were determined using a polarized Zeeman Atomic Absorption Spectrometer (Hitachi Z2000, Tokyo, Japan) after nitric acid-perchloric acid wet ash sample preparation.

Calculations

In Experiment 1, the DE and ME contents as well as the ATTD of GE of the 7 cottonseed co-products were calculated using the difference method as described by Adeola (2001). In Experiment 2, values for AID, endogenous losses, and SID of CP and AA in test diets were calculated according to equations described by Stein et al. (2007). Because cottonseed

co-products were the sole source of CP and AA in the test diets, the AID and SID for AA and CP in the cottonseed co-products was equal to those of the test diets. The AID for each AA in the test diet was calculated using the following equation:

$$\text{AID}(\%) = [1 - (\text{AA}_{\text{digesta}} / \text{AA}_{\text{diet}}) \times (\text{Cr}_{\text{diet}} / \text{Cr}_{\text{digesta}})] \times 100\%,$$

in which $\text{AA}_{\text{digesta}}$ and $\text{Cr}_{\text{digesta}}$ were the concentrations of AA and chromium in the ileal digesta (g/kg of DM), while AA_{diet} and Cr_{diet} were the concentrations of AA and chromium in the test diets (g/kg of DM). The basal endogenous loss of each AA (IAA_{end} , g/kg of DMI) was determined for pigs fed the N-free diet using the following equation:

$$\text{IAA}_{\text{end}} = \text{AA}_{\text{digesta}} \times (\text{Cr}_{\text{diet}} / \text{Cr}_{\text{digesta}}).$$

By correcting the AID of each AA, which was calculated for each sample for the IAA_{end} of each AA, the SID of each AA was calculated using the following equation:

$$\text{SID}(\%) = \text{AID} + (\text{IAA}_{\text{end}} / \text{AA}_{\text{ingredient}}) \times 100\%,$$

in which $AA_{\text{ingredient}}$ was the concentrations of AA in the test ingredients (g/kg of DM, equal to AA_{diet}). The concentration of standardized ileal digestible AA in each cottonseed co-product equal to the product of SID and the analyzed concentration for a particular AA in that ingredient. The calculations of the CP parameters followed the same equations.

Statistical Analysis

All the data were checked for normality and outliers were detected using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC, USA). Data for DE, ME, ME/DE ratio, and ATTD of GE were analyzed using the GLM procedure of SAS, with pig as the experimental unit and treatment diet as the only fixed effect in the model. Correlation coefficients between chemical characteristics and energy values of the cottonseed co-products were analyzed using the CORR procedure of SAS. Data for AID, SID, and concentration of SID AA were analyzed using the GLIMMIX procedure of SAS, with pig as the experimental unit. The statistical model included the fixed effect of diet, and the random effects of period and animal. In both models, treatment means were separated using the LSMEANS statement, and the multiple comparison was adjusted using the Tukey–Kramer test. An α value of 0.05 was used to assess statistical significances among means.

RESULTS

Composition of Ingredients

As presented in Table 2, among the 7 cottonseed co-products, the concentrations of DM, GE, EE, and AEE were the greatest in CSME, and 46CSM and 50CSM had the lowest DM and GE values, respectively. The concentration of CP was the greatest in 55CSM, and was the lowest in 46CSM.

The concentrations of CF, and NDF and ADF were the greatest in CSFM, and 46CSM. 55CSP had the greatest concentration of crude ash, while 50CSP had the greatest calcium level. Moreover, the concentration of free gossypol was the greatest in CSME, and was the lowest in 50CSP.

For the AA concentrations of the 7 cottonseed co-products, 55CSM had the greatest concentrations for all the 8 dispensable AA and the 9 indispensable AA except for Met. CSME had the lowest concentrations of the 18 AA analyzed except for Met, and 46CSM also had the lowest concentrations of Ala, Cys, and Pro.

Energy Contents and ATTD of GE

The energy concentrations and ATTD of GE of the 7 cottonseed co-products are shown in Table 5. The DE and ME values of the 7 ingredients varied from 12.72 to 15.63 MJ/kg and 12.24 to 14.83 MJ/kg, respectively. Among the 7 cottonseed co-products, CSME and 55CSP had the greatest DE and ME values (15.63 MJ/kg and 14.83 MJ/kg, DM basis), respectively ($P < 0.01$). 46CSM, 50CSP, and CSME had the lowest DE value (13.21 MJ/kg, 13.19 MJ/kg, and 12.72 MJ/kg, DM basis), while CSME had the lowest ME value (12.24 MJ/kg, DM basis, $P < 0.01$). The ME/DE ratio ranged from 95.7 to 98.8, and no significant differences were observed among the 7 ingredients. Furthermore, 55CSP also had the greatest ATTD of GE (77.3%, $P < 0.01$), while 46CSM and CSME had the lowest ATTD of GE (64.9% and 65.0%, $P < 0.01$).

The correlation coefficients between chemical characteristics and energy values of the 7 cottonseed co-products are shown in Table 6. In these ingredients, GE was positively correlated with both EE and AEE ($r = 0.94$ and $r = 0.93$, respectively, $P < 0.01$), and CP was negatively correlated with NDF ($r = -0.86$, $P < 0.05$). The ME value had

Table 5. Energy concentration and ATTD of GE of the 7 cottonseed co-products fed to growing pigs (Exp. 1, DM basis)^a

Item ^b	Cottonseed co-products diets ^c							SEM	P-value
	46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME		
DE, MJ/kg	13.21 ^c	14.42 ^{abc}	13.77 ^{bc}	13.19 ^c	15.49 ^{ab}	12.72 ^c	15.63 ^a	0.40	<0.01
ME, MJ/kg	12.68 ^{bc}	13.94 ^{abc}	13.58 ^{abc}	12.86 ^{bc}	14.83 ^a	12.24 ^c	14.68 ^{ab}	0.41	<0.01
ME/DE	96.0	98.8	98.6	97.7	95.7	98.7	96.8	1.51	0.59
ATTD of GE, %	64.9 ^b	71.2 ^{ab}	67.9 ^{ab}	67.5 ^{ab}	77.3 ^a	65.0 ^b	73.1 ^{ab}	0.02	<0.01

^aMeans in a row without a common superscript differ, $P < 0.05$. Means are the least square means ($n = 6$).

^bATTD: apparent total tract digestibility.

^c46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSME: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

Table 6. Correlation coefficients between chemical characteristics and energy values of the 7 cottonseed co-products fed to growing pigs

Item	DM	GE	CP	EE	AEE	CF	NDF	ADF	Ash	Free gossypol	DE	ME
DM	1.00											
GE	0.53	1.00										
CP	0.20	-0.34	1.00									
EE	0.31	0.94**	-0.57	1.00								
AEE	0.32	0.93**	-0.57	0.99**	1.00							
CF	-0.32	-0.38	-0.65	-0.14	-0.14	1.00						
NDF	-0.34	-0.09	-0.86*	0.11	0.11	0.81*	1.00					
ADF	-0.25	-0.29	-0.73	-0.09	-0.08	0.92**	0.92**	1.00				
Ash	0.18	-0.45	0.58	-0.52	-0.46	-0.18	-0.33	-0.22	1.00			
Free gossypol	-0.19	0.54	-0.62	0.65	0.63	0.14	0.40	0.08	-0.50	1.00		
DE	0.12	0.54	0.17	0.55	0.58	-0.66	-0.54	-0.69	0.14	0.20	1.00	
ME	0.11	0.47	0.32	0.44	0.47	-0.76*	-0.66	-0.79*	0.17	0.10	0.98**	1.00

* $P < 0.05$, ** $P < 0.01$.

positive correlation with DE ($r = -0.98$, $P < 0.01$), and had negative correlation with both CF and ADF ($r = -0.76$ and $r = -0.79$, respectively, $P < 0.05$).

AID and SID of CP and AA

Table 7 to 9 showed the AID, SID, and concentration of standardized ileal digestible CP and AA

of the 7 cottonseed co-products, respectively. No significant differences were observed among the 7 cottonseed co-products for the AID of Gly and Pro, the SID of CP, Trp, Gly, and Pro, and the concentration of standardized ileal digestible Gly and Pro. For the other results among the 7 ingredients, 55CSP had the greatest AID of CP and AA ($P < 0.05$), the greatest SID of AA ($P < 0.05$), and also the greatest

Table 7. Apparent ileal digestibility (%) of CP and AA in 7 cottonseed co-products fed to pigs^a

Item	Cottonseed co-products ^b							SEM	P-value
	46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME		
CP	80.2 ^{ab}	83.3 ^{ab}	75.1 ^b	83.6 ^{ab}	87.6 ^a	84.2 ^{ab}	78.0 ^{ab}	1.9	0.02
Indispensable AA									
Arg	91.6 ^{ab}	92.0 ^{ab}	87.9 ^b	92.7 ^{ab}	94.4 ^a	91.7 ^{ab}	90.8 ^{ab}	0.9	0.02
His	84.6 ^c	84.4 ^c	86.7 ^{ab}	87.7 ^{bc}	93.0 ^a	90.0 ^{ab}	88.9 ^{ab}	1.2	<0.01
Ile	74.7 ^b	77.4 ^{ab}	72.7 ^b	82.2 ^{ab}	87.8 ^a	83.0 ^{ab}	79.2 ^{ab}	2.1	<0.01
Leu	75.9 ^{bc}	78.8 ^{abc}	74.4 ^c	81.7 ^{abc}	88.8 ^a	84.2 ^{ab}	79.5 ^{abc}	1.9	<0.01
Lys	70.2 ^b	71.6 ^b	67.7 ^b	79.0 ^{ab}	86.9 ^a	79.5 ^{ab}	72.2 ^b	2.5	<0.01
Met	75.3 ^b	80.6 ^{ab}	77.0 ^{ab}	79.3 ^{ab}	86.8 ^a	84.7 ^{ab}	79.6 ^{ab}	2.3	0.03
Phe	83.8 ^c	85.9 ^{bc}	87.5 ^{abc}	87.3 ^{bc}	93.6 ^a	91.7 ^{ab}	89.7 ^{ab}	1.3	<0.01
Thr	71.4 ^b	73.5 ^b	69.9 ^b	80.2 ^{ab}	86.2 ^a	80.4 ^{ab}	74.4 ^{ab}	2.3	<0.01
Trp	80.5 ^b	81.9 ^{ab}	78.5 ^b	84.1 ^{ab}	90.0 ^a	83.7 ^{ab}	79.7 ^{ab}	1.9	0.04
Val	74.6 ^b	77.4 ^{ab}	71.5 ^b	80.2 ^{ab}	86.7 ^a	81.4 ^{ab}	76.9 ^{ab}	2.1	<0.01
Dispensable AA									
Ala	69.8 ^b	74.5 ^{ab}	69.1 ^{ab}	77.6 ^{ab}	84.7 ^a	80.5 ^{ab}	72.3 ^{ab}	2.8	0.02
Asp	80.7 ^b	80.9 ^{ab}	77.2 ^b	86.2 ^{ab}	90.8 ^a	84.0 ^{ab}	79.7 ^b	1.8	0.01
Cys	79.1 ^b	80.6 ^{ab}	78.8 ^{ab}	84.1 ^{ab}	88.5 ^a	81.1 ^{ab}	81.2 ^{ab}	1.8	0.03
Glu	87.7 ^b	88.9 ^{ab}	87.3 ^b	90.6 ^{ab}	94.4 ^a	89.5 ^{ab}	89.0 ^{ab}	1.2	0.03
Gly	69.6	72.5	66.0	76.7	81.3	75.1	68.3	3.0	0.21
Pro	64.4	72.9	48.4	76.8	66.5	68.4	48.9	9.5	0.37
Ser	78.5 ^b	79.9 ^{ab}	75.5 ^b	84.3 ^{ab}	89.1 ^a	83.6 ^{ab}	78.6 ^{ab}	1.8	<0.01
Tyr	78.2 ^c	81.3 ^{bc}	80.6 ^{bc}	85.4 ^{abc}	91.6 ^a	88.1 ^{ab}	84.2 ^{abc}	1.9	<0.01

^aMeans in a row without a common superscript differ, $P < 0.05$. Means are the least square means ($n = 6$).

^b46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSMF: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

Table 8. Standardized ileal digestibility (%) of CP and AA in 7 cottonseed co-products fed to pigs^{a,b}

Item	Cottonseed co-products ^c							SEM	P-value
	46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME		
CP	88.5	91.7	85.4	91.5	96.2	94.0	88.1	2.66	0.18
Indispensable AA									
Arg	95.8 ^{ab}	96.2 ^{ab}	92.2 ^b	96.4 ^{ab}	98.4 ^a	97.6 ^a	94.7 ^{ab}	0.98	0.06
His	87.3 ^{cd}	87.2 ^{bd}	88.9 ^{abcd}	90.4 ^{bcd}	95.9 ^a	93.6 ^{ab}	91.7 ^{ac}	1.36	<0.01
Ile	78.4 ^{bc}	81.3 ^{abc}	75.4 ^{cd}	85.9 ^{ac}	91.8 ^a	87.9 ^{ab}	82.6 ^{abc}	2.32	<0.01
Leu	80.5 ^c	83.6 ^{bc}	78.2 ^c	86.2 ^{bc}	93.6 ^a	90.2 ^{ab}	84.0 ^{abc}	2.04	<0.01
Lys	74.2 ^{cd}	76.0 ^{bcd}	70.1 ^d	83.2 ^{ab}	91.4 ^a	85.5 ^{abc}	76.1 ^{bcd}	2.60	<0.01
Met	78.0 ^c	83.6 ^{abc}	76.6 ^{bc}	82.6 ^{abc}	90.4 ^a	89.6 ^{abc}	82.4 ^{abc}	2.69	0.01
Phe	85.9 ^c	88.2 ^{bc}	88.8 ^{abc}	89.5 ^{bc}	95.9 ^a	94.6 ^{ab}	91.7 ^{ab}	1.34	<0.01
Thr	79.0 ^b	81.4 ^{ab}	77.2 ^b	86.8 ^{ab}	93.4 ^a	89.2 ^{ab}	82.3 ^{ab}	2.81	0.02
Trp	86.1	88.0	84.0	89.1	94.9	90.5	86.6	2.18	0.07
Val	81.7 ^b	84.3 ^{ab}	77.8 ^b	86.8 ^{ab}	93.8 ^a	90.2 ^{ab}	83.8 ^{ab}	2.45	0.02
Dispensable AA									
Ala	81.2 ^b	85.9 ^{ab}	80.3 ^{ab}	88.4 ^{ab}	96.2 ^a	93.8 ^{ab}	83.7 ^{ab}	3.22	0.05
Asp	84.7 ^b	84.7 ^{ab}	80.6 ^b	89.9 ^{ab}	94.7 ^a	88.8 ^{ab}	83.9 ^{ab}	2.19	0.02
Cys	85.0 ^b	82.2 ^{ab}	91.5 ^b	89.7 ^{ab}	94.4 ^a	88.7 ^{ab}	86.5 ^{ab}	2.19	0.03
Glu	89.9 ^b	91.3 ^{ab}	89.0 ^b	92.6 ^{ab}	96.4 ^a	92.0 ^{ab}	91.5 ^{ab}	1.40	0.02
Gly	96.0	96.9	92.4	100.2	106.4	106.3	93.0	4.64	0.60
Pro	144.8	149.2	134.5	147.8	140.3	157.6	123.3	12.72	0.51
Ser	84.8 ^b	86.5 ^{ab}	81.5 ^b	90.1 ^{ab}	95.2 ^a	91.6 ^{ab}	85.5 ^{ab}	2.26	0.03
Tyr	82.1 ^c	85.2 ^{bc}	84.7 ^{bc}	88.9 ^{ab}	95.7 ^a	93.2 ^{ab}	88.2 ^{abc}	2.05	<0.01

^aMeans in a row without a common superscript differ, $P < 0.05$. Means are the least square means ($n = 6$).

^bValues for SID were calculated by correcting AID values for basal endogenous losses. Basal endogenous losses were determined, using pigs fed the N-free diet, as (g/kg DMI) CP, 0.94; Arg, 0.42; His, 0.27; Ile, 0.36; Leu, 0.46; Lys, 0.41; Met, 0.29; Phe, 0.21; Thr, 0.79; Trp, 0.60; Val, 0.71; Ala, 1.16; Asp, 0.42; Cys, 0.56; Glu, 0.23; Gly, 2.61; Pro, 8.09; Ser, 0.67; and Tyr, 0.41.

^c46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSMF: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

concentrations of standardized ileal digestible CP and AA except for Arg ($P < 0.05$). The 46CSM had the lowest AID of AA except for Arg and Leu ($P < 0.05$), the lowest SID of AA except for Arg, Ile, and Lys ($P < 0.05$), and also the lowest concentrations of standardized ileal digestible CP and AA except for Arg, Met, Asp, and Ser ($P < 0.05$). In addition, 55CSM had the lowest AID of CP and AA except for His, Met, Phe, Ala, Cys, and Tyr ($P < 0.05$), the lowest SID of AA except for His, Met, Phe, Ala, and Tyr ($P < 0.05$), and the lowest concentration of standardized ileal digestible Met (0.31%, $P < 0.01$). However, 55CSM also had the greatest concentration of standardized ileal digestible Arg and Phe (6.26% and 2.63%, $P < 0.01$). Furthermore, 50CSM had the lowest AID of Lys and Thr (71.6% and 73.5%, $P < 0.05$). CSMF had the greatest SID of Arg (97.6%, $P < 0.05$), but the lowest concentrations of standardized ileal digestible Arg, Lys, Phe, Trp, and Glu (4.41%, 1.62%, 2.19%, 0.47%, and 8.14%, $P < 0.01$). The CSME had the lowest AID of Lys and Asp (72.2% and 79.7%, $P < 0.05$), and the lowest concentrations of standardized ileal digestible His, Lys, Phe, Trp, Glu,

and Ser (1.32%, 1.60%, 2.21%, 0.48%, 8.22%, and 1.67%, $P < 0.05$).

DISCUSSION

Composition of Ingredients

Cottonseed is the fourth largest source of protein produced in the world (following soybean, rapeseed, and sunflower seed) in 2014–2015 (Soya and Oilseed Blue Book, 2015). However, there has been little research conducted to explore the nutrient values of cottonseed co-products on pigs, and the existing literature has focused on the most common co-product CSM. In the present study, the nutrient values of different cottonseed co-products were measured, which includes 3 CSM (solvent extracted) and 2 CSP products with various protein levels, one fermented CSM and one expelled CSM. There were numerical differences for the chemical compositions, energy contents, and AA concentrations of these ingredients, indicating that protein levels and processing procedure can affect the nutrient values of cottonseed co-products. Among the 7 cottonseed co-products, 55CSM had

Table 9. Concentration (%) of standardized ileal digestible CP and AA in 7 cottonseed co-products fed to pigs^a

Item	Cottonseed co-products ^b							SEM	P-value
	46CSM	50CSM	55CSM	50CSP	55CSP	CSMF	CSME		
CP	40.4 ^d	48.4 ^{ab}	47.7 ^{ab}	47.3 ^b	52.8 ^a	46.7 ^{bc}	41.6 ^{cd}	1.33	<0.01
Indispensable AA									
Arg	5.55 ^d	5.92 ^{bc}	6.26 ^a	5.85 ^c	6.18 ^{ab}	4.41 ^f	5.04 ^e	0.07	<0.01
His	1.31 ^e	1.39 ^{cd}	1.54 ^{ab}	1.44 ^{bc}	1.57 ^a	1.31 ^{de}	1.32 ^e	0.02	<0.01
Ile	1.12 ^c	1.23 ^b	1.26 ^{abc}	1.30 ^b	1.40 ^a	1.17 ^{bc}	1.18 ^{bc}	0.04	<0.01
Leu	2.18 ^c	2.47 ^b	2.50 ^{ab}	2.49 ^b	2.77 ^a	2.33 ^{bc}	2.30 ^{bc}	0.06	<0.01
Lys	1.61 ^c	1.76 ^{bc}	1.71 ^{bc}	1.97 ^b	2.12 ^a	1.62 ^c	1.60 ^c	0.06	<0.01
Met	0.44 ^d	0.46 ^{cd}	0.31 ^e	0.51 ^{bc}	0.60 ^a	0.52 ^{bc}	0.53 ^b	0.01	<0.01
Phe	2.18 ^c	2.46 ^b	2.63 ^a	2.41 ^c	2.65 ^a	2.19 ^c	2.21 ^c	0.04	<0.01
Thr	1.29 ^c	1.44 ^b	1.48 ^{abc}	1.51 ^b	1.67 ^a	1.40 ^{bc}	1.34 ^{bc}	0.05	<0.01
Trp	0.49 ^c	0.56 ^b	0.58 ^{ab}	0.54 ^{ab}	0.64 ^a	0.47 ^c	0.48 ^c	0.01	<0.01
Val	1.63 ^c	1.81 ^{ab}	1.82 ^{abc}	1.85 ^b	2.05 ^a	1.70 ^{bc}	1.66 ^{bc}	0.05	<0.01
Dispensable AA									
Ala	1.51 ^c	1.74 ^{ab}	1.73 ^{abc}	1.73 ^{ab}	1.92 ^a	1.77 ^{abc}	1.57 ^{bc}	0.07	<0.01
Asp	3.86 ^{de}	4.19 ^{bc}	4.29 ^{abcd}	4.34 ^b	4.68 ^a	3.82 ^{cde}	3.60 ^e	0.10	<0.01
Cys	0.57 ^d	0.65 ^{bc}	0.70 ^{ab}	0.70 ^b	0.76 ^a	0.61 ^{cd}	0.64 ^{bc}	0.02	<0.01
Glu	8.36 ^c	9.26 ^b	9.84 ^{ab}	9.24 ^b	9.94 ^a	8.14 ^c	8.22 ^c	0.13	<0.01
Gly	1.86	2.07	2.09	2.03	2.23	1.94	1.82	0.10	0.03
Pro	3.25	3.42	3.55	3.49	3.47	3.61	2.98	0.28	0.75
Ser	1.72 ^{de}	1.90 ^{bc}	1.93 ^{abcd}	1.94 ^b	2.12 ^a	1.74 ^{cde}	1.67 ^e	0.05	<0.01
Tyr	1.03 ^d	1.18 ^{bc}	1.28 ^{ab}	1.21 ^{bc}	1.34 ^a	1.11 ^{cd}	1.13 ^{cd}	0.03	<0.01

^aMeans in a row without a common superscript differ, $P < 0.05$. Means are the least square means ($n = 6$).

^b46CSM: cottonseed meal, solvent extracted (CP = 46%); 50CSM: cottonseed meal, solvent extracted (CP = 50%); 55CSM: cottonseed meal, solvent extracted (CP = 55%); 50CSP: cottonseed protein (CP = 50%); 55CSP: cottonseed protein (CP = 55%); CSMF: cottonseed meal, fermented; CSME: cottonseed meal, expelled.

the greatest concentrations of all AA tested except for Met, which is reasonable considering the greatest CP level in 55CSM. The lowest concentrations of most AA appeared in CSMF, which is difficult to explain, because it was reported that the microbial fermentation process could increase the CP and AA contents in CSM (Zhang et al., 2006), which was not observed in the present study. In addition, most of the nutrient values in the CSM samples analyzed in the current study were greater than those reported in CVB (2007), NRC (2012), and literature from González-Vega and Stein (2012). However, those values from our study were lower than those from the INRA feedstuff tables (Sauvant et al., 2004), especially for the concentrations of CP and AA. This can be explained by the different cotton varieties in China and western countries. No literature was found to report the nutritional values of CSP and fermented CSM, thus no comparison between different data sources was made.

Energy Contents and Energy Digestibility

Knowing the energy contents of different ingredients is critical for feed formulation. Our results

demonstrated that the available energy values of different cottonseed co-products varied greatly. The DE and ME values of CSM (CP = 39.22%, CF = 13.96%) in pigs reported by NRC (2012) are 12.18 and 11.07 MJ/kg, respectively. While in INRA feedstuff tables, 2 kinds of CSM with different fiber contents (CF = 11.9% and 16.9%, CP = 42.6% and 36.3%, respectively) were reported in pigs, with DE values of 13.6 and 12.1 MJ/kg, and ME values of 12.3 and 11.1 MJ/kg, respectively (Sauvant et al., 2004). Except for fermented CSM, all the other cottonseed co-products tested in the current study had greater DE and ME values compared to those in NRC and INRA databases, which is reasonable considering the lower fiber contents in these ingredients produced in China. The correlation analysis also demonstrated significantly negative correlation between fiber contents (especially CF and ADF) and the ME value of the cottonseed co-products used in the current study. The different processing techniques (solvent extraction, expelling, fermentation, etc.) on cottonseed produce different co-products with various chemical characteristics. The correlation matrices established in our study illustrated that in addition to fiber contents, GE and oil

contents (EE and AEE) were also factors related to the DE and ME values, while CP, ash, and free gossypol had weak correlation with DE and ME. The correlation between fiber contents and DE or ME were greater than those between GE or oil contents and DE or ME, indicating that fiber contents (CF or ADF) may be the main driver to affect DE and ME in cottonseed co-products. Among the 7 ingredients, CSP with 55% CP level had the greatest ME value, which can be explained by its low fiber level. On the contrary, high fiber level may explain the lowest DE and ME values in 46CSM and CSMF. Moreover, even though with high fiber contents, CSME also showed great DE and ME values, which can be attributed to the high oil content in CSME.

AA Digestibility and Digestible AA

The AID and SID values for most AA in CSM that we observed agree with the reports in CVB (2007). However, the AID values for Gly and Pro were approximately 15% and 30% lower compared with those in CVB, and the SID values for Gly and Pro were approximately 10% and 40% greater compared with those in CVB, respectively. A plausible explanation is that big variations exist due to systematical errors when measuring these 2 AA. The concentrations of standardized ileal digestible AA in CSM in our study were also greater compared with the concentrations shown in the CVB database. The AID and SID values for all the AA we tested in 55CSM are close to the values of CSM reported in the INRA database except for Pro (Sauvant et al., 2004). Moreover, the AID and SID values for AA in CSM in the present experiment were all greater than the values reported in NRC (2012) and by González-Vega and Stein (2012). This may be attributed to the differences in cottonseed varieties, processing techniques, or experimental conditions.

Most anti-nutritional factors in feed ingredients have a negative effect on AA digestibility (Gilani et al., 2005). Free gossypol is the major anti-nutritional factor in cottonseed co-products (Stein et al., 2016). Among the 7 ingredients, the 2 CSP samples had the lowest free gossypol concentrations compared with the other ingredients. Accordingly, 55CSP had greater AID, SID, and concentrations of standardized ileal digestible CP and most AA compared with the other cottonseed co-products, which can partially illustrate the negative effect of anti-nutritional factors on AA digestibility. However, the 50CSP sample, with significant lower concentration of free gossypol compared with 55CSP, had no difference for AID of CP

and most of the AA but lower AID of His and Phe than 55CSP. These results indicate that the effect of other factors such as CP may surpass the effect of free gossypol on AA digestibility of cottonseed co-products, especially when the free gossypol levels of the ingredients is low. Among the 7 co-products, CSMF had the lowest concentrations of many kinds of standardized ileal digestible AA, even though the CP level in CSMF was not the lowest. The fermentation process may have negative effects on AA digestibility, but more studies are needed to confirm this hypothesis, because our results from only one sample cannot prove this inference.

Among the 10 indispensable AA and 8 dispensable AA we tested, the AID and SID of Lys were nearly the lowest for all the ingredients compared to all other AA. The low digestibility of Lys in cottonseed co-products, especially CSM, may be a result of heat damage. Heating process is a key step in production of all these cottonseed co-products (CSM and CSP) used in the current study, which can inactivate the gossypol. During this process, a gossypol-lysine complex can form (Batterham et al., 1990). Moreover, 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 (González-Vega et al., 2011; González-Vega and Stein, 2012). All of these reasons may explain the low digestibility of Lys in cottonseed co-products.

We also observed values exceeding 100% for SID of Pro in all 7 cottonseed co-products, which was in accordance with the observations from González-Vega and Stein (2012). This is a consequence of secretion of endogenous Pro into the intestinal tract of pigs, because proline is usually the AA that is present in endogenous losses in the greatest concentrations (Stein et al., 1999; Moter and Stein, 2004). González-Vega and Stein (2012) also observed negative values for the AID of Pro in CSM. Although the means of AID of Pro shown in the present experiment were all positive, some negative values were observed on individual pigs, making the AID of Pro ranging from 48.4% to 76.8% for the 7 cottonseed co-products. 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; González-Vega and Stein, 2012).

In conclusion, CSP with 55% CP level had greater ME value, and also had greater AID and SID of all the AA tested except for glycine and proline compared with the other cottonseed co-products. Cottonseed meal (solvent extracted) with 55%

CP and 46% CP had lower AID and SID of most AA tested compared with the other cottonseed co-products. Cottonseed protein with 55% CP level also had the greatest concentrations of standardized ileal digestible CP and all the AA tested except for glycine and proline. Regardless of the cost, only from the energy and AA digestibility point of view, CSP with CP level of 55% is a better dietary ingredient for growing pigs compared with the other cottonseed co-products.

ACKNOWLEDGMENTS

All the ingredients used in this experiment were supplied by Xinjiang Taikun Group Co., Ltd. Thanks for their support. This research was financially supported by the Modern Agricultural Industry Technology System (CARS-36), Developing key equipment for digital management and monitoring environment in animal production (2013AA10230602), National Natural Science Foundation of China (31372317), and the 111 Project (B16044).

LITERATURE CITED

- Adeola. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, *Swine nutrition*. CRC Press, Washington, DC. p. 903–916.
- AOAC. 2006. Official methods of analysis. 18th ed. Association of Official Analytical Chemists, Arlington, VA.
- AOCS. 2009. Official methods and recommended practices of the AOCS. 6th ed. American Oil Chemists Society, Chicago, IL.
- Batterham, E. S., L. M. Andersen, D. R. Baigent, R. E. Darnell, and M. R. Taverner. 1990. A comparison of the availability and ileal digestibility of lysine in cottonseed and soya-bean meals for grower/finisher pigs. *Br. J. Nutr.* 64:663–677.
- Church, D. C., and R. O. Kellems. 1998. Supplemental protein sources. In: R. O. Kellems and D. C. Church, editors, *Livestock feeds and feeding*. 4th ed. Prentice-Hall, Upper Saddle River, NJ. p. 135–163.
- CVB. 2007. CVB table pigs: chemical composition and nutritional values of feedstuffs, and feeding standards. Product Board Animal Feed, The Hague, The Netherlands.
- Gilani, G. S., K. A. Cockell, and E. Sepehr. 2005. Effects of antinutritional factors on protein digestibility and amino acid availability in foods. *J. AOAC Int.* 88:967–987.
- González-Vega, J. C., B. G. Kim, J. K. Htoo, A. Lemme, and H. H. Stein. 2011. Amino acid digestibility in heated soybean meal fed to growing pigs. *J. Anim. Sci.* 89:3617–3625. doi:10.2527/jas.2010-3465
- González-Vega, J. C., and H. H. Stein. 2012. Amino acid digestibility in canola, cottonseed, and sunflower products fed to finishing pigs. *J. Anim. Sci.* 90:4391–4400. doi:10.2527/jas.2011-4631
- Li, P., D. F. Li, H. Y. Zhang, Z. C. Li, P. F. Zhao, Z. K. Zeng, X. Xu, and X. S. Piao. 2015. Determination and prediction of energy values in corn distillers dried grains with solubles sources with varying oil content for growing pigs. *J. Anim. Sci.* 93:3458–3470. doi:10.2527/jas.2014-8782
- Moter, V., and H. H. Stein. 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs. *J. Anim. Sci.* 82:3518–3525. doi:10.2527/2004.82123518x
- Nagalakshmi, D., S. V. R. Rao, A. K. Panda, and V. R. B. Sastry. 2007. Cottonseed meal in poultry diets: a review. *Poult. Sci.* 44:119–134.
- NRC. 2012. Nutrient requirements of swine. 11th ed. Natl. Acad. Press, Washington, DC.
- Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats. In: W. Haresign and D. J. A. Cole, editors, *Recent advances in animal nutrition*. Butterworths, London. p. 77–81.
- Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pig, poultry, sheep, goats, rabbits, horses, fish. Wageningen Academic Publishers, Wageningen, The Netherlands and INRA, Paris, France.
- Soya and Oilseed Blue Book. 2015. Annual directory of the world oilseed industry. Soyatech LLC, Southwest Harbor, ME.
- Stein, H. H., L. L. Berger, J. K. Drackley, G. F. Fahey Jr, D. C. Hernot, and C. M. Parsons. 2008. Nutritional properties and feeding values of soybeans and their coproducts. In: L. A. Johnson, P. J. White, and R. Galloway, editors, *Soybeans: chemistry, production, processing and utilization*. AOCS Press, Urbana, IL. p. 615–662.
- Stein, H. H., L. V. Lagos, and G. A. Casas. 2016. Nutritional value of feed ingredients of plant origin fed to pigs. *Anim. Feed Sci. Technol.* 218:33–69.
- Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. de Lange; Committee on Terminology to Report AA Bioavailability and Digestibility. 2007. Invited review: amino acid bioavailability and digestibility in pig feed ingredients: terminology and application. *J. Anim. Sci.* 85:172–180. doi:10.2527/jas.2005-742
- 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.
- Stein, H. H., N. L. Trottier, C. Bellaver, and R. A. Easter. 1999. The effect of feeding level and physiological status on total flow and amino acid composition of endogenous protein at the distal ileum in swine. *J. Anim. Sci.* 77:1180–1187.
- Sun, H., J. W. Tang, X. H. Yao, Y. F. Wu, X. Wang, and J. Feng. 2013. Effects of dietary inclusion of fermented cottonseed meal on growth, cecal microbial population, small intestinal morphology, and digestive enzyme activity of broilers. *Trop. Anim. Health Prod.* 45:987–993. doi:10.1007/s11250-012-0322-y
- Thiex, N. J., S. Anderson, and B. Gildemeister. 2003. Crude fat, diethyl ether extraction, in feed, cereal grain, and forage (Randall/Soxtec/submersion method): collaborative study. *J. AOAC Int.* 86:888–898.
- USDA. 2017. China -Peoples Republic of oilseeds and products update: historic spike in net imports in MY16/17 likely to temper China's soybean imports in MY17/18. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Oilseeds%20and%20Products%20Update_Beijing_China%20-%20Peoples%20Republic%20of_10-27-2017.pdf (Accessed 28 October 2017).

- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2
- Yu, F., P. J. Moughan, T. N. Barry, and W. C. McNabb. 1996. The effect of condensed tannins from heated and unheated cottonseed on the ileal digestibility of amino acids for the growing rat and pig. *Br. J. Nutr.* 76:359–371.
- Zhang, W. J., Z. R. Xu, S. H. Zhao, J. Y. Sun, and X. Yang. 2006. Development of a microbial fermentation process for detoxification of gossypolin cottonseed meal. *Anim. Feed Sci. Technol.* 135:176–186.