Chemical composition, energy content and amino acid digestibility in cottonseed meals fed to growing pigs

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ABSTRACT
Two experiments were conducted to determine the content of digestible energy (DE) and metabolisable energy (ME) as well as the apparent ileal digestibility (AID) and standardised ileal digestibility (SID) of amino acids in cottonseed meal (CSM) for growing pigs. In Experiment 1, 78 growing pigs (51.1 ± 4.2 kg) were randomly allotted to 1 of 13 diets, including a corn–soybean meal basal diet and 12 CSM test diets. In Experiment 2, 11 growing barrows (55.2 ± 4.1 kg) were allotted to 6 × 11 Youden square with 6 periods and 11 diets. The diets included a N-free diet and 10 CSM test diets. The chemical composition of CSM varied among samples. The DE and ME also differed (p < 0.05) among the 12 CSM samples. The AID and SID of CP varied largely (p < 0.05) and of indispensable amino acids (AA) except for the tryptophan and valine varied largely (p < 0.05) among CSM samples. The results of the experiments indicated that there are significant variabilities in the chemical composition, energy content and the SID and AID of CP and AA among the CSM samples.

1. Introduction
Cottonseed meal (CSM) is a by-product of the cottonseed oil processing industry. Cotton seeds are produced in many countries in the world and annual global production is approximately 44 million tons (Soy and Oilseed Bluebook 2015). After removal of oil, lint and hulls, approximately 45% of initial cottonseed meal remains and is used as cottonseed meal, and global production of cottonseed meal is approximately 15 million tons per year (Soy and Oilseed Bluebook 2015). Although much of the meal is utilized in ruminant diets (Brown and Pate 1997; Cranston et al. 2006; Winterholl et al. 2009), the price relationship between cottonseed meal and other high-protein feedstuffs often provides an excellent opportunity for pork producers to use cottonseed meal in order to reduce feed costs (Tanksley 1990). Gossypol is a toxic factor indigenous to the cotton plant genus Gossypium (Berardi and Goldblatt 1969). Nonruminant animals are particularly sensitive to the toxic effects of gossypol, whereas ruminants are somewhat more resistant. Symptoms of chronic ingestion of high levels of free gossypol in cottonseed meal by swine include laboured breathing, dyspnea, decreased growth rate, and anorexia (Hale and Lyman 1957; Kornegay et al. 1961).

Due to the different cotton varieties produced as well as differences in growing conditions and processing methods used, the nutrient levels vary widely among different sources of cottonseed meal, especially with regard to crude protein and crude fibre. The uncertain nutrient content directly affects the consistency of the digestible energy (DE) and metabolizable energy (ME) content. Cottonseed meal diets supplemented with Lys can be used as a replacement for soybean meal (SBM) in grower/finisher pigs (Batterham et al. 1990). If other protein supplements, such as meat and bone meal, canola meal or CSM are used as a replacement for soybean meal, then the use of digestible amino acid values offers great potential to increase the precision of diet formulation (Sauer and Ozimek 1986).

There is little information about the DE, ME and the standardized ileal digestibility of amino acids (AA) in CSM. So more information on the nutritional value of CSM is needed for diet formulation. Therefore, the objective of this study was to determine the chemical composition and the contents of DE and ME as well as the amino acid digestibility in the CSM sources.

2. Materials and methods
The Institutional Animal Care and Use Committee at China Agricultural University (Beijing, China) reviewed and approved the protocols used in this study. Twelve CSM samples were obtained from 5 cottonseed oil processing plants located in the provinces of Xinjiang and Shandong, which are the main cottonseed meal producing areas in China. All samples were produced by the pre-press extraction method. Ten of the collected 12 CSM were selected to determine their ileal AA digestibility. The chemical composition and AA content of these CSM are shown in Tables 1 and 2.

2.1. Experiment 1: energy measurement
2.1.1. Experimental design
This experiment was conducted to determine the apparent total tract digestibility (ATTD) of gross energy (GE), DE and ME
and the ME:DE ratio of 12 CSM fed to growing pigs. Seventy-eight crossbred (Duroc × Landrace × Yorkshire) barrows weighing 51.1 ± 4.2 kg were assigned to 1 of 13 diets according to a completely randomised design, comprised of 1 basin diet and 12 CSM test diets with 6 pigs fed each diet. Pigs were individually housed in stainless-steel metabolism crates (1.44 × 0.66 × 1.22 m³) that allowed for the total, but separate, collection of feces and urine. Each crate was fitted with a one-hole feeder and a nipple drinker and was located in an environmentally controlled room with the temperature maintained at 22 ± 2°C.

Vitamins and minerals were supplemented to all diets to meet or exceed the estimated nutrient requirements for growing pigs, as recommended by NRC (2012). The basal diet contained 79.7% corn and 17.7% dehulled soybean meal. The 12 test diets were formulated to contain 19.48% of 1 of the 12 CSM, which replaced 20% of the energy supplied by corn and soybean meal in the basal diet. The inclusion level of CSM was determined on the basis of a preliminary experiment which found that 20% was the highest inclusion level which did not result in feed refusals. The composition and nutrient levels of the experimental diets were shown in Tables 3 and 4.

### 2.1.2. Experimental procedures

The daily feed allowance was set at 4% of BW (Adeola 2001). Two equal-sized meals were fed daily at 08:00 and 17:00 h. Feed refusals and spillage were recorded for each pig. Water was available ad libitum through a drinking nipple and the diets were provided in mash form. The experiment lasted 12 d, consisting of a 7-d adaptation to the diets followed by a 5-d total collection of feces and urine using the methods described by Ji et al. (2012).

#### 2.1.3. Sample collection

Feces were collected in a collection tray mounted under the metabolic crate and stored in plastic bags at −20°C. Urine was collected in buckets located under the metabolism crates. The buckets contained 10 mL of 6 N HCl for every 1000 mL of urine. The total volume of urine collected was measured and 10% of the daily urine collection was stored at −20°C. Feces and urine samples were thawed and mixed uniformly for each pig at the end of the collection period. Then, representative sub-samples of feces were weighed and dried in a 65°C forced-air oven and ground through a 1-mm screen prior to chemical analysis. Similarly, 100 mL samples of urine were obtained for subsequent chemical analysis.

### 2.2. Experiment 2: amino acid digestibility

#### 2.2.1. Experimental design

This experiment was conducted to determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of crude protein (CP) and AA in the 10 CSM (numbers 2, 3, 5–12; Table 1) fed to growing pigs. Sources 1 and 4 were removed because of their similar AA composition to sources 2 and 5. Eleven (Duroc × Landrace × Yorkshire) growing barrows (55.2 ± 4.1 kg) were randomly allotted to 6 × 11 Youden square designs with 6 periods and 11 diets with 10 CSM test diets and a N-free diet which was used to estimate basal ileal endogenous losses of CP and AA. The ten CSM test diets contained 40% CSM as the sole source of AA. Chromic oxide (0.3%) was included in the diets as an indigestible indicator. The diets used in this experiment were formulated based on the chemical composition of the individual feed ingredients (Table 3 and Table 5). Vitamins and minerals were supplemented to meet or exceed the estimated nutrient requirements for growing pigs as recommended by NRC (2012).

#### 2.2.2. Experimental procedures

Pigs were equipped with a simple T-cannula near the distal ileum using the procedures described by Stein et al. (1998). The pigs were housed individually in stainless steel metabolism crates (1.44 × 0.66 × 1.22 m³) in an environmentally controlled room. The temperature of the room was maintained at ±2°C. Each crate was fitted with a one-hole feeder and a nipple drinker.

The BW of the pigs was obtained at the beginning of each period. All pigs were provided a daily ration equivalent to 4% of their body weight, and two equal-sized meals were provided daily at 08:00 and 17:00 h. Pigs had free access to water throughout the experiment. During each of the 6 periods, the first 5 d were for adaptation to the diet. On d 6 and 7, ileal digesta samples were collected from 8:00–17:00 h.

#### 2.2.3. Sample collection

A 200 ml plastic bag was attached to the open cannula using a cable tie. Bags were removed whenever they were filled with
Table 2. Analysed amino acid composition of cottonseed meals (% DM basis).

| Item          | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | 11     | 12     | Max   | Min   | Mean  | CV  |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|-------|-----|
| Arginine      | 5.35   | 5.32   | 6.02   | 6.30   | 6.44   | 5.87   | 6.18   | 6.57   | 4.22   | 5.37   | 5.02   | 5.02   | 6.57  | 4.22  | 5.70  | 11.93|
| Histidine     | 1.20   | 1.24   | 1.46   | 1.50   | 1.52   | 1.39   | 1.42   | 1.56   | 1.06   | 1.23   | 1.22   | 1.30   | 1.56  | 1.06  | 1.34  | 11.50|
| Isoleucine    | 1.38   | 1.38   | 1.58   | 1.63   | 1.67   | 1.53   | 1.59   | 1.69   | 1.13   | 1.39   | 1.33   | 1.48   | 1.69  | 1.13  | 1.48  | 11.20|
| Leucine       | 2.76   | 2.74   | 3.14   | 3.27   | 3.33   | 3.02   | 3.15   | 3.37   | 2.28   | 2.78   | 2.64   | 2.95   | 3.37  | 2.28  | 2.95  | 11.06|
| Lysine        | 1.97   | 2.02   | 2.30   | 2.34   | 2.42   | 2.26   | 2.28   | 2.41   | 1.71   | 2.00   | 1.94   | 2.11   | 2.42  | 1.71  | 2.15  | 10.34|
| Methionine    | 0.67   | 0.69   | 0.75   | 0.79   | 0.80   | 0.72   | 0.73   | 0.76   | 0.55   | 0.73   | 0.67   | 0.73   | 0.80  | 0.55  | 0.72  | 9.19 |
| Phenylalanine | 2.90   | 2.87   | 3.19   | 3.21   | 3.25   | 3.09   | 3.17   | 3.32   | 2.31   | 2.94   | 2.78   | 2.95   | 3.25  | 2.31  | 3.00  | 9.30 |
| Threonine     | 1.46   | 1.44   | 1.64   | 1.71   | 1.74   | 1.60   | 1.65   | 1.76   | 1.19   | 1.47   | 1.39   | 1.54   | 1.76  | 1.19  | 1.55  | 10.77|
| Tryptophan    | 0.58   | 0.60   | 0.70   | 0.72   | 0.64   | 0.66   | 0.64   | 0.61   | 0.59   | 0.68   | 0.60   | 0.69   | 0.72  | 0.58  | 0.64  | 7.29 |
| Valine        | 2.01   | 2.02   | 2.28   | 2.36   | 2.41   | 2.20   | 2.31   | 2.46   | 1.64   | 2.03   | 1.92   | 2.16   | 2.46  | 1.64  | 2.15  | 11.05|

*aSources 1–8 were collected from Xinjiang Province of China. Sources 9–12 were collected from Shandong Province of China.

The method of Thiex et al. (2003). Acid hydrolysed Ether extract (AEE) was determined by acid hydrolysis using 3 N HCL (Sanderson 1986). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using filter bags and fibre analyser equipment (Fibre Analyzer, Ankom Technology, Macedon, NY) following a modification of the procedure of Van Soest et al. (1991). Free gossypol (FG) was determined according to the method described by Pons and Guthrie (1949). The gross energy (GE) in CSM, diets, feces and urine was measured using an Automatic Isoperibol Oxygen Bomb Calorimeter (Parr 6400 Automatic Energy Analyzer, Moline, IL).

Samples of CSM, diets and ileal digesta from experiment 2 were also analysed for the concentration of amino acids. Amino acids were analysed after being hydrolysed with 6 N HCl for 24 h at 110°C. Fifteen amino acids were analysed using an Amino Acid Analyzer (Hitachi L-8900, Tokyo, Japan). Tryptophan was determined after LiOH hydrolysis for 22 h at 110°C using High-performance Liquid Chromatography (Agilent 1200 Series, Santa Clara, CA). Methionine and cystine were determined as methionine sulphone and cysteic acid after cold performic acid oxidation overnight and hydrolysing with 7.5 N HCl for 24 h at 110°C using an Amino Acid Analyzer (Hitachi L-8800, Tokyo, Japan). The chromium content in the diets and digesta was measured using an Atomic Absorption Spectrophotometer (Hitachi Z-5000 Automatic Absorption Spectrophotometer, Tokyo, Japan) according to the procedure of Williams et al. (1962).

2.4. Calculations

In experiment 1, the energy-contributing ingredients in the basal diet were corn and soybean meal, which made up 97.4% of the basal diet. Therefore, the energy concentration of corn and soybean meal was calculated by dividing the DE and ME of the basal diet by 0.974. After that, the DE and ME values for each CSM sample were calculated by subtracting the contribution from corn and soybean meal in the CSM-containing diets using the difference procedure (Adeola 2001).
In experiment 2, values for AID and SID were determined according to the method of Stein et al. (2007). The AID for each amino acid was calculated using Equation (1):

\[
AID = [1 - (\frac{AAdigesta}{AAdiet})(\frac{Crdiet}{Crdigesta})] \times 100\% \tag{1}
\]

In this equation, AID is the apparent ileal digestibility of an amino acid (%), AAdigesta is the amino acid concentration in the ileal digesta (g/kg DM), AAdiet is the amino acid concentration in the diet (g/kg DM), Crdiet is the chromium concentration in the diet (g/kg DM) and Crdigesta is the chromium concentration in the ileal digesta (g/kg DM).

The basal endogenous loss of each amino acid (IAAend, g/kg DM) at the distal ileum was determined based on the outflow obtained when pigs were fed a N-free diet using Equation (2):

\[
IAA_{end} = AA_{digesta}(Crdiet/Crdigesta) \tag{2}
\]

In this equation, IAAend is the basal ileal endogenous loss of an amino acid (g/kg DM intake), AA_{digesta} is the amino acid concentration in the ileal digesta (g/kg DM). Crdiet is the chromium concentration in the diet (g/kg DM) and Crdigesta is the chromium concentration in the ileal digesta (g/kg DM). The endogenous flow of CP was also determined using the same equation.

By correcting the AID of each amino acid for the IAA_{end} of each amino acid, standardized ileal digestibility values (SID) were calculated using Equation (3):

\[
SID = AID + (IAA_{end}/AA_{diet}) \cdot 100\% \tag{3}
\]

where SID is the standardized ileal digestibility of an amino acid (%).

2.5. Statistical analysis

In experiment 1, the data were analysed using the GLM procedure (SAS Institute Inc., Cary, NC), with the pig as the experimental unit, if significant differences were found, the Student Newman Keul’s test was used to test the significance of differences between means. In experiment 2, the individual pig was the experiment unit for all analyses. The model included the fixed effect of CSM and the random effects of pig and period. The REPEATED statement was used to model the effect of period using the individual pig as the subject from
which repeated observations were recorded (Littell et al. 1998). The data on AID and SID were analysed using the GLM procedure, if significant differences were found, the Student Newman Keul’s test was used to test the significance of differences between means. In all analysis, the differences were considered significant if \( p < 0.05 \).

3. Results

3.1. Chemical composition of cottonseed meal

The chemical composition of the 12 CSM sources is shown in Table 1 and the chemical composition of the experimental diets is presented in Table 4. The coefficient of variation (CV) of CP, EE, AEE, CF, NDF, ADF, TP and FG was greater than the values published in the NRC (2012). All amino acids except for the cystine and proline were variable (CV > 10%) except methionine (Met), phenylalanine (Phe), tryptophan (Trp) and cystine (Cys) (CV < 10%). The average concentrations of indispensable amino acids, CSM had the highest content of glutamine and the lowest content of cystine with an average of 9.08% and 0.79%, respectively. The average concentrations of dispensable amino acids, CSM had the highest content of glycine (Gly) and the lowest content of tryptophan (Trp) with an average of 45.59% and 6.14%, respectively. The content of free gossypol ranged from 147.61–474.48 mg/kg (Table 6).

The AA composition for CSM is shown in Table 2. Most AA were variable (CV > 10%) except methionine (Met), phenylalanine (Phe), tryptophan (Trp) and cystine (Cys) (CV < 10%). For the indispensable amino acids, CSM had the highest content of arginine and the lowest content of tryptophan with an average of 5.70% and 0.64%, respectively. For the dispensable amino acids, CSM had the highest content of glutamine and the lowest content of cystine with an average of 9.08% and 0.79%, respectively. The average concentrations of all amino acids except for the cystine and proline were greater than the values published in the NRC (2012).

3.2. Energy digestibility

The DE, ME and ATTD of GE for the 12 CSM samples differed significantly (Table 7). The concentration of DE (mean 11.62 MJ/kg) and ME (mean 10.68 MJ/kg) ranged from 8.72–13.49 MJ/kg and 8.05–12.15 MJ/kg of DM, respectively. The difference between the highest and lowest values for DE and ME was 4.77 and 4.18 MJ/kg of DM, respectively. The ATTD of GE ranged from 45.59–67.93% with a mean value of 59.24%. However, the ratio of ME to DE did not differ among the 12 CSM samples.

3.3. Digestibility of crude protein and amino acids

The AID of CP was different among the CSM sources (\( p < 0.05 \)) (Table 8). The AID for CP varied between 70.41 and 77.73% with an average value of 75.31%. The AID for Lys, Met and Thr among samples ranged from 51.50–64.26%, 66.86–76.80% and 51.18–64.58%. Source 10 CSM had a higher AID for CP, Lys, Met and Thr than source 12 CSM (\( p < 0.05 \)).

The trend in SID for CP and AA was similar to AID. The SID of CP showed differences among the CSM sources (\( p < 0.05 \)) (Table 9). Sources 9 and 10 CSM had a higher AID for CP than sources 11 and 12 (\( p < 0.05 \)). The SID for Lys, Met and Thr among samples ranged from 55.00–68.02%, 69.94–79.98% and 59.33–73.14%. Source 10 CSM had a higher SID for CP, Lys, Met and Thr than source 12 CSM (\( p < 0.05 \)). For the indispensable amino acids, there were significant differences (\( p < 0.05 \)) among the AID and SID of the 10 CSM except for Trp and Val, and for the dispensable amino acids, there were significant differences among the AID and SID of the 10 CSM except for Gly, Pro and Tyr.

4. Discussion

4.1. Chemical composition of CSM sources

The chemical composition of the 12 CSM samples was quite variable in the current study and the CV for CP, EE, AEE, CF, NDF, ADF, TP and FG was high. This is likely a reflection of the different growing conditions and different varieties of CSM used in the experiment. Because of different processing conditions among plants, there is actually a wide range of protein quality among the prepress solvent meals. Although the same pre-press extraction method was used, there may be some differences in the treatment temperature and solvents used during the production of cottonseed oil among the cottonseed meal processing plants, also leading to variation in the quality of cottonseed meals (Lea and Hannan 1949; Anderson-Hafermann et al. 1993).

The EE content in all CSM samples was lower than the values reported by NRC (2012) and Tanksley et al. (1981), which indicates that more oil had been extracted from the cottonseed and, as a result, the GE of the CSM was lower than the values published in NRC (2012). The EE content in all CSM samples was similar to a previous report for prepress solvent cottonseed meal (Tanksley 1990).

The content of CP in sources 4, 5, and 8 (57.52%, 56.90%, and 56.78%, respectively) were much higher than previously

| Table 6. Daily energy for growing pigs fed basal diet and cottonseed meal (CSM) diets in experiment 1 (as-fed basis). |
|---------------------------------------------------------------|
| **Items** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **SEM** | **p-value** |
| Feed intake, kg/day | 1.99 | 1.98 | 1.98 | 1.99 | 1.96 | 1.91 | 2.01 | 1.98 | 2.00 | 1.96 | 1.95 | 2.01 | 0.02 | 1.00 |
| GE intake, MJ/day | 31.81 | 31.52 | 31.72 | 31.65 | 31.15 | 30.31 | 32.03 | 31.80 | 31.77 | 31.16 | 30.91 | 31.73 | 0.36 | 1.00 |
| GE in feces, MJ/day | 5.43<sup>a</sup> | 5.17<sup>a</sup> | 4.53<sup>a</sup> | 4.41<sup>a</sup> | 4.42<sup>a</sup> | 4.60<sup>a</sup> | 4.86<sup>a</sup> | 4.61<sup>b</sup> | 5.93<sup>a</sup> | 4.88<sup>a</sup> | 4.88<sup>a</sup> | 4.82<sup>a</sup> | 0.07 | <0.01 |
| GE in urine, MJ/day | 0.71 | 0.69 | 0.86 | 0.79 | 0.70 | 0.72 | 0.75 | 0.75 | 0.66 | 0.56 | 0.78 | 0.63 | 0.04 | 0.61 |
| DE of the diet, MJ/kg | 13.26<sup>c</sup> | 13.28<sup>c</sup> | 13.75<sup>c</sup> | 13.65<sup>abc</sup> | 13.66<sup>abc</sup> | 13.46<sup>abc</sup> | 13.51<sup>abc</sup> | 13.72<sup>ab</sup> | 12.93<sup>d</sup> | 13.37<sup>abc</sup> | 13.32<sup>bc</sup> | 13.42<sup>abc</sup> | 0.03 | <0.01 |
| ME of the diet, MJ/kg | 12.90<sup>ab</sup> | 12.94<sup>ab</sup> | 13.30<sup>a</sup> | 13.26<sup>a</sup> | 13.30<sup>a</sup> | 12.93<sup>ab</sup> | 13.15<sup>a</sup> | 13.31<sup>a</sup> | 12.60<sup>a</sup> | 13.08<sup>a</sup> | 12.94<sup>a</sup> | 13.10<sup>a</sup> | 0.03 | <0.01 |
| ATTD of GE (%) | 82.93<sup>a</sup> | 83.50<sup>a</sup> | 85.66<sup>a</sup> | 86.05<sup>a</sup> | 85.73<sup>a</sup> | 84.82<sup>a</sup> | 84.82<sup>a</sup> | 85.54<sup>a</sup> | 81.32<sup>a</sup> | 84.29<sup>a</sup> | 84.19<sup>a</sup> | 84.83<sup>a</sup> | 0.16 | <0.01 |

<sup>a</sup>Each CSM diet contained one of the twelve CSM sources. Sources 1–8 were collected from Xinjiang Province of China. Sources 9–12 were collected from Shandong Province of China. GE, Gross energy; DE, Digestible energy; ME, Metabolizable energy; ATTD, Apparent total tract digestibility.

<sup>b</sup>SEM, standard error of the mean. <sup>c</sup>Means within a row with different letters differ significantly (\( p < 0.05 \)).
published values (LaRue et al. 1985; Papadopoulos et al. 1987; Prawirodirdjo et al. 1998). The higher proportions of CP in these three CSM samples were likely due to the more advanced technology used for oil extraction of cottonseed. Although the 12 CSM samples used in this study were all prepress solvent cottonseed meals, we suspect the decortication process could result in the CSM with higher protein content and lower fibre content, which may make the CSM quality different (Corredor et al. 2006).

The CF, NDF and ADF content varied widely among the CSM sources. This may be the result of different amount of hulls added back to the CSM or the specific processing conditions employed (temperature, time and moisture) at each plant. In all samples, the content of CF was lower than those obtained by Papadopoulos et al. (1987), except for Source 9. Values for ADF concentrations in the CSM ranged from 10.40–25.89% (DM-basis) and an average value of 19.76% (DM-basis) was reported by NRC (2012).

Cottonseed meal fed to swine should have a high protein quality and a low free gossypol content. 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). High processing temperatures promote a reaction between free gossypol and free amino groups in the protein to form an indigestible complex (Baliga and Lyman 1957; Smith 1972). The ethanol used as a solvent could reduce free gossypol to a safe level in CSM for use as a general animal feed protein source (Hron et al. 1996). In a current study, the CSM samples were processed with the proper treatment temperature and solvent, so the free gossypol contents of the CSM sources were relatively low, ranging from 147.61–474.48 mg/kg, which is closer to the value obtained from Husby and Kroening (1971), but is higher than the published value of LaRue et al. (1985).

The average values (DM-basis) for most amino acids in the CSM sources were higher than the values reported by Sauvant et al. (2004) and Rostagno et al. (2011). The average values (DM-basis) for the indispensable amino acids of the CSM sources were higher than the values reported by González-Vega and Stein (2012) and NRC (2012), but were lower than the values for glandless CSM reported by Tanksley et al. (1981).

### 4.2. Energy digestibility

CSM can substitute soybean meal as a plant protein feed partly and its available energy content was critical for feed formulation (Noland et al. 1968). There were significant differences between DE and ME among CSM samples, the gap between the highest value and the lowest value was so large that it couldn’t be ignored during the feed formulation. The difference in DE and ME among the CSM samples may be caused by the difference in fibre and protein content. Bell (1993) reported that the reduction of fibre concentration and greater protein concentration increases the concentration of gross energy. With the wide range in composition of the CSM, the DE and ME varied with differences of 4.77 and 4.10 MJ/kg of DM among the CSM. Nevertheless, the differences were significant ($p < 0.05$) with an average of 11.62 and 10.68 MJ/kg of DM, respectively.

### Table 7. DE, ME and apparent total tract digestibility of GE of cottonseed meal sources in experiment 1.

| Item | Cottonseed meal source$^\gamma$ | Max | Min | Mean | SEM & p-value$^\gamma$ |
|------|---------------------------------|-----|-----|------|-----------------------|
| | | DE (MJ/kg DM) | ME (MJ/kg DM) | ATTD of GE (%) | ME/DE (%) |
| 1   | Sources 1–8 were collected from Xinjiang Province of China. Sources 9–12 were collected from Shandong Province of China. | | | |
| 2   | | 15.30 | 15.29 | 15.30 | 0.15 |
| 3   | | 15.29 | 15.27 | 15.29 | 0.15 |
| 4   | | 15.29 | 15.28 | 15.29 | 0.15 |
| 5   | | 15.29 | 15.28 | 15.29 | 0.15 |
| 6   | | 15.29 | 15.27 | 15.29 | 0.15 |
| 7   | | 15.29 | 15.27 | 15.29 | 0.15 |
| 8   | | 15.29 | 15.27 | 15.29 | 0.15 |
| 9   | | 15.29 | 15.27 | 15.29 | 0.15 |
| 10  | | 15.29 | 15.27 | 15.29 | 0.15 |
| 11  | | 15.29 | 15.27 | 15.29 | 0.15 |
| 12  | | 15.29 | 15.27 | 15.29 | 0.15 |

$^\gamma$ Sources: 1–8 were collected from Xinjiang Province of China. Sources 9–12 were collected from Shandong Province of China. GE, Gross energy; DE, Digestible energy; ME, Metabolizable energy; ATTD, Apparent total tract digestibility; ME/DE, The ratio of ME to DE.

$^\gamma$SEM, standard error of the mean. abcMeans within a row with different letters differ significantly ($p < 0.05$).
Tables 8. Apparent ileal digestibility (%) of crude protein and amino acids in cottonseed meal sources fed to growing pigs in experiment 2.

| Item                  | Mean ± SEM | p-value |
|-----------------------|------------|---------|
| **Crude protein**     | 74.57ab    | 80.39ab |
| **Indispensable amino acids** |           |        |
| Arginine              | 89.30ab    | 80.95ab |
| Histidine             | 77.72ab    | 79.04ab |
| Leucine               | 76.57ab    | 77.22ab |
| Isoleucine            | 70.06ab    | 70.00ab |
| Lysine                | 60.03ab    | 59.98ab |
| Methionine            | 72.60ab    | 72.52ab |
| Phenylalanine         | 79.31ab    | 78.99ab |
| Threonine             | 56.91bc    | 56.77ab |
| Tryptophan            | 69.84ab    | 69.57ab |
| Valine                | 64.22ab    | 64.31ab |
| **Dispensable amino acids** |           |        |
| Alanine               | 63.00a     | 63.03a  |
| Aspartate             | 73.12ab    | 72.93ab |
| Cystine               | 70.71ab    | 70.58ab |
| Glutamine             | 83.04ab    | 82.93ab |
| Glycine               | 66.50ab    | 66.37ab |
| Proline               | 66.27ab    | 66.14ab |
| Serine                | 67.30cd    | 67.15cd |
| Tyrosine              | 72.71ab    | 72.45ab |

§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, 9.80; Arg, 0.28; His, 0.15; Ile, 0.27; Leu, 0.48; Lys, 0.28; Met, 0.08; Phe, 0.32; Thr, 0.51; Trp, 0.11; Val, 0.29; Ala, 0.47; Asp, 0.63; Cys, 0.23; Glu, 0.76; Gly, 0.75; Pro, 1.06; Ser, 0.41; and Tyr, 0.20.

The average DE and ME for the 12 CSM samples are lower than the values published by NRC (2012). The concentration of DE and ME in cottonseed meal has been recently determined to be 12.62 and 11.30 MJ/kg (Rodriguez et al., 2013), which is higher than the average value of this study. The lower DE and ME values may be due to the lower content of ether extract (Noblet and Perez 1993; Ren et al., 2011) or greater fiber content (Bell 1993) of CSM used in the current study. The ATTD of GE varied (p < 0.05), which may be due to the different fibre contents (Noblet and Shi, 1993). The ME to DE ratio varied from 89.63–95.39%, with an average of 92.31%, which was higher than the value of 90.83% determined by NRC (2012) and was lower than the value of some research (Noblet and Perez 1993).

Table 9. Standardized ileal digestibility (%) of crude protein and amino acids in cottonseed meal sources fed to growing pigs in experiment 2.

| Item                  | Mean ± SEM | p-value |
|-----------------------|------------|---------|
| **Crude protein**     | 79.52ab    | 81.52ab |
| **Indispensable amino acids** |           |        |
| Arginine              | 90.54ab    | 90.51ab |
| Histidine             | 80.92ab    | 80.34ab |
| Leucine               | 80.24ab    | 79.32ab |
| Isoleucine            | 74.80ab    | 73.53ab |
| Lysine                | 64.05bc    | 64.11bc |
| Methionine            | 75.86ab    | 74.95ab |
| Phenylalanine         | 79.24ab    | 78.34ab |
| Threonine             | 66.18ab    | 70.30ab |
| Tryptophan            | 74.97ab    | 70.36ab |
| Valine                | 68.71ab    | 65.23ab |
| **Dispensable amino acids** |           |        |
| Alanine               | 69.75ab    | 68.15ab |
| Aspartate             | 77.11ab    | 76.61ab |
| Cystine               | 77.70ab    | 77.83ab |
| Glutamine             | 85.28a     | 85.65a  |
| Glycine               | 71.06ab    | 69.06ab |
| Proline               | 80.79bc    | 78.62bc |
| Serine                | 73.25bc    | 72.60bc |
| Tyrosine              | 77.76bc    | 76.86bc |

Notes: Mean, the average value of ten CSM sources. SEM, standard error of the mean. abcMeans within a row with different letters differ significantly (p < 0.05).

§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, 9.80; Arg, 0.28; His, 0.15; Ile, 0.27; Leu, 0.48; Lys, 0.28; Met, 0.08; Phe, 0.32; Thr, 0.51; Trp, 0.11; Val, 0.29; Ala, 0.47; Asp, 0.63; Cys, 0.23; Glu, 0.76; Gly, 0.75; Pro, 1.06; Ser, 0.41; and Tyr, 0.20.
because of the higher concentration of CP in the 10 CSM samples. The average values of AID for CP, Lys and Thr in the 10 CSM samples are higher than the values reported by Knabe et al. (1989) and Prawirodirdgo et al. (1998). The values for the AID of CP and Met in CSM that were determined in this experiment are within the range of previous values (Tanksley et al. 1981) while the AID of Lys and Thr are less than previously reported. Among the AID and SID of all amino acids, the average digestibility of arginine was the highest (89.29%) previously reported. Among the AID and SID of all amino acids, the high content of lysine, but the AID and SID of Lys was lower than the values reported by NRC (2012). The average value of SID for Lys in the 10 CSM samples was lower than the values reported by NRC (2012), but was higher than the values reported by González-Vega and Stein (2012). The average value of SID for Met in the 10 CSM samples was higher than the values reported by NRC (2012) and González-Vega and Stein (2012). Sample 5 CSM had a relatively high content of lysine, but the AID and SID of Lys was lower than the values reported by NRC (2012).

The decreased AA digestibility for Sample 5 CSM may be due to Maillard reaction that occurred during processing (Bell 1993; Woyengo et al. 2010). The reason for the low digestibility of lysine may be that heat damage may have taken place during processing (Almeida et al. 2014). Pahm et al. (2008) and Kim et al. (2012) reported that temperature differences during processing can cause Maillard reactions with protein, which reduces the digestion and utilization of lysine, and in turn, affects the AID and SID of amino acids. The reason for the poor AID and SID of most amino acids found in CSM source 12 is not known, but it may be due to some improper processing resulting in indigestible complexes that hinder amino acid digestibility.

5. Conclusions

In conclusion, the chemical composition, the DE and ME as well as the AID and SID of AA varied significantly among the 12 CSM samples. The greater DE and ME content of CSM made it an attractive alternative for pig diets. The nutritional values of CSM were affected by different chemical composition. In order to make better use of CSM in diets fed to swine as an alternative to SBM, future work should be conducted to identify the relationship between the chemical composition and the nutritional value and make their application wider.

Disclosure statement

No potential conflict of interest was reported by the authors.

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