



Determination and Prediction of the Amino Acid Digestibility of Sunflower Seed Meals in Growing Pigs

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ABSTRACT: This experiment was conducted to evaluate the chemical composition and amino acid (AA) digestibility of sunflower seed meal (SFSM) and to use this data to develop prediction equations for estimating AA digestibility for growing pigs. Ten SFSM were collected from five provinces in China. Twelve barrows (38.8±4.6 kg), fitted with ileal T-cannula were allotted into two 6×6 Latin square designs. Each of six experimental periods comprised a 5-d adaption period followed by a 2-d collection of ileal digesta. The ten test diets contained 50% SFSM as the sole source of AA. Another nitrogen-free diet was used to measure the basal endogenous losses of crude protein (CP) and AA. Chromic oxide (0.3%) was used as an inert marker in each diet. There was considerable variation (CV>10%) among the ten SFSM in chemical composition (dry matter [DM]). The concentration of CP and ether extract (EE) ranged from 29.33% to 39.09% and 0.88% to 11.33%, respectively. Crude fibre (CF), neutral detergent fibre and acid detergent fibre ranged from 21.46% to 36.42%, 38.15% to 55.40%, and 24.59% to 37.34%, respectively. There was variation among the ten SFSM in apparent ileal digestibility (AID) and standardized ileal digestibility (SID) for lysine and threonine, which ranged from 63.16 to 79.21 and 55.19% to 72.04% for AID and 67.03% to 82.07% and 61.97% to 77.01% for SID, respectively. The variation in CP and methionine ranged from 60.13% to 74.72% and 74.79% to 88.60% for AID and 66.70% to 79.31% and 77.16% to 90.27% for SID, respectively. Methionine was a good indicator to predict AA digestibility. These results indicate that conventional chemical composition of SFSM was variable (CV>10%) among the ten SFSM (DM). The results of AID, SID and prediction equations could be used to evaluate the digestibility of SFSM in growing pigs. (**Key Words:** Sunflower Seed Meal, Chemical Composition, Amino Acid Digestibility, Growing Pigs, Prediction Equations)

INTRODUCTION

Sunflower (*Helianthus annuus*, Asteraceae) is one of the most widely cultivated oil crops in the world (Flagella et al., 2002). The world-wide production of sunflower seed reached 37.08 million tonnes and subsequently produced 15.22 million tonne of oil (FAO, 2012). Together with soybeans, cottonseeds and canola (rapeseed), sunflower seeds are one of the major oilseeds produced in the world (Salunkhe et al., 1992).

Oilseed by-products play an important role in supplying plant protein (Church and Kellems, 1998). Soybean meal

(SBM) is often referred to as the gold standard compared with other protein sources (Cromwell, 2000; Zhang et al., 2013). The demand for soybean is increasing due to its inclusion in livestock feed and also its use for human consumption (Sasipriya and Siddhuraju, 2013). In order to satisfy the need for protein resources, other materials such as rapeseed meal (Baidoo et al., 1987; Brand et al., 2001; Opalkal et al., 2001; Zhang et al., 2012), cottonseed meal (Noland et al., 1968; Tanksley et al., 1981) and peanut meal (Batal et al., 2005; Sulabo et al., 2013) have been used to replace SBM in the feed industry.

Sunflower seed meal (SFSM) is a by-product of the oil extraction of sunflowers and could be an important protein resource for use in animal diets. Solvent extracted sunflower seed meal has an average concentration of crude protein (CP) of 30.7% and a higher concentration of

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Methionine (Met) than solvent extracted SBM, but has less lysine (Lys) than SBM (NRC, 2012). Another characteristic of SFSM is that it is not known to have antinutritional factors such as those found in soyabean, cottonseed and rapeseed meals. Although sunflower seed contains 1.56% chlorogenic acid (Milic et al., 1968), its concentration in SFSM does not lead to toxicity effects (Senkoylu and Dale, 1999). Sunflower seed meal diets supplemented with Lys can be used as a replacement for SBM in growing pigs (Seerley et al., 1974). However, the digestibility of these nutrients may vary considerably resulting in rather inaccurate measures for the nutritional value of actual batches of feed (Just et al., 1983). Therefore, the objective of this study was to compare the chemical composition of different SFSM and determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and amino acid (AA) of SFSM fed to growing pigs. In addition, the results of the chemical analysis were used to establish prediction equations for AID and SID that could be applied in future commercial practice.

MATERIALS AND METHODS

This experiment was conducted at the China Agricultural University (Beijing, China). The Institutional Animal Care and Use Committee at China Agricultural University approved the protocol for the experiment. All the pigs had been used in another experiment before being placed in this experiment.

Animals and housing

The experiment was conducted in the Metabolism Laboratory of the Ministry of Agriculture Feed Industry Centre, Beijing. Temperature and humidity of the room were automatically controlled at 18°C to 21°C and 50% to 65%.

Twelve barrows (Duroc×Landrace×Yorkshire) with an

initial body weight (BW) 38.8±4.6 kg were fitted with a simple T-cannula in the distal ileum (Stein et al., 1998). The barrows were individually placed in stainless-steel metabolism crates (1.4×0.45×0.6 m³). Each crate was installed with a one-hole feeder and a nipple drinker.

Source of sunflower seed meal and experiment design

Ten sunflower seed meals were collected from five provinces in China which are representative of more than 80% of the output of China. The chemical composition of ten SFSM differed from each other (Tables 1 and 2).

The 12 barrows were allocated into two 6×6 Latin square designs according to their initial BW with 6 pigs for each Latin square. Each Latin square contained 5 SFSM which were the only source of AA and one nitrogen-free diet which was used to estimate basal ileal endogenous losses of CP and AA. The diets used in this experiment were prepared based on the chemical composition of the feed ingredients (Tables 3 and 4). All diets were fed in mash form.

Sample collection

The daily feed intake at the beginning of each period was set at 4% of BW (Adeola, 2001). During each of the 6 experimental periods, the first 5 d were for adaptation to the diet. On d 6 and 7, ileal digesta samples were collected from 8:00 to 16:00 h. Cannulas were opened and plastic bags were fastened with the help of a rubber band in order to collect the digesta flowing into the bags. Every 30 minutes, the plastic bags were replaced and digesta samples were taken and stored at -20°C. Ileal digesta samples were thawed and mixed at the end of every two day collection period. All the samples were mixed and lyophilised in a Vacuum-Freeze Dryer (Tofflon Freezing Drying Systems, Minhang District, Shanghai, China) and passed a 1 mm screen before a sub-sample was obtained for chemical analysis.

Table 1. Analyzed chemical composition of sunflower seed meal (% DM)

Item	Sunflower seed meal number ¹										Min	Max	Mean	CV
	1	2	3	4	5	6	7	8	9	10				
DM	90.91	91.37	92.51	90.76	92.15	92.91	91.27	91.85	90.79	90.31	90.31	92.91	91.48	0.92
Composition														
CP	34.91	38.00	29.33	32.02	31.68	29.47	35.19	34.63	39.09	30.87	29.33	39.09	33.52	10.13
Ether extract	2.19	2.08	5.23	0.93	1.23	3.47	2.02	0.88	1.73	11.33	0.88	11.33	3.11	101.99
NDF	41.65	38.15	55.40	45.93	47.32	43.97	40.96	42.67	40.72	51.90	38.15	55.40	44.87	12.01
ADF	25.85	24.59	37.34	31.31	31.42	28.04	25.89	27.99	26.07	30.52	24.59	37.34	28.90	13.28
Crude fibre	21.83	23.11	36.42	30.54	29.87	27.25	21.46	25.66	22.47	33.69	21.46	36.42	27.23	19.31
Ash	6.86	7.15	5.45	6.32	6.82	7.75	8.30	6.40	6.76	6.71	5.45	8.30	6.85	11.37
Calcium	0.27	0.32	0.17	0.34	0.33	0.45	0.44	0.30	0.30	0.31	0.17	0.45	0.32	25.07
Phosphorus	1.04	1.15	0.63	0.81	0.94	0.84	1.02	0.98	1.06	0.92	0.63	1.15	0.94	15.89

DM, dry matter; Min, minimum; Max, maximum; CV, coefficient of variation; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre.

¹ Sources of sunflower seed meal: 1, 4, and 8 were from Xinjiang; 2, 7, and 9 were from Hebei; 3 was from Liaoning; 5 was from Shanxi; 6 and 10 were from Inner Mongolia.

Table 2. Analyzed AA composition of sunflower seed meal (% DM)

Item	Sunflower seed meal number ¹										Min ²	Max ³	Mean	CV ⁴
	1	2	3	4	5	6	7	8	9	10				
Indispensable AA														
Arginine	2.70	3.03	2.22	2.52	2.48	2.35	2.91	2.60	3.06	2.34	2.22	3.06	2.62	11.36
Histidine	0.89	1.11	0.87	0.86	0.85	0.80	0.97	0.88	1.18	0.83	0.80	1.18	0.93	13.67
Isoleucine	1.36	1.55	1.20	1.29	1.25	1.15	1.45	1.34	1.62	1.23	1.15	1.62	1.34	11.45
Leucine	2.18	2.38	1.78	2.04	1.99	1.92	2.29	2.07	2.46	1.81	1.78	2.46	2.09	11.06
Lysine	1.56	1.63	1.22	1.52	1.45	1.31	1.56	1.51	1.67	1.36	1.22	1.67	1.48	9.61
Methionine	0.80	0.86	0.61	0.74	0.76	0.65	0.80	0.77	0.89	0.66	0.61	0.89	0.75	12.00
Phenylalanine	1.45	1.67	1.22	1.23	1.30	1.17	1.45	1.42	1.71	1.28	1.17	1.71	1.39	13.39
Threonine	1.33	1.42	1.09	1.15	1.14	1.08	1.35	1.29	1.45	1.17	1.08	1.45	1.25	11.04
Tryptophan	0.37	0.43	0.33	0.34	0.35	0.32	0.40	0.34	0.44	0.35	0.32	0.44	0.37	11.64
Valine	1.85	2.02	1.57	1.60	1.62	1.52	1.83	1.76	2.05	1.80	1.52	2.05	1.76	10.47
Dispensable AA														
Alanine	1.70	1.76	1.41	1.55	1.54	1.49	1.74	1.66	1.79	1.52	1.41	1.79	1.62	8.10
Aspartate	3.08	3.50	2.66	2.88	2.68	2.71	3.23	3.03	3.56	2.77	2.66	3.56	3.01	11.04
Cystine	0.64	0.62	0.39	0.52	0.53	0.47	0.60	0.60	0.71	0.48	0.39	0.71	0.56	17.15
Glutamine	7.02	7.62	5.97	6.56	6.28	6.20	7.51	6.89	7.86	6.12	5.97	7.86	6.80	10.05
Glycine	2.05	2.32	1.70	1.93	1.91	1.69	2.12	2.01	2.35	1.92	1.69	2.35	2.00	11.22
Proline	1.19	1.30	1.12	1.16	1.17	1.11	1.28	1.17	1.33	1.16	1.11	1.33	1.20	6.58
Serine	1.45	1.64	1.14	1.38	1.37	1.29	1.53	1.41	1.66	1.36	1.14	1.66	1.42	11.00
Tyrosine	0.78	0.93	0.66	0.68	0.63	0.70	0.88	0.75	0.97	0.59	0.59	0.97	0.76	17.58

DM, dry matter; Min, minimum; Max, maximum; CV, coefficient of variation; AA, amino acid.

¹ Sources of sunflower seed meal: 1, 4, and 8 were from Xinjiang; 2, 7, and 9 were from Hebei; 3 was from Liaoning; 5 was from Shanxi; 6 and 10 were from Inner Mongolia.

Chemical analyses

All analyses in the experiment were performed in duplicate and the chemical analyses were repeated if the difference between duplicates were over 5%. The methods

Table 3. Ingredient composition of experimental diets (% as-fed)

Ingredients	Sunflower seed meal diets	Nitrogen-free diet
Sunflower seed meal	50.00	-
Corn starch	35.00	73.35
Soybean oil	2.00	3.00
Sucrose	10.00	15.00
Cellulose acetate ¹	-	4.00
Limestone	0.40	0.50
Dicalcium phosphate	1.50	2.50
Sodium chloride	0.30	0.45
Chromic oxide	0.30	0.30
Potassium carbonate	-	0.30
Magnesium oxide	-	0.10
Micromineral and vitamin premix ²	0.50	0.50

¹ Made by Chemical Reagents Company, Beijing, China.

² Premix provided the following per kg of complete diet: vitamin A, 5,512 IU; vitamin D₃, 2,200 IU; vitamin E, 30 IU; vitamin K₃, 2.2 mg; vitamin B₁₂, 27.6 µg; riboflavin, 4 mg; pantothenic acid, 13.8 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; vitamin B₁, 1.5 mg; vitamin B₆, 3 mg; biotin, 44 µg; Mn, 40 mg (MnO); Fe, 75 mg (FeSO₄·H₂O); Zn, 75 mg (ZnO); Cu, 10 mg (CuSO₄·5H₂O); I, 0.3 mg (KI); Se, 0.3 mg (Na₂SeO₃).

used to analyze the chemical composition were similar to the description by Ji et al. (2012).

The ten SFSM, diets and digesta samples were analyzed for dry matter (DM) (AOAC procedure 4.1.06, 2000), CP (AOAC procedure 990.03, 2000), Kjeldahl N (Thiex et al., 2002) and CP was calculated as N×6.25. The AA were analyzed after being hydrolysed with 6 N HCl for 24 h at 110°C. Fifteen AA were analyzed using an AA 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, USA). Methionine and cystine were determined as methionine sulfone and cysteic acid after cold performic acid oxidation overnight and hydrolysing with 7.5 N HCl for 24 h at 110°C using an AA Analyzer (Hitachi L-8800, Tokyo, Japan).

The 10 SFSM were also analyzed for crude fiber (CF), ether extract (EE) (Thiex et al., 2003), ash, calcium (Ca) (AOAC procedure 4.8.03, 2000) and total phosphorus (AOAC procedure 3.4.11, 2000). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using fibre bags and an analyser (Fibre Analyzer, Ankom Technology, Macedon, NY, USA) following an adaptation procedure described by Van Soest et al. (1991). Diets and ileal digesta samples were analyzed for chromium concentration. A Polarized Zeeman Atomic Absorption Spectrometer (Hitachi Z2000, Tokyo, Japan) was used after

Table 4. Analyzed composition of experiment diets (% DM)

Item	Sunflower seed meal number									
	1	2	3	4	5	6	7	8	9	10
DM	85.67	84.16	85.87	85.19	83.49	85.92	83.98	84.13	83.54	84.76
CP	18.94	22.77	16.09	17.84	17.49	16.80	20.38	19.20	23.06	17.16
Indispensable AA										
Arginine	1.41	1.64	1.18	1.32	1.37	1.27	1.56	1.38	1.66	1.31
Histidine	0.55	0.61	0.45	0.47	0.45	0.43	0.58	0.51	0.67	0.46
Leucine	0.73	0.90	0.65	0.66	0.68	0.63	0.81	0.69	0.92	0.65
Isoleucine	1.06	1.24	0.96	1.04	1.12	1.05	1.20	1.00	1.33	0.97
Lysine	0.80	0.86	0.66	0.80	0.81	0.70	0.79	0.79	0.89	0.72
Methionine	0.41	0.43	0.31	0.38	0.39	0.35	0.41	0.39	0.48	0.36
Phenylalanine	0.77	0.95	0.65	0.70	0.83	0.66	0.80	0.76	0.97	0.70
Threonine	0.74	0.78	0.58	0.61	0.63	0.58	0.75	0.70	0.80	0.64
Tryptophan	0.19	0.24	0.18	0.18	0.19	0.17	0.23	0.18	0.25	0.19
Valine	0.99	1.10	0.86	0.84	0.88	0.84	1.02	1.03	1.09	0.97
Dispensable AA										
Alanine	0.82	0.96	0.76	0.80	0.88	0.79	0.94	0.74	0.96	0.81
Aspartate	1.61	2.14	1.41	1.53	1.50	1.44	1.89	1.61	2.21	1.50
Cystine	0.32	0.35	0.21	0.29	0.29	0.25	0.33	0.30	0.36	0.24
Glutamine	3.60	4.15	3.22	3.36	3.47	3.29	4.14	3.55	4.30	3.23
Glycine	1.05	1.29	0.90	1.00	1.07	0.92	1.24	1.01	1.32	1.01
Proline	0.64	0.61	0.60	0.62	0.68	0.59	0.61	0.60	0.67	0.54
Serine	0.77	0.91	0.62	0.70	0.77	0.72	0.81	0.76	0.93	0.67
Tyrosine	0.41	0.49	0.38	0.37	0.33	0.33	0.47	0.39	0.52	0.33

DM, dry matter; CP, crude protein; AA, amino acid.

the samples were prepared by nitric acid-perchloric acid.

Calculations

Values for AID and SID of CP and each AA were determined according to the method of Stein et al. (2007) described previously.

Statistical analyses

Simple and multiple regression analyses (stepwise regression analysis) were conducted to determine the relationships among chemical components and AA digestibility. For prediction equations, the residual standard deviation (RSD) was used as the selection criterion. A smaller RSD was proposed to indicate a better fit. Data for AID and SID were analyzed using the Proc-Mixed procedure of SAS (SAS Institute; Cary, NC, USA). Means were calculated using the LSMEANS statement, and when a significant F-test for treatment was observed, means were separated using the PDIFF option. The value of 5% ($p < 0.05$) was used to determine significance.

RESULTS

Composition of ingredients

The chemical composition for 10 SFSM are shown in Table 1. Among all the ingredients, the CP, EE, NDF, ADF,

CF, Ash, Ca and P obviously differed with a coefficient of variation (CV) higher than 10%. The concentration of EE, CF, Ca and P showed the greatest difference with a CV higher than 15%. On DM basis, the content of CP, NDF, ADF and CF ranged from 29.33% to 39.09%, 38.15% to 55.40%, 24.59% to 37.34% and 21.46% to 36.42%, respectively.

The AA composition for SFSM is shown in Table 2. The results showed that most AA were variable ($CV > 10\%$) except proline, alanine, and Lys ($CV < 10\%$). The average concentration of AA in SFSM were lower than those published by NRC (2012). The level of the four commonly limiting AA were 1.48%, 0.75%, 1.25%, and 0.37% for Lys, Met, threonine (Thr) and tryptophan (Trp), respectively.

Ileal digestibility of crude protein and amino acid

The results of AID and SID are shown in Table 5 and 6. The AID for CP varied from 60.13% to 74.72% among the 10 sources of SFSM. Sunflower seed meal with a high concentration of CP (sources 2 and 9) had higher AID values than SFSM with a lower concentration of CP (sources 3, 6, and 10) ($p < 0.05$). The SFSM with the highest concentration of CP (source 9) had greater digestibility coefficients than the other SFSM for most AA ($p < 0.05$). The results of SID for CP among 10 SFSM were similar to the values for AID. Sources 2 and 9 SFSM had relatively

Table 5. Apparent ileal digestibility (%) of CP and AA in sunflower seed meal fed to growing pigs

Item	Sunflower seed meal number										Mean ¹	SEM	p-value
	1	2	3	4	5	6	7	8	9	10			
CP	67.13 ^{bcd}	73.38 ^a	60.13 ^f	64.69 ^{cde}	66.91 ^{bcd}	61.00 ^{ef}	69.31 ^b	68.66 ^{bc}	74.72 ^a	63.09 ^{def}	66.90	1.35	<0.01
Indispensable AA													
Arginine	89.19 ^a	88.19 ^a	84.93 ^{bc}	85.39 ^{bc}	87.37 ^{ab}	84.40 ^c	86.68 ^{abc}	84.98 ^{bc}	88.60 ^a	86.41 ^{abc}	86.61	0.88	<0.01
Histidine	79.25 ^{abc}	80.83 ^{ab}	67.47 ^e	75.26 ^{bcd}	77.95 ^{bcd}	73.56 ^d	79.82 ^{abc}	78.56 ^{abcd}	83.65 ^a	75.00 ^{cd}	77.14	1.77	<0.01
Leucine	68.16 ^b	75.21 ^a	63.42 ^c	69.42 ^b	74.77 ^a	69.53 ^b	75.35 ^a	67.47 ^{bc}	74.95 ^a	66.61 ^{bc}	70.49	1.53	<0.01
Isoleucine	73.02 ^c	80.11 ^a	70.38 ^c	72.02 ^c	73.89 ^{bc}	71.13 ^c	73.95 ^{bc}	68.92 ^c	78.66 ^{ab}	68.47 ^c	73.06	1.82	<0.01
Lysine	76.45 ^a	78.49 ^a	63.16 ^c	75.97 ^a	75.79 ^a	67.35 ^b	76.15 ^a	76.80 ^a	79.21 ^a	65.49 ^{bc}	73.49	1.09	<0.01
Methionine	84.24 ^{bc}	87.78 ^{ab}	74.79 ^d	83.41 ^c	84.22 ^{bc}	80.71 ^c	84.32 ^{bc}	83.11 ^c	88.60 ^a	74.92 ^d	82.61	1.19	<0.01
Phenylalanine	72.25 ^{bc}	81.99 ^a	69.80 ^c	78.01 ^{ab}	80.54 ^a	70.34 ^c	78.79 ^{ab}	78.04 ^{ab}	79.39 ^a	74.98 ^{abc}	76.41	2.21	<0.01
Threonine	67.90 ^{abc}	70.93 ^a	55.58 ^d	62.63 ^{bc}	66.72 ^{abc}	55.19 ^d	70.47 ^a	69.47 ^{ab}	72.04 ^a	61.74 ^{cd}	65.27	2.30	<0.01
Tryptophan	69.53 ^{bc}	75.68 ^a	62.53 ^d	68.95 ^{bc}	69.22 ^{bc}	64.64 ^{cd}	73.56 ^{ab}	68.20 ^c	77.40 ^a	65.42 ^{cd}	69.51	1.69	<0.01
Valine	62.91 ^{de}	75.39 ^a	62.00 ^e	66.79 ^{cde}	69.04 ^{abcd}	65.56 ^{de}	72.89 ^{abc}	73.98 ^{ab}	75.54 ^a	68.32 ^{bcd}	69.24	2.08	<0.01
Dispensable AA													
Alanine	68.21 ^{bcd}	73.56 ^a	61.55 ^{ef}	65.22 ^{de}	70.20 ^{abc}	66.19 ^{cd}	72.06 ^{ab}	64.03 ^{de}	74.02 ^a	59.64 ^f	67.47	1.43	<0.01
Aspartate	69.61 ^{bc}	79.59 ^a	59.63 ^d	70.36 ^{bc}	71.37 ^b	66.85 ^c	75.71 ^a	71.36 ^b	76.66 ^a	69.59 ^{bc}	71.07	1.34	<0.01
Cystine	62.76 ^{de}	71.26 ^{ab}	39.76 ^g	63.82 ^{cd}	67.27 ^{bcd}	57.80 ^{ef}	68.65 ^{abc}	64.20 ^{cd}	74.06 ^a	55.70 ^f	62.53	1.83	<0.01
Glutamine	79.28 ^b	84.04 ^a	75.13 ^c	79.71 ^b	80.94 ^b	79.34 ^b	83.84 ^a	80.38 ^b	83.78 ^a	79.32 ^b	80.58	0.80	<0.01
Glycine	55.89 ^d	60.93 ^c	44.94 ^e	47.17 ^e	55.34 ^d	48.60 ^e	66.19 ^b	58.20 ^{cd}	70.02 ^a	47.88 ^e	55.52	1.34	<0.01
Proline	71.86 ^b	71.58 ^b	42.80 ^f	67.28 ^c	51.50 ^c	61.20 ^d	70.22 ^{bc}	67.43 ^c	77.54 ^a	62.28 ^d	64.37	1.03	<0.01
Serine	67.00 ^{bc}	74.50 ^a	49.40 ^e	67.50 ^{cd}	63.53 ^{bc}	61.66 ^d	69.19 ^b	69.73 ^b	75.36 ^a	60.14 ^d	65.78	1.59	<0.01
Tyrosine	83.93 ^b	86.34 ^a	76.35 ^e	78.59 ^d	78.07 ^{de}	67.19 ^f	84.46 ^{ab}	80.54 ^c	84.90 ^{ab}	64.38 ^g	78.48	0.67	<0.01

CP, crude protein; AA, amino acid; SEM, standard error of the mean.

¹ The average value of 10 sunflower seed meal.^{a-g} Values within the same row with no common superscript differ significantly (p<0.05).

higher SID for CP than the other sources (p<0.05). However, the SID value of one sample with a lower concentration of CP (source 5) was higher than another sample with a higher concentration of CP (source 1) (p<0.05) which was a bit different compared with the result of AID.

Among indispensable AA of SFSM, the AID of Lys,

Table 6. Standardized ileal digestibility (%) of CP and AA in sunflower seed meal fed to growing pigs

Item	Sunflower seed meal number										Mean ¹	SEM	p-value
	1	2	3	4	5	6	7	8	9	10			
CP	72.71 ^{cd}	78.03 ^{ab}	66.70 ^e	70.62 ^{cde}	72.95 ^{cd}	67.30 ^e	74.49 ^{bc}	74.16 ^{bc}	79.31 ^a	69.25 ^{de}	72.55	1.35	<0.01
Indispensable AA													
Arginine	91.75 ^a	90.39 ^{abc}	88.00 ^{bcd}	88.11 ^{bcd}	90.02 ^{abcd}	87.25 ^d	88.99 ^{abcd}	87.60 ^{cd}	90.77 ^{ab}	89.18 ^{abcd}	89.21	0.88	<0.01
Histidine	81.83 ^{abc}	83.16 ^{ab}	70.66 ^d	78.31 ^{bc}	81.10 ^{abc}	76.84 ^c	82.29 ^{abc}	81.36 ^{abc}	85.79 ^a	78.11 ^{bc}	79.94	1.77	<0.01
Leucine	72.01 ^{bc}	78.51 ^a	67.66 ^c	73.37 ^b	78.41 ^a	73.44 ^b	78.75 ^a	71.57 ^{bc}	78.03 ^a	70.83 ^{bc}	74.26	1.53	<0.01
Isoleucine	75.81 ^{bc}	82.37 ^a	73.47 ^c	75.11 ^c	76.88 ^{bc}	74.35 ^c	76.46 ^{bc}	71.85 ^c	80.87 ^{ab}	71.58 ^c	75.87	1.82	<0.01
Lysine	79.63 ^a	81.46 ^a	67.03 ^c	79.17 ^a	78.96 ^a	70.99 ^b	79.40 ^a	80.04 ^a	82.07 ^a	69.02 ^{bc}	76.78	1.09	<0.01
Methionine	86.17 ^{bc}	89.63 ^{ab}	77.39 ^d	85.54 ^c	86.26 ^{bc}	82.99 ^c	86.25 ^{bc}	85.14 ^c	90.27 ^a	77.16 ^d	84.68	1.19	<0.01
Phenylalanine	74.46 ^{bc}	83.78 ^a	72.42 ^c	80.45 ^{ab}	82.58 ^a	72.93 ^c	80.90 ^{ab}	80.27 ^{ab}	81.15 ^{ab}	77.41 ^{abc}	78.64	2.21	<0.01
Threonine	73.29 ^{abc}	76.04 ^{ab}	62.39 ^{de}	69.18 ^{bcd}	72.97 ^{abc}	61.97 ^e	75.75 ^{ab}	75.10 ^{abc}	77.01 ^a	67.93 ^{cde}	71.16	2.30	<0.01
Tryptophan	75.41 ^{bcd}	80.15 ^{ab}	68.70 ^e	75.11 ^{bcd}	74.92 ^{bcd}	71.02 ^{de}	78.21 ^{abc}	74.41 ^{cd}	81.80 ^a	71.06 ^{de}	75.08	1.69	<0.01
Valine	66.69 ^d	78.79 ^a	66.36 ^d	71.20 ^{bcd}	73.26 ^{abc}	69.99 ^{cd}	76.56 ^{ab}	77.58 ^{ab}	78.94 ^a	72.16 ^{bcd}	73.15	2.08	<0.01
Dispensable AA													
Alanine	73.41 ^{bcd}	78.04 ^a	67.16 ^{ef}	70.55 ^{de}	75.06 ^{abc}	71.61 ^{cd}	76.59 ^{ab}	69.78 ^{de}	78.48 ^a	64.90 ^f	72.56	1.43	<0.01
Aspartate	72.78 ^{cd}	81.98 ^a	63.24 ^e	73.70 ^{cd}	74.77 ^{bc}	70.39 ^d	78.42 ^{ab}	74.52 ^{bcd}	78.97 ^a	73.00 ^{cd}	74.18	1.34	<0.01
Cystine	68.64 ^{bcd}	76.64 ^a	48.56 ^e	70.24 ^{bc}	73.65 ^{ab}	65.27 ^{cd}	74.30 ^{ab}	70.35 ^{bc}	79.27 ^a	63.43 ^d	69.03	1.83	<0.01
Glutamine	81.31 ^b	85.79 ^a	77.39 ^c	81.88 ^b	83.04 ^b	81.56 ^b	85.60 ^a	82.43 ^b	85.48 ^a	81.58 ^b	82.61	0.80	<0.01
Glycine	63.72 ^{bc}	67.32 ^b	54.15 ^d	55.43 ^d	63.07 ^c	57.54 ^d	72.82 ^a	66.39 ^{bc}	76.29 ^a	56.08 ^d	63.28	1.34	<0.01
Proline	79.79 ^b	79.84 ^b	51.24 ^f	75.44 ^c	58.96 ^e	69.75 ^d	78.48 ^{bc}	75.94 ^c	85.06 ^a	71.73 ^d	72.62	1.03	<0.01
Serine	72.21 ^{bc}	78.94 ^a	55.91 ^e	69.08 ^{cd}	72.75 ^{bc}	67.30 ^d	74.15 ^b	75.02 ^{ab}	79.70 ^a	66.14 ^d	71.12	1.59	<0.01
Tyrosine	93.01 ^a	93.93 ^a	86.20 ^c	88.58 ^b	89.45 ^b	78.53 ^d	92.40 ^a	90.13 ^b	92.15 ^a	75.74 ^e	88.01	0.67	<0.01

CP, crude protein; AA, amino acid; SEM, standard error of the mean.

¹ The average value of 10 sunflower seed meal.^{a-f} Values within the same row with no common superscript differ significantly (p<0.05).

Met, Thr, and Trp in the sample with the highest concentration of CP (source 9) was the highest at 79.21%, 88.60%, 72.04%, and 77.40%, respectively. Also, the SID of most AA in sources 2, 7, and 9 were the highest among all SFSM. Source 2 had relatively higher AID and SID values for leucine and isoleucine than other SFSM ($p < 0.05$). The AID of phenylalanine in source 5 was 80.54% which was beyond the average level ($p < 0.05$). Additionally, SFSM (sources 3 and 10) with lower concentrations of indispensable AA had lower AID and SID than other SFSM ($p < 0.05$).

Correlations and prediction equations for nitrogen and amino acid digestibility

Several factors affected the prediction equations for N and AA. Among the representative chemical constituents (% of DM), EE had a negative correlation with Lys and Met ($p < 0.05$). The best single predictor for AID and SID was Met according to a linear stepwise regression. The best fit equations were obtained for AID N and SID N, which were: $\text{AID N} = 22.97 + (0.74 \times \text{CP}) + (25.44 \times \text{Met})$ with $R^2 = 0.96$, $\text{RSD} = 0.87$, $p < 0.05$; and $\text{SID N} = 35.22 + (0.54 \times \text{CP}) + (25.38 \times \text{Met})$ with $R^2 = 0.96$, $\text{RSD} = 0.83$, $p < 0.05$. In addition, CP, Trp and Ca were also used to estimate the digestibility in different equations (Table 7).

DISCUSSION

Composition of ingredient

According to the reports, SFSM is a valuable ingredient for swine because of its high energy concentration and ease of handling in feed mills (Thacker, 1998). It is also a good ingredient because it is free of most antinutritional factors (Wahlstrom, 1990).

The results of the chemical analysis of SFSM conducted in this experiment varied greatly. The CV of CP, NDF, ADF,

CF, Ash, Ca, and P was higher ($\text{CV} > 10\%$) due to the selection of samples before the official experiment. Preparations for collecting samples from the major provinces which cultivate SFSM in China involved contacting the representative plants, acquiring basic information on the chemical concentration of SFSM in each plant and collecting typical samples in person. In addition, the variation of SFSM might result from different growth conditions, such as climate and soil conditions (Alpaslan and Gündüz, 2000). Although, most SFSM underwent a similar production process of a pre-pressing extraction method (Fick and Miller, 1997). The differences, such as temperature, pressure and time during the production process might lead to the changes in chemical concentration in SFSM (Clandinin and Robblee, 1950; Parrado et al., 1991). The large variation of EE (0.88% to 11.33%) was mainly related to the different extraction process.

The average concentration of CP (sources 1, 2, 7, 8, and 9) were higher than other sources and NRC (2012) probably because of genetic improvement (Robertson, 1972). The concentrations of EE among the ten SFSM sources varied from 0.88% to 11.33% depending on the extraction process and the amount of residual oil left after extraction (Dinussan, 1990). The EE in source 4 and 8 SFSM were lower than the others which means the oil had been extracted according to the Association of American Feed Control Officials (AAFCO, 2011). The 10 SFSM had an higher average value of NDF but lower ADF than González-Vega et al. (2012) which was similar to the value reported in NRC (2012).

Digestibility of crude protein and amino acid

Waldroup et al. (1970) reported that SFSM can be effectively used to replace up to 50% of SBM in broiler diets. The AID and SID values for CP in this experiment were lower than NRC (2012) because of the lower

Table 7. Linear regression equations for prediction of AA digestibility (%) based on the chemical composition (% of DM) of sunflower seed meal fed to growing pigs¹

Number	Linear regression equations	RSD ²	R ²	p-value
1	$\text{AID N} = 22.97 + (0.74 \times \text{CP}) + (25.44 \times \text{Met})$	0.87	0.96	<0.01
2	$\text{AID Lys} = 30.00 - (0.62 \times \text{EE}) + (30.70 \times \text{Lys})$	0.78	0.97	<0.01
3	$\text{AID Lys} = 34.04 + (94.25 \times \text{Met}) - (86.16 \times \text{Trp})$	0.85	0.98	<0.01
4	$\text{AID Met} = 53.56 - (0.48 \times \text{EE}) + (8.52 \times \text{Ca}) + (36.86 \times \text{Met})$	0.77	0.97	<0.01
5	$\text{AID Thr} = 17.22 + (63.72 \times \text{Met})$	2.17	0.87	<0.01
6	$\text{SID N} = 35.22 + (0.54 \times \text{CP}) + (25.38 \times \text{Met})$	0.83	0.96	<0.01
7	$\text{SID Lys} = 36.24 - (0.61 \times \text{EE}) + (28.70 \times \text{Lys})$	0.93	0.97	<0.01
8	$\text{SID Lys} = 39.65 + (90.30 \times \text{Met}) - (84.36 \times \text{Trp})$	0.84	0.98	<0.01
9	$\text{SID Met} = 58.02 - (0.49 \times \text{EE}) + (7.96 \times \text{Ca}) + (33.98 \times \text{Met})$	0.77	0.97	<0.01
10	$\text{SID Thr} = 28.39 + (56.73 \times \text{Met})$	2.04	0.87	<0.01

AA, amino acid; DM, dry matter; RSD, residual standard deviation; AID, apparent ileal digestibility; CP, crude protein; Met, methionine; Lys, lysine; EE, ether extract; Trp, tryptophan; Thr, threonine; SID, standardized ileal digestibility.

¹ Regression equations were developed based on stepwise regression analyses.

² RSD = The root mean square of the error that applies to the whole model.

concentration of CP in the 10 SFSM. The results of AID and SID of CP and AA in source 3 SFSM resulted from the highest concentration of NDF, ADF, and CF which had depressive effect on AA digestibility (Sauer et al., 1980; Lenis et al., 1996).

The SFSM with relatively higher concentration of EE associated with lower NDF and ADF (source 2) had higher AID and SID values ($p < 0.05$). The different content of EE in the diets also affected the digestibility of ten sunflower seed meal (Noblet and Perez, 1993). The relatively higher concentration of NDF and CF may contribute to a decreased AA digestibility (Sauer et al., 1980; Lenis et al., 1996).

Jørgensen et al. (1984) reported that the digestibility of sunflower seed products is lower than SBM. Sunflower seed meal has a lower content of Lys than SBM (Smith, 1968; Sosulski and Sarwar, 1973). Sources 2 and 9 SFSM had a higher concentration of Lys. However, the average AID and SID values of Lys among all SFSM were lower than NRC (2012). Differences in heating temperature probably also caused the variation of AID and SID value of CP resulting in Maillard reaction which decreased the concentration and digestibility of Lys in corn distillers dried grains with solubles (Pahm et al., 2008). In addition, the concentration of Met was relatively higher in SFSM than SBM (Olvera-Novoa et al., 2002).

For most indispensable AA, the AID was lower than the value shown in NRC (2012). However, the SID of those AA had less variation. This means that endogenous loss of AA can not be ignored for evaluation of AA. In addition, the SID value had greater accuracy than AID (González-Vega et al., 2012).

Correlations and prediction equation of nitrogen and amino acid digestibility

The results of the study indicated that the variability of chemical composition in SFSM could contribute to the difference of AID and SID values. The AID and SID of CP could be accurately predicted by Met which means that Met was highly correlated with CP. The concentration of reactive Lys was a good predictor for the concentration of Lys in distillers dried grains with solubles and canola meal, respectively (Almeida et al., 2014). The Lys concentration per unit CP could be an acceptable predictor of Lys SID in wheat distillers dried grains with solubles (Cozannet et al., 2010). Other factors, such as CP, Trp, and Ca were also essential for estimating the digestibility of AA.

In conclusion, the digestibility of SFSM has great variation resulting from differences in chemical composition. The concentration of Met was the major factor affected in the equations established in this experiment. In order to improve SFSM as an alternative to SBM for use in diets for swine, more SFSM samples should be collected and further research should be conducted to increase the

accuracy of the equations.

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