True Metabolisable Energy and True Amino Acid Availability in Chinese Varieties of Dehulled and Hulled Soybean Meals Determined with Adult Roosters*

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ABSTRACT : Studies were conducted with intact White Leghorn roosters to determine the true metabolisable energy (*TME*) and the true amino acid availability (*TAAA*) in five dehulled and hulled soybean meals produced in China. 60 roosters, kept in individual cages, were fasted for 48 h and then tube-fed 50 g of one of experimental feedstuffs and their excreta was then collected for the subsequent 48 h period. Two separate collection periods were used with each meal being fed to 12 roosters. The birds were given a 15-day recovery period between collection periods. An additional 12 roosters were either fasted or fed a protein-free diet in order to estimate the extent of endogenous losses of energy and amino acids in excreta. The average values per bird for nitrogen loss, endogenous energy losses (*EEL*) and endogenous energy losses corrected to zero-nitrogen balance (EEL_n) were found to be 0.74 g, 47.0 kJ and 21.5 kJ, respectively. It was found that the *TME* and *TAAA* values of dehulled soybean meal were higher than those of hulled soybean meal. The *TME* and nitrogen-corrected *TME* metabolisable energy values of dehulled soybean meal were 10.58 and 10.74 MJ/kg, respectively, while the corresponding values for hulled soybean meal were 10.03 and 10.27 MJ/kg, respectively. The average indispensable and dispensable amino acid availability of dehulled soybean meal was 92.1 and 93.5%, compared with 89.3 and 91.4% for hulled soybean meal. Dehulled soybean meal would therefore appear to be superior to hulled soybean meal as a source of protein and energy for use in poultry rations. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 10 : 1487-1494)***

Key Words : *TME*, *TAAA*, Dehulled and Hulled Soybean Meal, Intact Roosters

INTRODUCTION

Sibbald (1976) developed the true metabolisable energy (*TME*) bioassay in which excreta energy from a test ingredient is corrected for endogenous energy excretion measured using an accompanying fasted bird. Many studies had been conducted to evaluate the accuracy of this bioassay and to measure the *TME* of different diets and feed ingredients using adult roosters (Askbrant, 1988; Farrell, 1981; Han and Parsons, 1990; McNab and Blair, 1988).

A series of experiments by Sibbald (1979a) demonstrated that the amino acid excretion associated with different feedstuffs was independent of energy intake. Thus, the basic design of the *TME* bioassay can be used with confidence for estimating the true amino acid availability (*TAAA*) in feedstuffs. Studies evaluating the *TAAA* of feed ingredients using cecetomized chickens or intact chickens are also numerous (Sibbald, 1979ab; Parsons, 1985; Johns et al., 1986; Green et al., 1987ab).

Dehulled soybean meal is widely utilized in animal diets because the content of crude protein in dehulled soybean meal is higher (48%) and its crude fiber content lower than hulled soybean meal (NRC, 1994). However, there is a lack of information describing the *TME* and *TAAA* of dehulled soybean meals produced in China. Therefore, the purpose of the present study was to determine the *TME* and *TAAA* of different varieties of Chinese soybean meals in order to compare the quality of dehulled soybean meal with that of hulled soybean meal.

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MATERIALS AND METHODS

Feedstuffs and diets

Five paired-samples of dehulled and hulled soybean meals were obtained from various commercial sources across China. For a given location, the dehulled and hulled meals were initially drawn from the same batch of meal and then a portion of the meal was dehulled by the normal method used at that location. Three of the meals came from the East Ocean Cereal and Oil Chemistry Company located in Jiangsu Province, one from the Jinzhou Liulu Oil Industry Company located in Liaoning Province and one from Jilin Deda Company Limited located in Jilin Province.

Determination of True Metabolisable Energy (TME)

TME assays were conducted according to the method of Sibbald (1976) with several modifications. Sixty White Leghorn roosters (1.98±0.20 kg BW) were kept in individual cages ($50.3\times45.0\times37.2$ cm^3) in a temperature-controlled room (18°C) under a daily light period of 16 h and with free access to water.

In order to test the ten soybean meal samples, two separate collection periods were used. During each collection, five samples of soybean meal were tested using

12 roosters per treatment. The five samples tested in the first collection period were randomly chosen from the batch of ten and the remaining five samples were tested during the second collection period. At the completion of each collection period, the birds were given a 15-day recovery period during which they were fed ad libitum a diet composed of 74.7% corn, 20.3% soybean meal and 5% of a vitamin-mineral premix.

Immediately before the start of a collection period, the birds were fasted for 48 h and then tube-fed exactly 50 g of one of the 10 soybean meals. During the subsequent 48 h, birds had free access to water and their excreta were collected.

The fecal collection apparatus consisted of an 80 mL rigid plastic container with a threaded cap. A 3 cm hole was cut through the center of the cap, and six equally spaced slots were cut through the lid around the periphery. Three silk threads of equal length were inserted through the slots. The silk threads were then taped onto the skin around the cloacae. In this way, the hole in the center of the cap could be located directly over the bird's vent. The collection cup was weighed before each collection and then threaded firmly onto the apparatus.

The collected feces were transported to the laboratory and stored frozen at -20°C until needed for analysis. The frozen excreta from each bird was freeze-dried for 24 h, allowed to come to equilibrium with atmospheric moisture for a further 24 h period, weighed and then ground to pass a 40-mesh sieve. Excreta from two birds from the same treatment were then pooled in order to obtain sufficient sample for analysis. The extent of replication was therefore six replicates per treatment.

Endogenous energy losses (*EEL*) and endogenous energy losses corrected to zero-nitrogen balance (EEL_n) were determined in a separate collection using 12 roosters with an average body weight of 2.1 kg. The individual birds were fasted for four consecutive days and excreta were collected daily during the last 48 h (Sibbald, 1981b) using the collection procedures previously described. The roosters had free access to water and received 50 g of glucose/bird/day via the water supply.

The AME and AMEn values of the soybean samples were calculated as follows:

$$AME = \frac{GE \cdot FI - EE}{FI}$$

$$AME_n = \frac{GE \cdot FI - EE + \mathrm{RN2}}{FI}$$

The *TME* and TME_n values of the soybean samples were calculated as follows:

$$TME = \frac{GE \cdot FI - (EE - EEL)}{FI}$$

$$TME_n = \frac{GE \cdot FI - (EE + \mathrm{RN2} - EEL\mathrm{n})}{FI}$$

Where *GE*=gross energy of meal (kJ/g), *FI*=feed intake (g), *EE*=excreta energy of fed birds (kJ), EEL=excreta energy of fasted bird (kJ), *RN*=N balance of fed birds (g)× 34.4 kJ, *EELn*=*EEL*+(-RN_f×34.4 kJ) and RN_f=N balance of fasted birds (g).

Determination of True Amino Acid Availability (TAAA)

TAAA assays were conducted according to the method of Sibbald (1976). Sixty White Leghorn roosters (average body weight 2.1 kg) were fed and housed in the same manner as those used for the determination of *TME*. The *TAAA* of the ten samples of soybean meal were determined using two separate collection periods. Five samples of soybean meal were tested during each collection period using 12 roosters per treatment. At the completion of each collection period, the birds were given a 15-day recovery

Table 3. Ingredient composition and chemical analysis of experimental diets used to measure true amino acid availability of dehulled and hulled soybean meals

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3	
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled
Ingredients (% as fed)										
Maize starch	63.0	64.0	61.0	64.0	60.0	63.5	62.0	62.0	62.0	64.0
Soybean meal	33.0	34.0	35.0	32.0	36.0	32.5	34.0	34.0	34.0	32.0
Vitamin mineral premix	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Chemical composition (% as fed)										
Dry matter (%)	90.9	90.9	91.1	90.9	89.3	91.4	90.6	91.5	91.0	90.7
Crude protein (%)	15.9	16.0	16.0	16.0	16.1	16.1	16.2	16.2	16.3	16.1
Crude fiber (%)	6.0	5.9	5.8	6.2	6.1	6.0	6.2	6.4	5.8	5.9

[1] Provided per kilogram of diet: vitamin A, 4,400 IU; Cholecalciferol, 1,000 ICU; vitamin E, 11 IU; vitamin B_{12}, .011 mg; riboflavin, 4.4 mg; d-pantothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfite complex, 2.33 mg; manganese, 75 mg; iron, 75 mg; zinc, 75 mg; copper, 5 mg; iodine, .75 mg; selenium, 0.1mg.

[2] Chemical analysis based on duplicate assay.

Table 1. Chemical composition (as fed) of dehulled and hulled soybean meals produced at various locations throughout China

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3	
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled
Chemical constituent										
Dry matter (%)	91.92	91.00	91.95	91.60	89.53	92.19	90.72	91.07	94.04	93.77
Crude protein (%)	47.58	48.98	45.13	49.49	43.79	48.68	46.11	46.70	46.49	49.36
Gross energy (MJ/kg)	17.85	17.71	17.53	17.59	17.21	17.71	17.43	17.31	18.26	18.17
Calcium (%)	0.53	0.34	0.34	0.34	0.27	0.28	0.29	0.34	0.23	0.28
Total phosphorus (%)	0.73	0.69	0.73	0.74	0.74	0.75	0.69	0.66	0.64	0.69
Ether extract (%)	1.82	0.77	1.75	0.57	0.69	1.00	1.75	0.64	1.93	1.27
Neutral detergent Fiber (%)	11.92	9.88	9.47	8.58	9.07	9.92	9.13	8.91	10.92	7.93
Ash (%)	6.90	6.88	7.08	6.81	6.51	6.26	6.25	6.01	5.66	6.17
Urease activity (mg/g)	0.07	0.03	0.04	0.00	0.02	0.00	0.07	0.00	0.06	0.03
Protein solubility (%)	78.30	81.41	81.66	79.10	81.23	80.24	81.92	83.31	63.90	72.04

[1] All chemical analysis based on duplicate assays.

period during which they were fed ad libitum the same diet as that which was used in the recovery period for the *TME* determination.

Ten corn starch-based diets were formulated to contain approximately 16% crude protein using one of the ten test soybean meals as the sole source of crude protein and amino acids (Table 3). Vitamins and minerals were supplemented according to *NRC* (1994) standards. The diets were fed in meal form.

Immediately before the start of a collection period, the birds were fasted for 48 h. The birds were then tube-fed 50 grams of one of the soybean meal containing diets. During the subsequent 48 h, birds had free access to water and their excreta were collected using the same procedures as for the determination of *TME*. Again, excreta from two birds per treatment were pooled in order to have sufficient sample for analysis leading to a total of six replicates per treatment.

An additional twelve roosters (2.0 kg) were selected to determine the endogenous amino acid secretion using a highly digestible protein-free diet. The diet consisted of 45.5% cornstarch, 45.5% glucose, 5.0% fiber and 4.0% vitamin-mineral premix and contained 93.9% dry matter, 0.2% crude protein and provided a gross energy of 15.8 kJ per g air-dry.

TAAA values for the soybean meals were calculated as follows:

$$TAAA = \frac{(AAC - AAE + EAA) \times 100\%}{AAC}$$

Where *AAC*=amino acid consumed (g/day), *AAE*=amino acid excreted (g/day), *EAA*=endogenous amino acid excreted (g/day).

Chemical analysis

Analyses for dry matter, crude protein, ash, ether extract, calcium, and total phosphorus were assayed according to the methods of the *AOAC* (1990). Neutral detergent fiber was analyzed according to the principles outlined by Goering and Van Soest (1970) using an Ankom[220] Fiber Analyzer (Ankom Technology Corporation, USA). Gross energy was determined using an adiabatic oxygen bomb calorimeter (Gallenkamp).

For AA analyses, with the exception of the sulfur-containing amino acids and tryptophan, the samples were hydrolyzed with 6 N HCl at 110°C for 24 h, then analyzed using an Automatic Amino Acid Analyzer (Hitachi L-8800, Japan). Methionine and cysteine were determined as methionine sulfone and cysteine acid after oxidation with performic acid. The oxidation process was carried out according to the AOAC (1990) method. The oxidized samples were then hydrolyzed and analyzed in the same manner as in the acid hydrolysis. Tryptophan analysis was carried out using high performance liquid chromatography (Shimadzu LC-10A, Japan) according method GB/T18246-2000 of the Chinese Quality Supervisory Bureau (2000). Protein solubility and urease activity were determined by the methods of Yang (1993).

Statistical analysis

Statistical analysis was performed by *SPSS* 6.0 software (SPSS Inc., USA). The *TME* and *TAAA* values of feedstuffs were subjected to Analysis of Variance (*ANOVA*). When *ANOVA* indicated a significant P value, means were separated using Duncan's multiple range test (Duncan, 1955). Paired-sample tests were used to compare the metabolisable energy and true amino acid availability of dehulled soybean meal with hulled soybean meal.

RESULTS

The chemical composition of the ten soybean samples is shown in Table 1. The crude protein content of the hulled soybean meals averaged 45.82% (range 43.13 to 47.58%) while the protein content of the dehulled soybean meals averaged 48.64% (range 46.70 to 49.49%). As expected, the content of neutral detergent fiber was lower for the dehulled

Table 2. Amino acid content (as fed) of dehulled and hulled soybean meals produced at various locations throughout China

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3	
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled
Indispensable amino acids (%)										
Arginine	3.28	3.44	3.21	3.68	3.30	3.47	3.34	3.31	3.22	3.52
Histidine	1.49	1.47	1.43	1.35	1.26	1.32	1.45	1.49	1.47	1.52
Isoleucine	2.15	2.19	2.04	2.13	1.98	2.02	2.19	2.17	2.19	2.30
Leucine	3.69	3.77	3.54	3.78	3.46	3.63	2.43	3.49	3.49	3.82
Lysine	3.03	3.09	2.90	3.14	2.88	3.08	3.06	3.08	2.98	3.05
Methionine	0.60	0.56	0.59	0.62	0.57	0.65	0.60	0.56	0.57	0.60
Phenylalanine	2.41	2.60	2.37	2.75	2.52	2.57	2.54	2.32	2.28	2.55
Threonine	1.95	1.95	1.94	1.97	1.74	1.90	1.94	1.96	1.77	1.87
Tryptophan	0.61	0.64	0.61	0.63	0.57	0.52	0.63	0.55	0.54	0.67
Valine	2.05	2.11	2.03	2.11	1.96	1.96	2.02	2.04	2.07	2.16
Dispensable amino acids (%)										
Alanine	2.04	2.08	2.04	1.98	1.87	1.79	1.98	1.99	2.00	2.17
Aspartate	5.34	5.37	5.06	5.69	5.14	5.42	5.41	5.46	5.28	5.74
Cysteine	0.60	0.61	0.51	0.62	0.50	0.54	0.77	0.74	0.66	0.70
Glutamate	2.03	2.04	1.93	2.13	1.96	2.04	1.94	1.95	1.87	1.97
Glycine	9.04	9.04	8.41	8.96	8.12	8.49	83.89	8.69	8.39	8.69
Proline	3.23	2.68	2.52	2.56	3.41	4.30	2.87	2.86	2.61	2.73
Serine	2.29	2.33	2.22	2.18	2.00	2.10	2.26	2.30	2.23	2.43
Tyrosine	1.73	1.81	1.65	1.75	1.60	1.73	1.82	1.61	1.57	1.69

[1] Values based on duplicate amino acid analysis.

Table 4. Endogenous losses of energy, nitrogen and amino acids by fasted roosters (mean±sd)

	Nutrient loss
Nitrogen and energy	
Nitrogen loss (g)	0.74±0.2
Energy loss (kj)	47.0±5.2
Indispensable amino acid loss (mg)	
Arginine	8.5±0.3
Histidine	26.7±3.4
Isoleucine	13.2±2.0
Leucine	21.5±3.6
Lysine	19.0±4.0
Methionine	20.7±7.2
Phenylalanine	26.0±5.6
Threonine	22.3±6.9
Tryptophan	13.3±3.6
Valine	34.1±9.0
Dispensable amino acid loss (mg)	
Alanine	45.3±3.8
Aspartate	33.4±9.5
Cysteine	16.2±2.2
Glutamate	59.3±3.0
Glycine	58.8±5.7
Proline	35.5±8.2
Serine	18.7±5.3
Tyrosine	34.4±4.5

[1] Nitrogen, energy and amino acid loss is based on a 48 h collection period.
[2] Chemical analysis conducted in duplicate.

soybean meals that averaged 9.04% (range 7.93 to 9.92%) compared with 10.10% (range 9.07 to 11.92%) for hulled soybean meal. Protein solubility was higher for the dehulled soybean meals, which averaged 79.22% (range 72.04 to 83.31%), than for the hulled soybean meals, which averaged 77.34% (range 63.90 to 81.92%).

The amino acid content of the ten soybean meals is presented in Table 2. In general, the amino acid content of the dehulled soybean meals was higher than that for the hulled soybean meals. Of primary interest to nutritionists would be the contents of lysine, threonine and tryptophan. The lysine content of the hulled meals averaged 2.97% (range 2.88 to 3.06%) compared with 3.08% (range 3.05 to 3.14%) for dehulled meal. The threonine content of the hulled meals averaged 1.88% (range 1.77 to 1.95%) compared with 1.93% (range 1.87 to 1.97%) for dehulled meal. The tryptophan content of the hulled meals averaged 0.59% (range 0.54 to 0.63%) compared with 0.60% (range 0.55 to 0.67%) for dehulled meal.

Endogenous losses of energy and nitrogen for 12 fasted White Leghorn roosters are shown in Table 4. The weight loss of roosters during excreta collection (48 h) following 48 h of starvation ranged from 56 to 105 g with a mean of 72.7±7.0 g. Nitrogen loss of roosters was 0.74±0.17 g. The *EEL* value of birds was 47.0±5.2 kJ/bird/48 h.

The endogenous outputs of amino acids by roosters fed on the protein-free diet are also listed in Table 4. Indispensable amino acid loss averaged 19.0±4.0 mg, 22.3±6.9 mg and 13.3±3.6 mg for lysine, threonine and tryptophan respectively.

The nitrogen and energy balances of the roosters fed the ten soybean meals are shown in Table 5. These values were then used in calculating the *AME*, *AMEn*, *TME*, and *TMEn*

Table 5. Nitrogen and energy balance of roosters fed dehulled and hulled soybean meals produced at various locations throughout China

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3			
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	SEM	P Value
Crude protein (%)	47.58	48.98	45.13	49.49	43.79	48.68	46.11	46.70	46.49	49.36		
Gross energy (MJ/kg)	17.85	17.71	17.53	17.59	17.21	17.71	17.43	17.32	18.26	18.17		
Energy intake (kJ)	892.50^{bc}	885.50^{b}	876.50^{ab}	879.50^{b}	860.50^{a}	885.50^{b}	871.50^{a}	865.50^{a}	913.00^{c}	908.50^{c}	9.50	<0.01
Nitrogen intake (g)	3.81^{b}	3.92^{c}	3.61^{a}	3.96^{c}	3.50^{a}	3.89^{c}	3.69^{ab}	3.74^{b}	3.72^{b}	3.95^{c}	0.18	<0.01
Excreta voided (g)	34.64^{c}	32.39^{b}	33.80^{c}	32.30^{b}	32.14^{b}	32.14^{b}	30.47^{b}	29.64^{a}	29.97^{a}	28.30^{a}	1.35	<0.01
Excreted energy (kJ)	454.63^{c}	423.02^{bc}	440.99^{c}	406.24^{b}	420.50^{bc}	391.72^{a}	402.36^{ab}	387.40^{a}	406.80^{a}	387.76^{a}	10.40	<0.01
Excreta nitrogen (g)	4.15^{bc}	4.16^{bc}	4.06^{ab}	4.26^{c}	3.86^{a}	4.05^{ab}	3.99^{a}	4.12^{bc}	4.06^{ab}	4.12^{bc}	0.21	<0.01
Gross energy digestibility (%)	49.1^{a}	52.2^{ab}	49.7^{a}	53.8^{bc}	51.1^{a}	55.8^{c}	53.8^{bc}	55.2^{c}	54.2^{bc}	57.3^{c}	1.20	<0.01

[a-c] Means in each row with no common superscript differ significantly ($p \leq 0.05$).

[1] Based on 6 observations during excreta collection (48 h). [2] All values are presented on an air-dried basis.

Table 6. Apparent and true metabolisable energy values (MJ/kg) of dehulled and hulled soybean meals produced at various locations throughout China

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3			
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	SEM	P values
Apparent metabolisable energy	8.76^{a}	9.25^{b}	8.72^{a}	9.46^{b}	8.80^{a}	9.87^{b}	9.39^{b}	9.56^{b}	10.12^{c}	10.42^{c}	0.21	<0.01
Apparent metabolisable energy$_n$	8.99^{a}	9.42^{b}	9.02^{a}	9.67^{b}	9.05^{a}	9.98^{b}	9.59^{b}	9.82^{b}	10.34^{c}	10.50^{c}	0.24	<0.01
True metabolisable energy	9.70^{a}	10.19^{b}	9.66^{a}	10.40^{b}	9.74^{a}	10.82^{b}	10.33^{b}	10.49^{b}	11.06^{c}	11.36^{c}	0.21	<0.01
True metabolisable energy$_n$	9.93^{a}	10.36^{b}	9.97^{a}	10.61^{b}	9.99^{a}	10.93^{b}	10.54^{b}	10.76^{b}	11.28^{c}	11.44^{c}	0.24	<0.01

[a-c] Means in each row with no common superscript differ significantly ($p \leq 0.05$).

as well as the energy digestibilities presented in Table 6. Because nitrogen retention was negative, the *AMEn* and *TMEn* values of feedstuffs were higher than the corresponding *AME* and *TME* values. The extent of fecal excretion of amino acids is presented in Table 7. These values were then used in the calculation of TAAA shown in Table 8.

Table 9 summarizes the differences in *AME, AMEn, TME*, and *TMEn*, between the dehulled and hulled soybean meals. In general, the energy values for the dehulled meals were higher than for the hulled soybean meals. The *AME* and the respective *AMEn* values for the dehulled soybean meals were 9.36 and 9.80 MJ/kg while the corresponding values for the hulled soybean meals were 9.09 and 9.64 MJ/kg. The *TME* and the respective *TMEn* values for the dehulled soybean meals were 10.58 and 10.74 MJ/kg while the corresponding values for the hulled soybean meals were 10.03 and 10.27 MJ/kg, respectively.

The *TAAA* values for dehulled soybean meal were only modestly higher than those for hulled soybean meals ($p>0.05$). The indispensable and dispensable amino acid availability of the dehulled soybean meals averaged 92.1 and 93.5% while the corresponding values for hulled soybean meal averaged 89.3 and 91.4%.

DISCUSSION

In our studies, the average endogenous energy loss during the 48 h collection period was 47.4 kJ for the White Leghorn roosters, which agrees with the results of Yalcin and Onol (1994), Shires et al. (1980) and McNab and Blair (1988). In one study, endogenous energy loss in 48 h showed considerable variation from 32.6 to 82.0 kJ (Farrell, 1981) while others have shown less variation with endogenous energy excretion varying between 25.0 and 69.0 kJ (Sibbald and Morse, 1983; Sibbald and Wolynetz, 1984).

Endogenous nitrogen loss was extremely variable and averaged 0.74 g during the 48 h collection period (range 0.46 to 1.68 g). The average N loss, for the 2.1 kg birds used in the present study, was converted to a body weight based and was found to be 0.35 g/kg BW. This nitrogen loss

Table 7. Feces weight and amino acid content from roosters fed diets containing dehulled and hulled soybean meals produced throughout China

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3		SEM	P Value
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled		
Feces weight (g)	19.29	14.83	14.63	17.02	16.04	12.79	15.54	13.45	14.97	14.65	1.77	0.41
Indispensable amino acid (%)												
Arginine	0.36^{a}	0.56^{b}	0.51^{b}	0.43^{b}	0.43^{b}	0.41^{a}	0.28^{a}	0.24^{a}	0.47^{b}	0.30^{a}	0.06	0.02
Isoleucine	0.42	0.44	0.40	0.43	0.42	0.47	0.38	0.30	0.38	0.36	0.04	0.12
Leucine	0.64^{bc}	0.75^{bc}	0.60^{bc}	0.58^{bc}	0.61^{bc}	0.73^{c}	0.48^{ab}	0.38^{a}	0.48^{a}	0.55^{b}	0.06	<0.01
Lysine	0.40^{b}	0.46^{b}	0.42^{b}	0.39^{b}	0.38^{b}	0.43^{b}	0.31^{a}	0.23^{a}	0.41^{b}	0.34^{a}	0.04	<0.01
Methionine	0.17	0.16	0.18	0.18	0.15	0.16	0.16	0.15	0.16	0.17	0.01	0.39
Phenylalanine	0.41^{b}	0.46^{c}	0.43^{c}	0.37^{b}	0.42^{b}	0.48^{c}	0.27^{a}	0.24^{a}	0.42^{b}	0.32^{ab}	0.04	<0.01
Threonine	0.44	0.45	0.40	0.41	0.44	0.48	0.43	0.35	0.43	0.37	0.03	0.31
Tryptophan	0.05	0.06	0.08	0.06	0.07	0.07	0.05	0.06	0.07	0.06	0.01	0.38
Valine	0.46	0.48	0.47	0.49	0.52	0.60	0.44	0.38	0.57	0.45	0.05	0.12
Dispensable amino acid (%)												
Alanine	0.58	0.61	0.64	0.60	0.69	0.79	0.61	0.53	0.68	0.60	0.06	0.14
Aspartate	0.89	0.86	0.79	0.96	0.90	0.95	0.80	0.64	0.83	0.74	0.08	0.14
Cysteine	0.19^{a}	0.17^{a}	0.17a	0.18^{a}	0.18^{a}	0.22^{b}	0.22^{b}	0.21^{ab}	0.25^{b}	0.19^{a}	0.01	<0.01
Glutamate	1.49	1.50	1.45	1.44	1.56	1.55	1.14	1.05	1.25	1.26	0.12	0.06
Glycine	0.90^{c}	0.85^{bc}	0.86^{bc}	0.87^{bc}	0.83^{bc}	0.73^{a}	0.80^{ab}	0.82^{ab}	0.78^{ab}	0.80^{ab}	0.03	0.03
Proline	0.54	0.52	0.57	0.46	0.50	0.67	0.53	0.45	0.58	0.39	0.06	0.08
Serine	0.47^{ab}	0.47^{ab}	0.41^{a}	0.44^{a}	0.45^{ab}	0.50^{b}	0.39^{a}	0.32^{a}	0.36^{a}	0.36^{a}	0.03	0.02
Tyrosine	0.39^{bc}	0.46^{bc}	0.39^{bc}	0.28^{bc}	0.28^{bc}	0.36^{bc}	0.21^{a}	0.18^{a}	0.23^{a}	0.26^{ab}	0.03	<0.01
EAA	2.95^{bc}	2.36^{a}	3.07^{bc}	2.96^{b}	3.06^{c}	3.40^{c}	2.49^{ab}	2.09^{a}	2.97^{bc}	2.59^{a}	0.23	0.01
NEAA	5.45	5.34	5.29	5.23	5.38	5.78	4.71	4.19	4.95	4.59	0.33	0.05
TAA	8.39^{bc}	8.82^{bc}	8.36^{bc}	8.19^{bc}	8.44^{bc}	9.18^{c}	7.19^{a}	6.28^{a}	7.92^{b}	7.18^{a}	0.55	0.03

[1] Amino acid contents based on duplicate chemical analyses. [a-c] means in each row with no common superscript differ significantly ($p \le 0.05$).

Table 8. True amino acid availability of dehulled and hulled soybean meal produced at various locations throughout China

Province of origin	Jiangsu # 1		Jiangsu # 2		Jilin		Liaoning		Jiangsu # 3		SEM	P values
Type of meal	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled	Hulled	Dehulled		
	Indispensable amino acids (%)											
Arginine	90.6^{b}	85.1^{a}	85.7^{a}	89.5^{ab}	88.5^{ab}	89.7^{ab}	93.1^{b}	94.2^{b}	87.8^{ab}	93.2^{b}	1.9	0.01
Isoleucine	84.2^{a}	83.6^{a}	84.4^{a}	83.3^{ab}	82.7^{ab}	80.4^{a}	86.3^{b}	89.7^{c}	86.0^{b}	87.9^{c}	1.7	0.03
Leucine	86.0^{a}	83.4^{a}	86.7^{a}	87.8	85.8^{a}	83.4^{a}	85.3^{a}	92.9^{b}	89.9^{b}	89.3^{b}	1.6	<0.01
Lysine	90.4^{a}	88.8^{a}	89.4^{a}	90.9^{a}	90.5^{a}	89.6^{a}	93.4^{b}	96.0^{b}	89.9^{a}	93.3^{b}	1.2	<0.01
Methionine	91.9	93.8	90.8	89.3	93.7	94.1	93.9	95.8	92.6	94.0	1.7	0.32
Phenylalanine	89.5^{a}	88.3^{a}	88.1^{a}	91.8^{a}	88.9^{a}	87.3^{a}	95.6^{b}	96.2^{b}	88.5^{a}	94.1^{b}	1.6	<0.01
Threonine	84.2	84.2	86.0	85.3	81.7	81.8	84.9	88.9	84.1	89.1	1.8	0.09
Tryptophan	93.4	90.6	88.0	91.9	90.0	87.9	93.8	91.7	88.5	92.8	1.9	0.24
Valine	87.4^{ab}	86.9^{ab}	86.7^{ab}	85.6^{a}	83.0^{a}	79.8^{a}	87.9^{ab}	91.2^{b}	81.5^{a}	89.1^{b}	2.3	0.04
Dispensable amino acids (%)												
Alanine	84.5^{b}	83.3^{b}	81.5^{b}	82.6^{b}	76.6^{a}	70.8^{a}	82.6^{b}	86.7^{b}	78.5^{a}	85.2^{b}	2.8	0.02
Aspartate	87.0	87.6	88.2	86.1	86.1	86.0	88.9	91.9	88.3	91.0	1.5	0.08
Cysteine	84.1^{b}	87.7^{b}	86.0^{b}	86.2^{b}	82.9^{b}	76.7^{a}	83.6^{b}	84.3^{b}	78.2^{a}	88.4^{b}	1.8	<0.01
Glutamate	87.4^{ab}	87.3^{ab}	86.9^{ab}	87.7^{ab}	84.8^{a}	85.8^{ab}	91.1^{c}	91.9^{c}	89.6^{ab}	90.8^{b}	1.5	0.02
Glycine	84.4^{a}	86.8^{a}	85.4^{a}	85.1^{a}	85.8^{a}	92.7^{b}	88.6^{ab}	88.6^{ab}	88.0^{ab}	91.0^{b}	1.6	0.01
Proline	85.6	83.4	80.4	84.9	87.6	86.2	84.3	86.8	82.2	89.4	1.9	0.09
Serine	84.4^{ab}	84.6^{ab}	86.3^{ab}	84.7^{ab}	82.8^{a}	81.7^{a}	87.8^{b}	91.1^{c}	88.7^{b}	90.0^{c}	1.6	<0.01
Tyrosine	82.2^{a}	78.7^{a}	81.2^{a}	88.4^{ba}	87.4^{ba}	83.7^{a}	92.8^{c}	93.5^{c}	90.4^{bc}	89.9^{bc}	1.8	<0.01
Indispensable AA	84.9^{a}	85.7^{a}	89.5^{ab}	91.6^{b}	89.1^{a}	91.8^{b}	91.6^{b}	95.9^{c}	91.2^{b}	92.8^{b}	1.8	0.03
Dispensable AA	87.9^{a}	91.4^{ab}	91.3^{ab}	93.4^{bc}	91.0^{a}	92.6^{bc}	93.2^{bc}	96.1^{c}	93.6^{bc}	94.2^{bc}	1.4	0.04
Total AA	86.5^{a}	90.1^{ab}	90.4^{ab}	92.5^{b}	90.1^{a}	92.2^{b}	92.5^{b}	96.0^{c}	92.5^{b}	93.5^{b}	1.6	0.03

[1] Means in each row with no common superscript differ significantly ($p \le 0.05$).

was lower than the values of 0.45 and 0.61 g N/kg BW obtained using starved roosters by Sibbald and Morse (1983) and Sibbald and Wolynetz (1984), respectively.

In the present study, because nitrogen correction was

Table 9. Comparison of metabolisable energy, nutrient digestibility and true amino acid availability of dehulled and hulled soybean meals

Item	Dehulled soybean meal[1]	Hulled soybean meal[2]	SEM	P values
Energy, MJ/kg				
Apparent metabolisable energy	9.36	9.09	0.51	0.29
Apparent metabolisable energy$_n$	9.80	9.64	0.50	0.17
True metabolisable energy	10.58	10.03	0.51	0.28
True metabolisable energy$_n$	10.74	10.27	0.50	0.18
Gross energy digestibility (%)	51.4	54.4	2.47	0.06
Indispensable amino acids (%)				
Arginine	90.4	89.1	0.90	0.58
Isoleucine	85.0	84.7	0.80	0.19
Leucine	87.3	86.7	0.90	0.35
Lysine	91.7	90.7	0.90	0.94
Methionine	93.4	92.6	0.80	0.24
Phenylalanine	91.5	90.1	0.90	0.96
Threonine	85.9	84.2	0.90	0.60
Tryptophan	91.0	90.7	0.80	0.63
Valine	86.5	85.3	1.10	0.61
Dispensable amino acids (%)				
Alanine	81.7	80.7	0.60	0.61
Aspartate	88.5	87.7	0.70	0.16
Cysteine	84.6	83.0	1.00	0.89
Glutamate	88.7	87.9	0.80	0.80
Glycine	88.9	86.4	0.80	0.54
Proline	86.1	84.0	0.90	0.51
Serine	86.4	86.0	0.80	0.37
Tyrosine	86.8	86.8	0.30	0.76
Indispensable amino acid	92.1	89.3	0.90	0.38
Dispensable amino acid	93.5	91.4	0.70	0.39
Total amino acid	92.7	90.4	0.70	0.43

negative, the *AMEn* and *TMEn* values for the soybean meals were higher than the corresponding *AME* and *TME* values (Table 6). This emphasizes the importance of nitrogen correction of the obtained endogenous energy loss estimate. Nitrogen correction has been shown to have a profound effect on the amount and variability of the energy voided by starved birds and also on the variability of the *AME* and *TME* estimates (Sibbald and Morse, 1983; Sibbald, 1982). In the present study, nitrogen correction resulted in a 2.15-4.36% increase in the *TME* values of the soybean meals.

Our study showed that the *ME* values of dehulled soybean meal were higher than those of hulled soybean meal. The main reason for this difference is likely the variation in the chemical composition of these feedstuffs, especially in neutral detergent fiber. *ME* has been shown to be strongly correlated with the content of indigestible materials, such as fiber (Tenesaca and Sell, 1978; Farrell, 1981). The present study supports the conclusion that excreted energy output can be increased with an increase in the neutral detergent fiber content in the feed, thereby reducing the finial ME estimates. At the same time, hulls of soybean contain higher fiber and energy provided by hulls is not starch but availability fiber. However, hulls dilute the energy content of the test material and can inhibit digestive enzymes (Longstaff and McNab, 1991). ME values of hulled soybean meal were decreased because of this cause.

The endogenous outputs of amino acids in the present study were determined with adult intact roosters fed on protein-free diet. Some studies have shown that quantities of the endogenous outputs of amino acids excreted after feeding a protein-free diet significantly differed between intact and caecectomised birds (Kessler and Thomas, 1979; Johns et al., 1986; Green and Kiener, 1989; Parsons, 1992; Hou et al., 1997). Cecectomized roosters excreted higher amounts of amino acids and tended to have a lower amino acid digestibility than intact birds (Parsons, 1985; John et al., 1986; Green et al., 1987a). However, other studies had shown that the microbes in the cecum have little direct effect on the amino acid availability of high digestible feedstuffs when determined with either cecectomized or intact birds (Sibbald, 1979a; Green et al., 1989; Han et al., 1990; Hou et al., 1997; Ragland et al., 1999). The *TAAA* values for hulled soybean meal obtained in the present study were similar to values obtained using intact roosters (Ragland et al., 1999), but higher than values obtained using cecectomized roosters (Ragland et al., 1999).

Compared with hulled soybean meal, the amino acid availability of dehulled soybean meal was generally higher for most of amino acids. However, the improvement was not as dramatic as was the case for energy. Again the principle reason for the higher *TAAA* in the dehulled meals can be attributed to a reduction in fiber content of these meals.

In conclusion, the present study determined that the metabolisable energy and true amino acid availability content of dehulled soybean meals were higher than hulled soybean meal. As a result, dehulled soybean meal is a higher quality feedstuff for use in poultry feeds.

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REFERENCES

Askbrant, S. U. S., 1988. Metabolisable energy content of rapeseed meal, soybean meal and white-flowered peas determined with laying hens and adult cockerels. Br. Poult. Sci. 29:445-455.

AOAC. 1990. Official Methods of Analysis 15th edn. Association of Official Analytical Chemists, Arlington, Virgninia.

Chinese Quality Technical Supervisory Bureau. 2000. Standard method to determine the amino acid content in feed. Method GB/T 18246-2000. Beijing, China.

Duncan, D. B. 1955. Multiple range and multiple F test. Biometrics 11: 1-42.

Farrell, D. J., 1981. An assessment of quick bioassays for determining the true metabolisable energy and apparent energy of poultry foodstuffs. World Poult. Sci. J. 37:72-83.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures and some application). Agriculture Handbook. No. 379. ARS, USDA, Washington. DC.

Green, S., S. L. Bertrand, M. J. C. Duron and R. Maillard, 1987a. Digestibility of amino acids in maize, wheat and barley meals, determined with intact and caecectomised cockerels. Br. Poult. Sci. 28:631-641.

Green, S. S. L. Bertrand, M. J. C. Duron and R. Maillard, 1987b. Digestibility of amino acids in soyabean, sunflower and groundnut meals, determined with intact and caecectomised cockerels. Br. Poult. Sci. 28:643-652.

Green, S. and T. Kiener, 1989. Digestibilities of nitrogen and amino acids in soybean, sunflower, meat and rapeseed meals measured with pigs and poultry. Anim. Prod. 48: 157-179

Han, Y. and C. M. Parsons. 1990. Determination of available amino acids and energy in alfalfa meal, feather meal and poultry by-product meal by various methods. Poult. Sci. 69:1544-1552.

Hou, S. S., L. Zhao, J. Y. Yu, J.C. Huang and S. R. Wang. 1997. Effect of cockerel caecum on amino acid digestibility of soybean cake, fish and maize gluten meals. In: Studies on Animal Nutrition and Metabolism. Edited by the Key Laboratory of Animal Nutrition, Ministry of Agriculture, People's Republic of China, pp.19-25.

Johns, D. C., C. K. Low, J. R.. Sedcole and K. A. C. James. 1986. Determination of amino acid digestibility using caecectomised and intact adult cockerels. Br. Poult. Sci. 27:451-461.

Kessler, J. W. and O. P. Thomas. 1979. A further evaluation of the true metabolisable energy systems. In: Proceedings of the Maryland Nutrition Conference, Washington, USA. pp. 83-87.

Longstaff, M. and J. M. McNab. 1991. The inhibitory effects of hull polysaccharides and tannin of faba beans (Viciafaba L.) on the digestion of amino acids, starch and lipid and on digestive enzyme activities in youngchicks. British Journal of Nutrition 65: 199-216.

McNab, J. M. and J. C. Blair. 1988. Modified assay for true and apparent metabolisable energy based on tube feeding. Br. Poult.. Sci. 29:697-707.

National Research Council, 1994. Nutrient Requirements of poultry. 9th rev. ed. National Academy Press, Washington, DC.

Parsons, C. M. 1985. Influence of caecectomy on digestibility of amino acids by roosters fed distiller's dried grains with solubles. J. Agric. Sci. 104:469-472.

Parsons, C. M. 1992. Application of the concept of amino acid availability in practical feed formulation. Zootecnica-Int. 12:64-69.

Ragland, D., C. R. Thomas, R. G. Elkin, D. J. Shafer and O. Adeola. 1999. The influence of cecectomy on metabolisable energy and amino acid digestibility of select feedstuffs for white Pekin ducks. Poult. Sci. 78:707-713.

Shires, A., A. R. Robblee, R. T. Hardin and D. R. Clandinin. 1980. Effect of the age of chickens on the true metabolisable energy values of feed ingredients. Poult. Sci. 59:396-403.

Sibbald, T. R. 1976. A bioassay for true metabolisable energy in feedingstuffs. Poult. Sci. 55:303-308.

Sibbald, T. R. 1979a. A bioassay for available amino acid and true metabolisable energy in feedingstuffs. Poult. Sci. 58:934-939.

Sibbald, T. R. 1979b. Bioavailable amino acids and true metabolisable energy of ceceal grains. Poult. Sci. 58:934-939.

Sibbald, I. R. 1982. Measurement of bioavailable energy in poultry feedstuffs: A review, Can. J. Anim. Sci. 62:983-1048.

Sibbald, I. R. and P. M. Morse. 1983. The effects of feed input and excreta collection time on estimates of metabolic plus endogenous energy losses in the bioassay for true metabolisable energy. Poult. Sci. 62:68-76.

Sibbald, I. R. and M. S. Wolynetz. 1984. A longitudinal study of energy and nitrogen excretion by fasted cockerels. Poult. Sci. 63:691-702.

Tenesaca, G. and J. L. Sell. 1978. Influence of indigestible material on energy excretion and true metabolisable energy of corn. Poult. Sci. 57:1167-1175.

Yalcin, S. and A. G. Onol. 1994. True metabolisable energy values of some feedingstuffs. Br. Poult. Sci. 35:119-122.

Yang, S. 1993. Measuring method of protein solubility. In: Feed Analyses and Supervision Technology of Quality of Feed. (Ed. S. Yang), Beijing Agricultural University Press, Beijing, China. pp. 183-185