Effect of De-hulling on Ileal Amino Acids Digestibility of Soybean Meals Fed to Growing Pigs*

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ABSTRACT : A study was carried out to determine the effect of de-hulling on apparent and true ileal amino acids digestibility of soybean meals for growing pigs. Twenty barrows (Duroc×Large white×Longer white) were fitted with a simple T-cannula at the distal ilium. Digestibility of 20 experimental diets was determined, nine of them were de-hulled soybean meal diets, and nine of them were regular soybean meal diets and two low protein casein diets for determination of endogenous amino acid correction for true digestibility determination. A 5×5 Latin Squares Design was adopted in this trail. The results showed that de-hulling increased apparent ileal digestibility of isoleucine, threonine, aspartic, tyrosine and indispensable and dispensable amino acid ($p<0.05$) in soybean meals. Furthermore, dehulling is also increased apparent digestibility of arginine, leucine, lysine, phenylalanine, alanine, glutamic acid, serine and gross amino acids ($p<0.01$). However, there were no significant differences found for histidine, methionine, tryptophan, cystine and glycine ($p>0.05$). Similar responses were found for true ileal digestibility. In three dehulled and non-dehulled pairs soybean meals from the same respective sources, de-hulling increased apparent digestibility of lysine, methionine, threonine and cystine 1.42%, 2.06%, 2.18% and 1.40% respectively. True digestibility of lysine, methionine, threonine and cystine was increased 1.65%, 1.94%, 2.30% and 1.82% respectively. A prediction equation for true ileal amino acid digestibility (including lysine and arginine) was established by multivariate linear regression. The independent variables included relevant amino acid, organic matter, crude protein, ether extract and nitrogen free extract. The coefficient R^2 values of lysine and agrinine were 0.596 and 0.531 respectively. According to the crude protein content, a prediction equation for lysine and arginine content in soybean meal was also established by single linear regression. The coefficient R^2 values of lysine and agrinine were 0.636 and 0.636 respectively. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 6 : 928-938)***

Key Words : Amino Acid, Soybean Meal, De-hulling, Ileal Digestibility, Pigs

INTRODUCTION

Soybean meal is the most widely used as source of plant protein in swine diets due to its excellent amino acid profile, dependable supply, competitive price, and especially a high level of lysine content of about 2.83-3.02% (NRC, 1998). Many studies have been done on the digestibility of amino acids in soybean meals (Tandsley et al, 1981b; Jmarty and Cavz, 1994; Thacker, 1984; Furuya and Kaji, 1991). The effect of different batches, soybean meal particle size and different soybean processors on amino acid digestibility in swine has been reported (Vestgen et al., 2000; Robert, 2000; Kempen and Kim. 2000; Scott and Brandon, 2000; Fasing and Mahan, 2000; Gabert, 2000). De-hulling may improve the protein and energy levels in soybean meal and increase quantity of soybean oil from soybean. It is economical to use de-hulled soybean meal (Erickson, 1995; Swick, 1999). However, only limited data are available on the effect of de-hulling on the digestibility of amino acid in soybean meals. Rudolph et al. (1983) compared apparent ileal amino acid digestibility between soybean meals with crude protein of 44.0% and 48.5%.

A knowledge of de-hulling effects and the digestible amino acid content of de-hulled and regular soybean meals may lead to more accurate formulation of swine diets based on digestible amino acid, and provide the materials for establishing the digestible amino acid data of China.

MATERIALS AND METHODS

Soybean meal samples and experimental diets

In this research, the effect of de-hulling on apparent and true ileal amino acid digestibility was determined in nine de-hulled soybean meals (DSBMs) and nine regular soybean meals (RSBMs) which were provided by American Soybean Association from China, America and South America. The origin, nutrient contents, urease activity (UA), protein solubility (KOH) and amino acid contents of the samples where shown in table 1 and table 2.

The experimental diets (table 3 and table 4) were corn starch-based, with the soybean samples and provided 16% crude protein on an as-fed basis. The casein diet was corn starch-based with 5% casein and provided 4.4 percentage units of crude protein. One percent soybean oil was added to the diets to improve palatability. Chromic oxide was added to each diet at a level of 0.5% as an indigestible marker for determination of amino acid digestibility (Huo, 1996).

Animals and experimental design

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Table 1. Analyzed composition and urease activity of nine de-hulled soybean meals

Item	D1	D2	D3	D4	D5	D6	D7	D8	D9
Producer of SBM	Zhangjiagang Donghai	Zhangjiagang Donghai	Jinlin Deda	Jizhou Liulu	South America	America	America	America	Jinlin Deda
Soybean resource	America	America	America	Jinlin	——	America	America	America	Jinlin
Protein(N×6.25), %	47.80	48.60	47.23	46.31	47.53	47.81	46.52	45.57	47.25
Ash, %	5.09	5.79	6.07	6.15	5.85	6.08	6.38	6.82	5.68
Crude fiber, %	4.82	3.85	4.35	4.05	3.94	3.16	2.77	2.44	3.12
Ether extract, %	0.75	0.56	0.97	0.63	2.00	2.19	1.09	2.01	1.68
Moisture, %	11.2	10.1	10.6	9.7	10.2	10.0	10.8	11.1	12.0
Protein solubility, %	84.50	84.73	79.81	81.73	80.58	85.48	80.62	80.50	86.66
Urease activity (UI)	0.03	0.00	0.00	0.17	0.00	0.05	0.00	0.01	0.06
Amino acid, %									
Arginine	3.36	3.61	3.37	3.28	3.53	3.60	3.31	3.15	3.52
Histidine	1.43	1.33	1.28	1.48	1.31	1.35	1.43	1.42	1.50
Isoleucine	2.14	2.09	1.96	2.15	2.10	2.23	2.25	2.12	2.22
Leucine	3.68	3.71	3.52	3.46	3.65	3.73	3.60	3.49	3.74
Lysine	3.02	3.08	2.99	3.05	2.99	3.16	3.06	2.96	3.09
Methionine	0.55	0.61	0.63	0.56	0.60	0.71	0.60	0.62	0.60
Phenylalanine	2.54	2.70	2.49	2.30	2.75	2.48	2.52	2.41	2.51
Threonine	1.96	1.93	1.84	1.94	1.86	1.97	1.99	1.90	2.00
Tryptophan	0.62	0.62	0.50	0.55	0.63	0.68	0.63	0.62	0.65
Valine	2.06	2.07	1.90	2.02	2.09	2.19	2.08	1.97	2.11
Avg. of indispensable	21.36	21.75	20.48	20.79	21.51	22.10	21.47	20.66	21.94
Alanine	2.03	1.94	1.74	1.97	2.00	2.00	2.01	1.94	2.04
Asparitic acid	5.24	5.59	5.26	5.41	5.50	5.48	5.44	5.21	5.63
Cystine	0.60	0.61	0.52	0.73	0.55	0.66	0.62	0.71	0.69
Glutamic acid	8.82	8.80	8.24	8.82	8.60	9.10	8.85	8.51	9.20
Glycine	1.99	2.09	1.98	1.93	2.07	1.99	1.95	1.86	1.94
Proline	2.62	2.51	4.17	2.84	3.61	2.48	2.88	2.71	2.77
Serine	2.27	2.14	2.04	2.28	2.13	2.31	2.23	2.17	2.35
Tryosine	1.77	1.72	1.68	1.60	1.75	1.34	1.65	1.69	1.65
Avg. of dispensable	25.34	25.40	25.63	25.58	26.21	25.36	25.63	24.80	26.27

Twenty barrows (Duroc×Large White×Longer White) were obtained from a commercial pig farm. The animals were housed individually in metabolic cases in an air-conditioned room. The pigs were surgically fitted with a simple T- cannula at the distal ilium using the procedures described by Huo (1996).

After recovery from surgery, the barrows were fed the experimental diets using four what of 5×5 Latin square design with observations from five pigs for every diet. Digestibility of amino acid was determined in 18 experimental diets, of which nine were de-hulled soybean meals and nine were regular soybean meals, as well as two casein diets. The experiments were divided into three trials. In trial 1, nine experimental diets D_1, R_1, D_2, R_2, D_3, R_3, D_5, D_6, D_7 and one casein diet were evaluated, using ten barrows with initial body weight 35.9±1.6 kg in two what of 5×5 Latin square design. In trial 2, four experimental diets

D_4, D_8, R_5, R_5 and another Casein diet were evaluated, using five barrows with initial body weight 37.5±1.9 kg, one what of 5X5 Latin square design. Using five barrows with 29.8±0.9 kg initial body weight, one what of 5X5 Latin square design, for five experimental diets D_9, R_7, R_8, R_9 and R_4 diets were evaluated in trial 3. The pigs remained healthy and consumed their meals throughout the experiment.

The barrows were fed twice daily, at 0800 and 1800, with equal amounts at each meal. The feeding level was initially set at 3.5% of body weight, and then increased 50-100 g at the beginning of each period. Water was provided *ad libitum*..

The duration of each experiment was 8 days. The barrows were allowed to adapt to each experimental diet for 4 days, and ileal digesta were collected on the final 4 days. Digesta were collected over ten hours, from 0900 to 1900 on each of the 4 days of collection. Digesta were frozen immediately after collection. The digesta samples for every period were mixed and freeze-dried. Samples were preserved at -20°C.

Sample preparation and chemical analyses

The samples of soybean meals, diets and digesta were subjected to analyses. The items included dry matter, crude

Table 2. Analyzed composition and urease activity of nine regular soybean meals

Item	R1	R2	R3	R4	R5	R6*	R7*	R8*	R9*
Producer of SBM	Zhangjiagang Donghai	Zhangjiagang Donghai	Jinlin Deda	Jizhou Liulu	Langfang oil industry	Mixed SBM	Mixed SBM	Mixed SBM	Mixed SBM
Soybean resource	America	Argentina	America	Jilin	Jilin	Mixed	Mixed	Mixed	Mixed
Protein(Nx 6.25), %	43.97	44.15	43.58	44.65	43.21	45.01	45.85	46.43	43.61
Ash, %	6.07	6.05	5.88	5.96	5.38	6.03	5.75	6.11	5.88
Crude fiber, %	5.83	5.21	4.09	4.10	4.42	4.24	3.91	4.33	4.27
Ether extract, %	1.76	1.71	0.69	1.69	1.48	1.73	1.21	0.86	2.12
Moisture, %	11.10	10.05	10.90	12.05	15.95	10.41	11.00	10.02	10.81
Protein solubility, %	84.04	87.66	86.27	84.67	84.16	83.58	79.81	82.48	85.62
Urease activity (UI)	0.07	0.04	0.02	0.00	0.00	0.02	0.33	0.10	0.05
Amino acid, %									
Arginine	3.17	3.14	3.28	3.23	3.21	3.21	3.21	3.32	2.78
Histidine	1.44	1.40	1.25	1.40	1.35	1.39	1.37	1.37	1.32
Isoleucine	2.08	2.00	1.97	2.12	2.00	2.12	2.09	2.15	1.99
Leucine	3.57	3.46	3.44	2.35	3.27	3.44	3.37	3.48	3.37
Lysine	2.93	2.94	2.87	2.96	2.77	2.89	2.84	2.96	2.88
Methionine	0.58	0.58	0.57	0.58	0.60	0.59	0.58	0.57	0.57
Phenylalanine	2.33	2.32	2.51	2.46	2.21	2.44	2.39	2.48	2.16
Threonine	1.89	1.90	1.73	1.88	1.76	1.90	1.86	1.90	1.88
Tryptophan	0.59	0.60	0.57	0.61	0.51	0.55	0.59	0.56	0.56
Valine	1.98	2.01	1.95	1.96	1.90	1.99	1.96	2.04	1.88
Avg. of indispensable	20.56	20.35	20.14	19.55	19.58	20.45	20.26	20.83	19.39
Alanine	1.97	2.00	1.86	1.92	1.83	1.94	1.90	1.90	1.94
Asparitic acid	5.16	4.95	5.12	5.24	5.04	5.14	5.12	5.32	5.14
Cystine	0.58	0.50	0.50	0.75	0.69	0.66	0.62	0.66	0.65
Glutamic acid	8.74	8.23	8.08	8.61	8.10	8.48	8.39	8.71	8.29
Glycine	1.96	1.89	1.95	1.88	1.78	1.84	1.82	1.88	1.85
Proline	3.12	2.47	3.39	2.78	2.61	2.68	2.77	2.81	2.62
Serine	2.21	2.17	1.99	2.19	2.07	2.18	2.14	2.21	2.23
Tryosine	1.67	1.61	1.59	1.76	1.52	1.63	1.60	1.56	1.56
Avg. of dispensable	25.41	23.82	24.48	25.13	23.64	24.51	24.36	25.05	24.28

* Mixed by some soybean meal samples:
R6 mixed from Dalian oil industry, Dalian Huanong, Liaoning Pulandian, Langfang Huamei. Soybeans from America, Brazil and Argentina.
R7 mixed from Shanghai, Heilongjiang Zhengda, Neimeng Zhalantu. Soybeans from America and Jilin.
R8 mixed from Langfang, Jili Guojiadian, Jinli Jiutai. Soybeans from America and Jilin.
R9 mixed from Sichuan Jiali and Guangzhou Dongling. Soybean come from America and Argentina.

protein, chromic oxide and contents of eighteen amino acid. Amino acid contents were determined with an Amino Acid Analyzer (Japan, L-8800) according to procedures described by the AOAC (1984). Acid hydrolysis (6 N HCl for 24 h with constant N_2 flushing) was used in the analyses of all amino acids except tryptophan, methionine and cystine. Tryptophan was determined following the procedure of Kohler and Palter (1967), methionine and cystine were determined by the procedure of Moore (1963). Chromic oxide in diets and digesta was determined by mixing acid (HNO_3:$HClO_4$=5:1) hydrolysis and was analyzed with an Atomic Absorption Spectroscopy (Japan, Z-5000) as described by Li (1998).

Data analysis

Ileal digestibility was calculated using the following equation:

Apparent digestibility, %=(1-(Md×AAi)/(AAd×Mi)) ×100

Where, Md is chromium concentration in diet;

AAd is amino acid concentration in ileal digesta;

AAi is amino acid concentration in diet;

Mi is chromium concentration in ileal digesta.

EO=((100-AD)/100)×IDM

Where, EO is endogenous output of amino acids on a g/kg dry matter intake basis;

AD is apparent digestibility of amino acid from the casein diet;

IDM is dry matter intake of an amino acid from the casein diet.

True digestibility, %=AD+EO×10×IDM

Where, AD is apparent digestibility of amino acid from the experiment diet;

EO is endogenous output of amino acids;

IDM is dry matter intake of an amino acid from the experimental diet.

The data were analyzed statistically using multivariate linear regression and single linear regression with SPSS 9.0.

Table 3. Formulation of the experimental diets (as-fed basis) of de-hulled soybean meal (%)

Ingredient	Diet									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	Casein
Soybean meal	33.40	32.90	33.55	35.80	33.00	34.00	34.00	34.30	33.50	
Casein*	-	-	-	-	-	-	-	-	-	5.00
Sucrose	-	-	-	-	-	-	-	-	-	20.00
Cellulose	-	-	-	-	-	-	-	-	-	5.00
Corn starch**	61.75	62.25	61.60	59.85	62.15	61.80	61.05	60.75	60.05	54.45
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Limestone	0.30	0.30	0.30	0.40	0.30	0.30	0.40	0.40	0.40	1.00
Dicalcium phosphate	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
1% premix****	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chromic oxide***	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nutrient level										
GE, kcal/g	3.68	3.68	3.68	3.64	3.69	3.68	3.65	3.65	3.62	3.81
Crude protein, %	16.10	16.09	16.03	16.07	16.06	16.02	16.01	16.02	16.01	4.40
Calcium, %	0.59	0.59	0.57	0.62	0.59	0.61	0.57	0.61	0.60	0.60
Effective phosphorus	0.37	0.37	0.37	0.38	0.37	0.37	0.37	0.37	0.34	0.38

* Denoted by Gansu Casein Company, with crude protein 88.8%.

** Purchased from Beijing Redstar Starch Company, with gross energy 3.81 kcal/g, crude protein 0.44%, calcium 0.074% and total Phosphorus 0.074%.

*** Purchased from Yixing city Yangxixudu Chemical Company.

**** Premix provide the following per kg of complete diet: vitamin A, 5512 IU; vitamin D3, 2200 IU. vitamin E, 6.1 IU; vitamin B12, 27.6 ug; riboflavin, 5.5 mg; D-pantothenic acid, 13.8 mg; niacin, 30.3 mg; choline chloride, 551 mg; Mn 100g; Fe,100 mg; Ze,100 mg; Cu, 234 mg; I, 1.4 mg; Se, 0.3 mg; Co, 1.0 mg.

Table 4. Formulation (%) of the experimental diets (as-fed basis) of regular soybean meal

Ingredient	Diet								
	R1	R2	R3	R4	R5	R6	R7	R8	R9
Soybean meal	35.30	36.50	36.03	37.15	36.65	35.00	34.60	33.50	33.50
Corn starch*	58.95	58.25	59.22	57.90	58.85	60.45	61.70	61.55	61.55
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Limstone	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Dicalcium phosphate	1.50	1.50	1.50	1.70	1.70	1.70	1.70	1.70	1.70
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
1% premix***	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chromic oxide**	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nutrient level									
GE, kcal/g	3.60	3.65	3.66	3.629	3.643	3.627	3.629	3.638	3.648
Crude protein, %	16.01	16.07	16.06	16.04	16.01	16.01	16.00	16.02	16.05
Calcium, %	0.60	0.60	0.57	0.62	0.61	0.61	0.61	0.61	0.60
Effective phosphorus	0.37	0.35	0.35	0.38	0.38	0.34	0.34	0.34	0.37

* Purchased from Beijing Redstar Starch Company Gross energy 3.81 kcal/g, crude protein 0.44%, calcium 0.074% and total phosphorus 0.074%.

** Purchased from Yixing city Yangxixudu Chemical Company.

*** Premix provide the following per kg of complete diet: vitamin A, 5512 IU; vitamin D3, 2200 IU. vitamin E, 6.1 IU; vitamin B12, 27.6 ug; riboflavin, 5.5 mg; D-pantothenic acid, 13.8 mg; niacin 30.3 mg; choline chloride, 551 mg; Mn 100g; Fe, 100 mg; Ze, 100 mg; Cu, 234 mg; I,1.4 mg; Se, 0.3 mg; Co, 1.0 mg.

RESULTS AND DISCUSSION

Effect of de-hulling on apparent ileal amino acid digestibility

Apparent ileal digestibility of indispensable and dispensable amino acids for nine DSBMs and nine RSBMs are shown in table 5 and table 6.

The results showed that apparent ileal digestibility of all amino acid were different in different sources of DSBMs ($p<0.01$), with the exception of histidine, leucine and serine ($p<0.05$) and tryptophan ($p>0.05$). The apparent amino acids digestibility in lysine, methionine and threonine ranged from 88.52%-91.91%, 85.49%-91.60%, 84.05%-

89.12% respectively between the different DSBMs sources. For the soybean imported from U.S., there was a difference in the apparent digestibility of amino acid among three soybean meals in which apparent lysine digestibility were 91.91%(D_3), 91.80% (D_6) and 90.96%(D_2) respectively, but it was not significant ($p>0.05$). For Chinese local soybean meals, the apparent lysine digestibility between dehulled and non-dehulled was 89.82% (D9) and 88.41% (D_4), which was a significant difference ($p<0.05$). This may be attributed to different extent of de-hulling and other processing technology. De-hulling may remove 6-8% by weight of soybeans in America (David, 1995).

Table 5. Apparent digestibility of amino acids in nine de-hulled soybean meal samples

Item	D1	D2	D3	D4	D5	D6	D7	D8	D9	SEM	P value
Indispensable, %											
Arginine	93.04	94.84	94.28	93.16	93.84	95.33	94.06	93.13	91.66	1.0393	0.0000
Histidine	91.16	89.25	92.31	85.43	85.13	89.91	90.03	89.37	85.74	2.5978	0.0159
Isoleucine	87.76	90.29	90.21	89.06	89.01	90.81	88.65	89.30	87.80	1.4615	0.0026
Leucine	88.09	89.28	89.95	87.56	87.91	90.00	88.39	88.85	87.58	1.4883	0.0167
Lysine	88.52	90.96	91.91	88.41	89.19	91.80	89.54	89.80	89.29	1.4437	0.0027
Methionine	88.19	88.62	85.49	91.00	85.79	90.43	88.85	90.91	91.60	1.9820	0.0080
Phenylalanine	88.78	89.63	89.31	89.89	88.07	89.92	88.95	90.12	86.01	1.3952	0.0001
Threonine	81.64	84.88	84.28	82.09	81.37	86.27	82.03	83.21	80.50	2.0130	0.0004
Tryptophan	86.91	86.82	84.05	87.67	85.41	89.12	85.68	87.32	88.55	2.0961	0.1578
Valine	79.34	83.63	81.93	83.49	81.03	83.82	77.88	84.80	77.37	2.2775	0.0001
Avg. of indispensable	87.34	88.82	88.38	87.77	86.67	89.74	87.41	88.68	86.61	1.4521	0.0010
Alanine	83.19	87.12	85.66	84.47	86.68	88.39	85.53	85.49	82.33	2.0110	0.0001
Asparitic acid	86.72	89.79	90.89	87.35	87.99	90.55	87.89	86.82	87.08	1.7438	0.0055
Cystine	73.48	78.17	72.49	82.80	75.89	84.44	76.89	77.09	70.87	2.5971	0.0000
Glutamic acid	88.53	89.15	89.27	89.72	89.15	90.97	92.65	88.79	89.46	1.6012	0.0019
Glycine	74.85	82.44	75.66	77.23	77.74	81.48	78.11	81.84	69.69	2.6697	0.0000
Proline	80.29	89.45	82.65	86.49	86.13	92.21	86.96	86.01	88.92	2.4689	0.0002
Serine	85.46	88.42	88.08	85.25	86.63	90.46	88.10	86.74	87.61	2.2389	0.0335
Tryosine	89.24	90.31	90.11	90.64	87.94	90.23	90.13	90.31	84.90	1.3855	0.0000
Avg. of dispensable	82.98	87.14	84.57	85.49	84.79	88.80	85.27	85.39	82.61	1.5529	0.0000

Table 6. Apparent digestibility of amino acid in nine regular soybean meal samples

Item	R1	R2	R3	R4	R5	R6	R7	R8	R9	SEM	P value
Indispensable, %											
Arginine	92.11	93.35	93.57	93.83	90.8	90.21	90.26	90.68	87.32	2.0070	0.0081
Histidine	83.86	88.57	89.22	89.79	85.32	86.31	79.13	81.07	82.25	2.4435	0.0000
Isoleucine	85.84	88.63	88.58	87.86	86.16	86.97	83.45	85.57	84.93	1.4813	0.0005
Leucine	85.59	87.38	88.00	86.64	85.63	86.68	83.19	85.16	82.78	1.5343	0.0001
Lysine	86.22	90.26	89.62	88.06	86.53	86.59	81.86	84.21	85.27	1.3255	0.0000
Methionine	85.47	91.17	85.86	87.54	90.93	88.98	89.16	86.98	88.61	1.8256	0.0320
Phenylalanine	86.17	87.68	87.89	88.94	84.79	87.8	82.59	86.66	82.99	1.5277	0.0000
Threonine	77.43	83.48	82.38	81.3	79.62	81.1	72.9	78.95	79.11	2.0108	0.0000
Tryptophan	83.21	87.19	87.42	86.48	83.79	84.76	82.41	84.2	89.11	2.4288	0.0933
Valine	76.18	81.74	79.44	82.72	76.4	82.29	75.81	79.77	77.38	2.0378	0.0011
Avg. of indispensable	84.21	87.95	87.19	87.32	85.00	86.22	82.08	84.33	83.98	1.3822	0.0001
Alanine	79.14	85.37	84.88	82.84	80.58	83.28	77.42	81.16	80.61	1.7513	0.0001
Asparitic acid	84.34	88.71	87.39	85.72	84.52	85.49	79.43	83.61	83.61	1.9399	0.0000
Cystine	73.17	79.00	71.85	78.28	72.87	77.16	78.19	73.01	70.26	2.6299	0.0032
Glutamic acid	86.02	89.89	91.48	88.05	86.91	87.86	80.32	84.29	87.07	2.8463	0.0079
Glycine	72.9	79.23	75.83	77.96	67.51	74.67	64.21	68.23	71.19	2.6979	0.0000
Proline	81.17	87.66	82.48	87.28	79.67	84.59	74.96	80.35	80.42	3.5969	0.0084
Serine	82.74	86.15	86.56	84.81	82.93	83.86	79.36	82.35	81.43	1.5566	0.0000
Tryosine	85.37	88.67	88.68	91.03	86.48	89.56	84.38	87.07	83.39	1.5512	0.0000
Avg. of dispensable	80.61	85.49	83.36	84.5	80.19	83.31	77.28	80.01	79.45	1.4902	0.0000

Apparent ileal digestibility for all amino acids was different in different sources of RSBMs ($p<0.01$), with the exception of methionine ($p<0.05$) (table 6). For lysine, methionine and threonine the values ranged from 84.21%-90.26%, 85.47%-91.17% and 83.21%-89.11% respectively between the different RSBMs sources.

Table 7. True amino acid digestibility of nine de-hullled soybean meals

Item	D1	D2	D3	D4	D5	D6	D7	D8	D9	SEM	P value
Indispensable, %											
Arginine	95.02	96.61	95.92	95.29	95.95	96.92	96.08	95.01	94.46	1.0622	0.0004
Histidine	94.72	92.56	95.28	88.96	89.06	92.70	93.75	92.06	91.33	2.5475	0.0927
Isoleucine	92.72	94.75	94.35	93.71	94.37	95.00	93.76	93.46	92.96	1.5689	0.2590
Leucine	91.08	92.10	92.52	90.43	91.18	92.55	91.49	91.27	90.79	1.5275	0.2082
Lysine	92.06	94.28	94.48	91.68	93.61	94.73	93.18	92.63	92.12	1.5037	0.0623
Methionine	93.84	94.33	91.56	93.06	91.92	94.72	93.59	92.66	92.79	1.8101	0.3372
Phenylalanine	90.79	91.57	91.09	91.95	90.28	91.73	91.00	91.88	89.29	1.4490	0.0031
Threonine	89.18	91.76	90.54	89.29	89.48	92.37	89.36	89.42	89.37	2.1449	0.0632
Tryptophan	91.89	93.33	89.67	91.60	91.20	93.57	92.82	90.98	93.79	1.8865	0.1029
Valine	87.29	90.40	88.47	88.85	89.22	90.39	86.18	89.40	88.20	2.2930	0.0049
Avg. of indispensable	91.65	92.82	91.69	91.87	91.36	93.34	91.87	92.19	90.58	1.4859	0.0756
Alanine	91.02	93.68	92.03	91.67	94.45	94.70	93.35	91.58	91.26	2.0627	0.0105
Asparitic acid	89.67	92.43	93.33	90.06	91.16	92.98	90.88	89.24	88.88	1.7779	0.0374
Cystine	86.01	88.98	82.52	86.79	86.39	93.22	86.22	81.07	79.08	2.7807	0.0000
Glutamic acid	93.28	94.57	93.81	92.85	92.93	95.41	91.97	91.53	91.17	1.6382	0.0147
Glycine	86.82	93.37	85.66	88.21	90.80	91.48	90.37	91.49	87.47	2.7847	0.0142
Proline	91.86	101.25	95.08	95.92	99.10	101.62	101.50	93.90	98.22	2.8188	0.0030
Serine	93.72	95.81	94.86	96.96	95.50	97.18	96.39	97.11	99.60	2.5665	0.0495
Tryosine	91.86	92.85	92.40	93.27	90.82	92.46	92.70	92.56	90.22	1.4640	0.0004
Avg. of dispensable	88.49	92.20	89.20	90.44	90.72	93.32	91.25	89.72	89.92	1.6402	0.0007

In the case of three pairs of DSBMs and RSBMs from the same respective sources, de-hulling increased the apparent digestibility of histidine ($p<0.05$) and tyrosine ($p<0.10$) about 2 percentage units (Table 10). There were no differences in other amino acids ($p>0.10$). For key amino acids, the digestibility of lysine, methionine, threonine and cystine in DSBMs were 1.42, 2.06, 2.18 and 1.40 percentage units higher than that in RSBMs. The digestibility of arginine and glycine in DSBMs was just 0.32 and 0.35 percentage units higher than that in RSBMs. However, the digestibility of proline in DSBMs was 0.50 percentage units lower than that in RSBMs. This may be attributed to adding chromic oxide in cornstarch-soybean meal diets, which increased the amount of endogenous proline.

Effect of de-hulling on true ileal amino acid digestibility

The average amount of endogenous amino acids in two casein diets was measured: LYS 0.55; THR 0.77; MET

Table 8. True amino acid digestibility of nine regular soybean meals

Item	R1	R2	R3	R4	R5	R6	R7	R8	R9	SEM	P value
Indispensable, %											
Arginine	94.24	95.33	95.31	95.68	93.36	92.03	92.19	92.75	90.34	1.9739	0.0312
Histidine	87.66	91.89	92.36	92.55	90.64	89.71	82.32	84.56	87.74	2.3969	0.0000
Isoleucine	91.16	93.56	93.04	92.25	93.33	91.01	87.99	90.26	92.99	1.3637	0.0002
Leucine	88.74	90.38	90.81	89.3	90.02	89.12	86.01	88.05	87.67	1.4823	0.0010
Lysine	90.01	93.77	92.83	91.11	91.69	89.47	84.95	87.61	90.81	1.2472	0.0000
Methionine	91.05	95.29	91.45	89.79	94.35	91.11	90.97	89.39	92.64	1.7613	0.0052
Phenylalanine	88.29	89.72	89.89	90.87	87.84	89.56	84.78	88.72	86.44	1.4653	0.0002
Threonine	85.37	90.66	89.02	88.09	90.58	87.22	80.04	86.21	90.69	1.8978	0.0000
Tryptophan	88.73	92.41	92.5	90.39	91.77	89.03	86.45	88.54	97.18	2.3186	0.0010
Valine	84.57	89.07	86.43	87.76	84.76	86.77	80.92	85.18	85.96	1.8921	0.0128
Avg. of indispensable	88.80	92.18	91.14	91.07	91.09	89.75	86.02	88.47	90.68	1.2854	0.0001
Alanine	87.25	92.26	91.69	89.59	91.78	89.27	84.06	88.42	91.95	1.6359	0.0006
Asparitic acid	87.5	91.62	90.02	88.27	88.6	87.86	82.07	86.37	88.16	1.9174	0.0000
Cystine	86.35	88.53	82.14	82.63	80.55	81.12	81.39	77.66	79.33	2.6969	0.0026
Glutamic acid	89.61	92.52	92.19	90.98	91.01	90.58	83.35	87.46	91.46	2.8176	0.0060
Glycine	85.67	90.78	86.64	88.37	85.03	84.16	74.85	79.78	89.42	2.5897	0.0000
Proline	94.16	98.66	93.29	96.6	96.96	93.02	85.83	90.47	96.52	3.9078	0.0194
Serine	91.48	94.21	93.87	95.85	98.2	94.21	90.38	94.35	98.28	1.7674	0.0000
Tryosine	88.14	91.27	91.2	93.46	90.55	91.84	87.2	89.84	88.39	1.4870	0.0008
Avg. of dispensable	86.5	90.87	88.32	89.18	87.54	87.63	82.13	85.11	87.63	1.4912	0.0000

Table 9. Comparison of apparent and true amino acid digestibility between nine de-hulled soybean meals and nine regular soybean meals in growing pigs

Item	Apparent amino acid digestibility			True amino acid digestibility		
	De-hulled SBMs	Regular SBMs	P value	De-hulled SBMs	Regular SBMs	P value
Indispensable, %						
Arginine	93.44	90.23	0.0058	95.42	93.47	0.0049
Histidine	88.45	85.06	0.3131	92.00	88.83	0.3177
Isoleucine	88.95	86.44	0.0017	93.90	91.73	0.0022
Leucine	88.37	85.67	0.0021	91.38	88.90	0.0018
Lysine	89.67	86.51	0.0009	93.20	90.25	0.0006
Methionine	88.72	88.30	0.9234	93.16	91.78	0.1536
Phenylalanine	88.71	86.71	0.0066	90.80	88.46	0.0054
Threonine	82.68	79.59	0.0294	90.09	87.54	0.0624
Tryptophan	86.58	85.48	0.1051	92.09	90.78	0.0778
Valine	81.25	79.08	0.2314	88.20	85.71	0.2124
Avg. of indispensable	87.68	85.31	0.0119	91.93	89.91	0.0114
Alanine	85.16	81.70	0.0025	92.64	89.59	0.0030
Asparitic acid	88.09	84.76	0.0070	90.96	87.83	0.0085
Cystine	76.70	74.87	0.1538	85.36	82.19	0.0110
Glutamic acid	89.48	86.88	0.0124	93.06	89.99	0.0135
Glycine	77.47	72.41	0.0005	89.26	84.97	0.0004
Proline	86.31	82.06	0.0001	97.61	93.95	0.0017
Serine	87.16	83.35	0.0001	96.35	94.54	0.0074
Tryosine	89.06	87.18	0.2700	91.86	90.21	0.2928
Avg. of dispensable	84.99	81.58	0.0003	90.32	87.21	0.0003

0.07; CYS 0.21; TRP 0.119; ILE 0.56; VAL0.82; LEU 0.57;PHE 0.27; TYR 0.25; HIS 0.27; ARG 0.34; ALA 0.62; ASP 0.82; GLU 1.53; GLY 1.23; SER 1.01; PRO 1.55. These values were used in calculating true ileal digestibility of amino acids (Low protein casein standardized digestibility).

The true digestibility of amino acids of nine DSBMs and nine RSBMs are shown in table 7 and table 8.

The results indicated that there was a difference to true ileal digestibility of most of amino acids from different sources of DSBMs. With the exception of isoleucine, leucine and methionine ($p>0.10$) and lysine, histidine and threonine ($p<0.1$), there were significant differences found for arginine, phenylalanine, valine, cysine, proline, tyrosine and indispensable and gross amino acids ($p<0.01$) and alanine, aspartic, glutamic acid, glycine and serine ($p<0.05$). The true digestibility in lysine, methionine and threonine ranged from 91.68%-94.48%, 91.56%-94.72% and 89.67%-93.79% respectively between the different DSBMs sources. For soybean meals from soybeans imported from America, there were differences in true digestibility among three

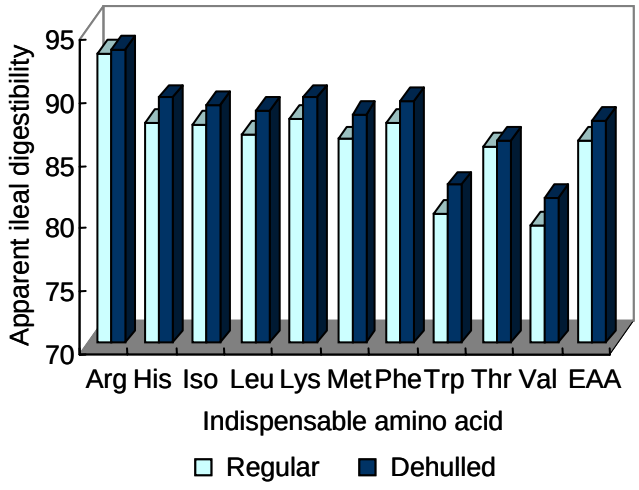

Figure 1. Effect of de-hulled on apparent ileal indispensable amino acid

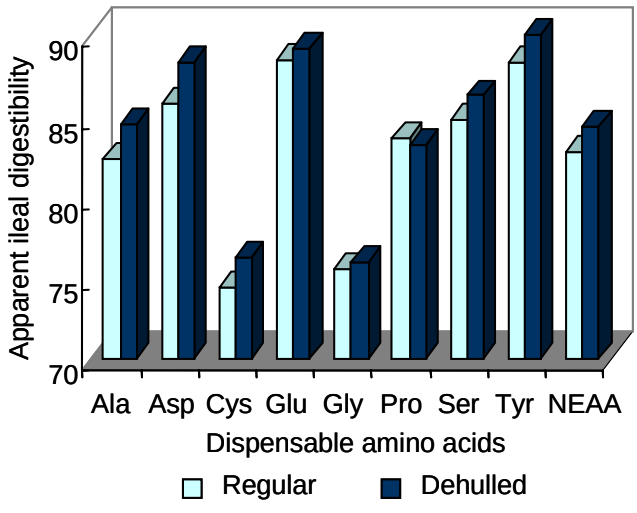

Figure 2. Effect of de-hulled on apparent ileal dispensable amino acid

Table 10. Comparison of apparent amino acid digestibility and true amino acid digestibility between three pairs de-hulled and regular soybean meals in growing swine

Item	Apparent amino acid digestibility			Ture amino acid digestibility		
	De-hulled SBMs	Regular SBMs	P value	De-hulled SBMs	Regular SBMs	P value
Indispensable, %						
Arginine	93.49	93.17	0.1250	95.41	95.08	0.1999
Histidine	89.63	87.62	0.0012	92.99	90.86	0.0017
Isoleucine	89.01	87.43	0.3887	93.59	92.15	0.5682
Leucine	88.53	86.74	0.1827	91.34	89.62	.2548
Lysine	89.61	87.97	0.1520	92.74	91.32	0.2557
Methionine	88.23	86.29	0.7978	93.82	91.76	0.9195
Phenylalanine	89.33	87.67	0.2016	91.28	89.68	0.2733
Threonine	82.67	80.37	0.1703	89.67	87.49	0.2472
Tryptophan	86.21	85.70	0.8351	91.05	90.54	0.8161
Valine	81.59	79.45	0.2611	88.20	86.25	0.3289
Avg. of indispensable	87.83	86.24	0.1550	91.74	90.34	0.2473
Alanine	84.44	82.28	0.3217	91.57	89.51	0.4849
Asparitic acid	88.32	85.82	0.2723	91.02	88.60	0.3262
Cystine	76.26	74.43	0.5704	85.11	83.71	0.5307
Glutamic acid	89.17	88.52	0.2035	93.31	90.93	0.2524
Glycine	75.91	75.56	0.5887	86.90	86.89	0.8906
Proline	83.14	83.64	0.9911	94.29	94.68	0.7634
Serine	86.26	84.70	0.1959	95.18	93.73	0.5586
Tryosine	90.00	88.36	0.0661	92.51	90.93	0.0907
Avg. of dispensable	84.35	82.82	0.4227	89.38	88.00	0.5805

soybean meals ($p>0.05$), which were 94.73% (D_6), 94.48% (D_3) and 94.28% (D_2) respectively, but were not significantly different ($p>0.05$). For Chinese local soybean, the true lysine digestibility in two soybean meals were 92.12% (D9) and 91.68% (D_4) respectively, it was also not significant ($p>0.05$).

True ileal digestibility for all amino acids showed a difference in different sources of RSBMs. For lysine, methionine and threonine the values were found from 84.21%-90.26%, 85.47%-91.17% and 83.21%-89.11% respectively between the different RSBMs sources. There were significant differences found for arginine, valine and proline ($p<0.05$) and other amino acids and the average value of indispensable and dispensable amino acids ($p<0.01$). This may be related to the many sources of RSBMs used in this work. Samples R_6, R_7, R_8 and R_9 were produced at the laboratory by mixing by several soybean meal samples respectively. R_6 mixed from Dalian oil industry, Dalian Huanong, Liaoning Pulandian, Langfang Huamei, whose soybeans came from America, Brazil and Argentina; R_7 mixed from Shanghai, Heilongjiang Zhengda, Neimeng Zhalantun, whose soybeans from America; Jilin R_8 mixed from Langfang, Jilin Guojiadian, Jinlin Jiutai, whose soybeans from America and Jilin; R_9 mixed from Sichuan Jiali and Guangzhou Dongling, whose soybeans come from America and Argentina. The weight of each of the soybean meal samples mixed was 25 kg.

The average value of true amino acid digestibility between nine DSBMs and nine RSBMs was compared by T-test. The results showed that except for histidine, methionine, tryptophan, threonine, valine and tyrosine, de-hulling increased the true ileal digestibility of cysine and glutamic acid ($p<0.05$) , and arginine, isoleucine, leucine, lysine, phenylalanine, alanine, aspartic, glycine, proline, serine and indispensable and gross amino acids ($p<0.01$). Thus is clear that de-hulling had a positive effect on true ileal digestibility among different sources and producers.

However, it is most important to study the effect of de-hulling on soybean meals from the same sources. In three pair's soybean meals from the same respective sources, the true digestibility of four key amino acids lysine, methionine, threonine and cystine in DSBMs were 92.74%, 93.82%, 89.67% and 85.11% respectively, and which were 1.64, 1.94, 2.30 and 1.82 percentage units higher than that in RSBMs respectively. The digestibility of arginine and glycine in DSBMs were 0.32 and 0.01 percentage unit higher than that in RSBMs. However digestibility of proline in DSBMs was 0.39 % lower than that in RSBMs. For of all six of the above samples, on average the true digestibility of each amino acid in DSBMs did not differ from that in RSBMs ($p>0.05$), with the exception of histidine ($p<0.05$) (table 10).

For apparent digestibility in DBMs and RSBMs there were differences for each amino acid. This was shown in table 10, figure 1 and figure 2. In RSBMs the apparent digestibility of argnine was highest which was 93.17%; The range of digestibility of histidine, isoleucine, leucine, lysine, methionine, phenylalanine, aspartic acid, glutamic acid and

Table 11. Comparison with different resource data of apparent ileal amino acid digestibility

Item	Current[a]	Current[a]	H.Y.Zhong (1997)	B.C.Rudolgh (1983) [b]	B.C.Rudolgh (1983) [b]	Van Kempen (2002) [c]	NRC (1998)
Sample numbers	n=9	n=9	n=1	n=1	n=1	n=1	
Crude protein	44.96	47.18	47.30	44.00	48.50	48.0	47.5
Amino acid, %							
Arginine	93.44	90.23	94.00	89.30	88.30	92.5	90
Histidine	88.45	85.06	88.30	86.60	85.20	88.3	86
Isoleucine	88.95	86.44	89.30	82.30	79.30	85.5	84
Leucine	88.37	85.67	86.90	81.20	78.30	84.9	84
Lysine	89.67	86.51	85.70	85.10	83.50	86.2	85
Methionine	88.72	88.30	89.10	90.20	89.40	88.2	86
Phenylalanine	88.71	86.71	87.00	85.80	83.10	86.5	84
Threonine	82.68	79.59	-	74.50	72.90	87.6	81
Tryptophan	86.58	85.48	84.80	77.50	78.80	78.3	78
Valine	81.25	79.08	88.90	80.20	77.40	88.5	81
Alanine	85.16	81.70	81.90	78.20	76.20	-	-
Asparitic acid	88.09	84.76	88.90	82.60	80.80	-	-
Cystine	76.70	74.87	-	77.60	77.90	77.3	79
Glutamic acid	89.48	86.88	89.10	87.20	86.40	-	-
Glycine	77.47	72.41	83.20	66.30	66.50	-	-
Proline	86.31	82.06	84.30	65.10	66.80	-	-
Serine	87.16	83.35	85.10	80.10	79.10	-	-
Tryosine	89.06	87.18	-	82.30	79.80	-	-
Dispensable	84.99	81.58	85.40	77.43	76.69	-	-

[a] 1.0% soybean oil, 0.5% Chrimic oxide and 16% crude protein were used in the diets.
[b] 6.0% cellulose, 0.25% and 12% crude protein were used in the diets.
[c] 20% sucrose, 2% corn oil and 0.5% Chrimic oxide were used in diets.

serine was 87.62%-84.70%; and that of proline, threonine, valine, cystine and glycine was small as 83.64%, 80.37%, 79.45%, 74.34%, 75.56% respectively. The apparent digestibility of indispensable amino acid at about 86.24% was higher than that of dispensable amino acid at about 82.82% in RSBMs. These results are similar to the values reported by Rudolph (1983). The low apparent digestibility for proline, glycine, and threonine at the end of the small intestine probably resulted from their high concentrations in the endogenous secretions, as was discussed by Low (1979).

Apparent ileal digestibility of most indispensable and dispensable amino acids in the soybean meals in this research, and of those previously cited, were higher than other values reported. Lysine digestibility averaged were 86.51% for RSBMs and 89.6% for DSBMs. Previously reported values were 83.5% for soybean meal that contain 48.5% crude protein and 85.1% for soybean meal that contain 44.0% crude protein (Rudolph, 1983), in diets with 6% added cellulose; and that of Zhong (1997) was 85.7*%* for DSBMs The data is shown in table 11. Numerically, the samples tested in this experiment had a higher value than the NRC data in all amino acid expect of valine and cystine. The apparent lysine digestibility of 85% in both RSBMs and DSBMs is found in NRC (1998). The NRC tables are compilations of digestibility data collected from several countries and thus is more likely to include batches of soybean meal that were produced under poor condition (Kempen et al., 2002). Kempen (2002) reported that 86.3% apparent lysine digestibility for a common soybean meal with 48% crude protein tested by five sites in America with the diets which had 17% crude protein content and 20% added sucrose.

For of all the diets, there were differences in the digestibility of lysine in the soybean meals in the present results. However, the ileal amino acid digestibility values of lysine, methionine and threonine in different soybean meal samples, ranged from 80.1% to 90.7%, 74.5% to 96.7% and 70.7% to 82.2% respectively (Sauer and Ozimek, 1986; Knable et al., 1989). Perhaps this may be attributed to the formulation of diet and the weights of the trial pigs. Differences is crude protein and amino acid content in the assay diets may explain, in part, the variation in apparent ileal amino acid digestibility values among different samples of the same feedstuff (Sauer and Ozimek, 1986). Different amounts of cellulose, sucrose, chromic oxide and crude protein were found in different cornstarch-soybean meal diets (table 11). Pigs with different ages were found to have different endogenous secretions. The use of young pigs in digestibility trials may result high endogenous secretions (Kempen, 2002).

The prediction equations of true amino acid digestibility and amino acid content

A prediction equation for true ileal indispensable amino acids digestibility (including lysine and arginine) from the data of the eighteen experimental soybean meals was established using the method of multivariate linear regression. The independent variables included relevant amino acid (lysine or arginine), organic matter (OM), crude protein (CP), ether extract (EE) and nitrogen free extract (NFE).

The prediction equations were as:

Tlys%=117.25+15.34 LYS+1.10 OM-2.60 CP-1.24 NFE-0.82 EE, R^2=0.596;

Targ%=85.53+8.23 ARG+1.15 OM+1.92 CP-0.83 EE-0.74 NFE, R^2=0.531

In the equations, Tlys was true ileal lysine digestibility; Targ was true ileal arginine digestibility; LYS was lysine content of soybean meal; ARG was arginine content of soybean meal; OM was organic matter content of soybean meal; CP was crude protein content of soybean meal; NFE was nitrogen free extract content of soybean meal; EE was ether extract content of soybean meal. All parameters were percentage unit. The respective R^2 of lysine and arginine were 0.596 and 0.531 respectively. The equations were certified by F-test showing that greatest difference ($p<0.01$).

Equations to predict ileal amino acid digestibility in protein resources have been developed by different researchers (Villamide, 1998; Kempen et al., 2002). Zhang (2001) established a prediction equation for apparent ileal amino acid digestibility (including lysine, methionine, threonine and tryptophan) in cottonseed meals by multivariate linear regression. The independent variables included relevant amino acid, gossypol, NDF, organic matter, crude protein and crude fiber. However, only limited data are available on ileal amino acid digestibility for soybean meals. Kempen (2002) confirmed regression coefficients R^2 of digestible vs. total methionine , lysine, cystine and threonine of 0.96, 0.98, 0.90 and 0.89, respectively.

A prediction equation for lysine and arginine contents in soybean meal by single linear regression was also established by crude protein content using the 18 soybean meals in this research.

The prediction equations were as:

LYS%=0.8396+0.04645 CP%, R^2=0.636;

ARG%=0.09298 CP%-0.9688, R^2=0.636。

In the equations, LYS was lysine content of soybean meal; ARG was arginine content of soybean meal; CP was crude protein content of soybean meal. The coefficient R^2 of lysine and arginine were 0.636 and 0.636 respectively. The equations were certified by F-test showing the greatest difference ($p<0.01$).

From all of this, we can conclude that the above equations should be effective for accurately estimating true ileal digestibility of two indispensable amino acids and in estimating lysine and arginine contents in soybean meal.

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