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Determination and Prediction of Digestible and Metabolisable Energy of Dehulled and Regular Soybean Meals for Pigs

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Abstract: The digestible energy (DE) and metabolisable energy (ME) content of seven dehulled and seven regular soybean meals were determined in growing pigs fed cornstarch- soybean meal diets using the total fecal collection method. The energy values for the dehulled soybean meals were higher than for the regular soybean meals. The mean DE and ME values for the seven dehulled soybean meals averaged 16.91 and 15.85 MJ/kg DM, respectively, while the corresponding values for the seven regular soybean meals averaged 16.79 and 15.54 MJ/kg DM, respectively. The chemical composition of each sample was determined and used to establish prediction equations ($R^2>0.90$, RSD<0.1) for DE and ME values. Chemical components included in the prediction equations included ash (%), calcium (Ca), ether extract (EE), acid detergent lignin (ADL), nitrogen free extract (NFE), acid detergent fiber (ADF) and soluble carbohydrate (SCHO). The best equations for predicting DE and ME (MJ/kg DM) were as follows: DE = 25.3 - 0.70ash + 2.59Ca - 0.22EE + 0.41ADL - 0.099NFE ($R^2=0.98$, RSD=0.025) ME = 25.0 - 0.65ash + 0.12ADF - 0.16NFE - 0.059SCHO ($R^2=0.98$, RSD=0.019). The correlation between the determined DE and the predicted DE values as well as between the determined ME and the predicted ME values were significant while the differences between predicted and determined values were not significant ($P>0.05$), which indicates that the above prediction equations are suitable to predict DE and ME values of soybean meal for swine.

Key words: DE, ME, Soybean meal, Prediction equations, Chemical composition, Pigs

Introduction

Dehulled soybean meal is widely utilized in swine diets because the crude protein content in dehulled soybean meal is higher and the crude fiber content is lower than regular soybean meal (NRC, 1998). Dehulling may also improve the digestibility of energy (Rudolph *et al.*, 1983; Erickson, 1995 and Ragland *et al.*, 1998) and amino acids (Rudolph *et al.*, 1983 and Van Kempen *et al.*, 2002) in soybean meals fed to swine.

Dehulled soybean meals have only recently become available in China (Xiong, 2001) and there is little published information describing the digestible (DE) and metabolisable (ME) energy content of the typical soybean meals produced in China. Such information is essential for the Feedstuffs Database in China (Information Internet Center of China Feed Database, 2000) and to enable these products to be effectively utilized by livestock nutritionists. DE and ME are commonly obtained using balance trial methods, which are relatively time consuming and expensive (Zhang and Wu, 1981). Therefore, many researchers have attempted to develop prediction equations for DE and ME based on chemical analysis (King and Taverner, 1975; Morgan *et al.*, 1975; Yang, 1979; Just *et al.*, 1984 and Noblet and Perez, 1993). This study was designed to evaluate the nutritional value of dehulled and regular soybean meals produced in China and to develop prediction equations for DE and ME in these soybean meals based on their chemical composition.

Materials and Methods

Soybean Meal Samples: Seven dehulled soybean meals (D1, D2, D3, D4, D5, D6, D7) and seven regular soybean meals (R1, R2, R3, R4, R5, R6, R7) were sampled and provided by the American Soybean Association for use in this experiment. The sources of these soybean meals and their genetic origin are shown in Table 1. The chemical composition of the soybean meals is shown in Table 2.

Digestion Trial: Fourteen cornstarch-based diets were formulated using the soybean meals as the sole source of supplementary protein (Table 3). The diets were formulated to contain approximately 18% crude protein (DM basis) and to meet or exceed NRC (1998) nutrient recommendations for growing swine.

Animals and Experimental Design: The experiment was conducted as two separate feeding trials with each trial divided into four phases. In trial 1 (phase 1), four experimental diets based on D1, R1, D2, and R2 soybean meal samples were evaluated using twelve barrows (Large White × Landrace × Pietran) with an initial body weight of 36.65 ± 2.64 kg. Each diet was fed to a block of 3 pigs for a nine-day period (six days adaptation period followed

Table 1: Sources of soybean meal samples used in the feeding trials

Sample name	Code	Produced or imported by	Location in	Orgin of soybean
Trial 1				
Regular Soybean Meal	R1	East Ocean Cereal & Oil Industry Co. Ltd., China	Jiangsu Province	America
Dehulled Soybean Meal	D1	East Ocean Cereal & Oil Industry Co. Ltd., China	Jiangsu Province	America
Regular Soybean Meal	R2	East Ocean Cereal & Oil Industry Co. Ltd., China	Jiangsu Province	Argentina
Dehulled Soybean Meal	D2	East Ocean Cereal & Oil Industry Co. Ltd., China	Jiangsu Province	America
Regular Soybean Meal	R3	Jilin Deda Co. Ltd., China	Jilin Province	America
Dehulled Soybean Meal	D3	Jilin Deda Co. Ltd., China	Jilin Province	America
Dehulled Soybean Meal	D4	America Soybean Meal	America	America
Dehulled Soybean Meal	D5	South America Soybean Meal	South America	South America
Trial 2				
Dehulled Soybean Meal	D6	Jinzhou Liulu Oil Industry, China	Liaoning Province	China
Dehulled Soybean Meal	D7	American Soybean Meal	America	America
Regular Soybean Meal	R4[a]	Mixed by 4 Soybean Meals in China	America, Argentina and Brazil	America and South America
Regular Soybean Meal	R5[b]	Mixed by 3 Soybean Meals from Argentina and China	America, Heilongjiang and Jilin Province	America and China
Regular Soybean Meal	R6[c]	Mixed by 4 Soybean Meals in China	America and Jilin Province	America and China
Regular Soybean Meal	R7[d]	Mixed by 2 Soybean Meals in China	America and Argentina,	America and Argentina

[a] R4 mixed from four regular soybean meals from Dalian Cereal and Oil Factory, Dalian Huanong Co. Ltd, Liaoning Pulandian Oil Factory, Langfang Huamei Cereal and Oil Food Co. Ltd. in China.
[b] R5 mixed from 3 regular soybean meals from Shanghai Oil Factory No.1, Heilongjiang Zhengda Oil factory, Neimeng Zhalantu Oil Factory.
[c] R6 mixed from 4 regular soybean meals from Beijing Langfang Plant Oil Factory, Jilin Plant Oil Co. Ltd., Jili Plant Oil Co. Ltd and Jinli Jiutai Plant Oil Factory.
[d] R7 mixed from 2 regular soybean meals from Sichuan Jiali Cereal and Oil Industry Co. Ltd. and Guangzhou Dongling Oil Co. Ltd..

by three days total collection of feces and urine). The experiment was then repeated (phase 2) with each diet being fed to a different block of 3 pigs. In trial 1 (phase 3), four experimental diets based on R3, D3, D4 and D5 soybean meal samples were evaluated using the same twelve barrows (initial body weight of 43.55 $\pm$ 3.12 kg). Again, a crossover was conducted, with the experiment being repeated (phase 4) with each diet being fed to a different block of 3 pigs. In experiment 2, nine barrows (Large White $\times$ Landrace $\times$ Pietran) with initial body weight of 49.59 $\pm$ 3.59 kg, were used in the same design as in experiment 1 to test the diets based on soybean meals R4, D6 and D7 during phase 1 and 2. In phase 3 and 4, the same nine barrows, with initial body weight of 56.8 $\pm$ 3.62 kg, were used to test diets based on soybean meals R5, R6 and R7. As a result of the experimental design, each of the 14 diets was fed to six pigs independently resulting in six observations per treatment

Each barrow was housed individually in a metabolism crate located in an air-conditioned room and was assigned to an experimental diet according to its body weight. The collection periods consisted of a 6-day adaptation period followed by a 3-day for total collection of feces and urine (Huo, 1996). During the 6-day adaptation period, the barrows were allowed to attain a feed intake equivalent to 3.5-4.0% of their body weight. Each barrow was fed twice a day at 0800 and 1800 h. Water was provided ad libitum.

On the evening of the sixth day, fecal trays and urine collection vessels containing 10 ml of 10% tartaric acid were placed under the metabolism crates to collect the feces and urine. The samples were collected once daily, weighed and then frozen for future analysis. The fecal samples were dried in a 60°C oven for 48 hours. The oven dried fecal samples were then ground through a 0.45 mm screen and stored in a 4°C refrigerator until analysis.

Chemical Analysis: The methods of the AOAC (1995) were used to measure moisture (MOIS), ash, calcium (Ca), total phosphorus (P), crude protein (CP), ether extract (EE) and crude fiber (CF). Urease activity (UA) was assayed according to China Feed Industry Standard Procedure (GB 8622-88). Protein solubility (PS) was determined by KOH method, according to Dale (1987). Cell wall contents such as neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL), were determined using the methods of Van Soest and Wine (1967), with a sequential procedure involving an amylolytic treatment. Soluble carbohydrate (SCHO), nitrogen free extract (NFE), cellulose (CL) and hemicellulose (HECL) were calculated using the equations of Noblet and Perez (1993). The organic matter content was calculated based on the equation of Noblet and Shi (1993). The gross energy contents of the feed and excreta samples were determined with an Auto Bomb Calorimeter (PARR 1281, U.S.A). Samples of soybean meal were hydrolyzed with 6 N HCl at 110°C for 24 h and analyzed for their amino acid contents using an automatic amino acid analyzer (Hitachi L-8800, Japan). Methionine was determined using formic acid (9 parts of 88% formic acid plus 1 part 30% hydrogen peroxide) protection before acid hydrolysis. Tryptophan analysis was

Table 2: Chemical composition of dehulled and regular soybean meals (dry matter basis)

				Trail 1								Trail 2		
	D1	D2	D3	D4	D5	R1	R2	R3	D6	D7	R4	R5	R6	R7
Gross energy (MJ/kg)	19.46	19.20	19.21	19.89	19.69	19.42	19.07	19.23	19.00	19.42	19.26	19.12	19.25	19.32
Organic matter (%)	94.27	93.56	93.21	92.98	93.49	93.17	93.27	93.40	93.46	92.85	93.26	93.54	93.21	93.41
Ether extract (%)	0.84	0.62	1.08	2.42	2.23	1.98	1.90	0.77	0.70	1.22	1.93	1.36	0.96	2.38
Ash (%)	5.73	6.44	6.79	6.73	6.51	6.83	6.73	6.60	6.81	7.15	6.73	6.46	6.79	6.59
Calcium (%)	0.37	0.37	0.30	0.33	0.36	0.57	0.37	0.30	0.34	0.31	0.33	0.29	0.31	0.36
Phosphorus (%)	0.75	0.81	0.82	0.79	0.76	0.80	0.79	0.83	0.72	0.74	0.71	0.67	0.71	0.68
Crude fiber (%)	5.43	4.28	4.86	3.50	4.39	6.56	5.79	4.59	4.48	3.10	4.73	4.39	4.81	4.79
NDF (%)	10.55	10.14	9.25	11.86	8.22	12.70	12.78	15.23	12.82	12.58	17.85	14.45	13.36	16.80
ADF (%)	5.78	4.72	5.11	4.38	4.03	7.14	5.80	5.69	5.76	4.47	7.15	6.51	7.39	7.61
Hemicellulose (%)	4.77	5.41	4.15	7.47	4.20	5.57	6.98	9.27	7.06	8.10	10.70	7.94	5.97	9.18
Cellulose (%)	5.52	4.49	4.82	4.07	3.86	6.91	4.77	5.57	5.67	4.33	6.81	6.25	7.22	7.28
ADL (%)	0.26	0.23	0.11	0.31	0.17	0.24	1.03	0.12	0.10	0.15	0.35	0.26	0.17	0.36
Nitrogen free extract (%)	46.79	45.80	46.26	45.13	45.28	47.66	47.67	51.36	47.46	48.45	47.98	48.63	46.98	49.47
Soluble Carbohydrate (%)	28.25	28.77	30.08	25.76	30.14	29.03	29.51	28.48	28.39	26.92	23.25	26.21	27.29	25.34
Crude Protein (%)	53.83	54.03	52.80	52.94	52.90	49.46	49.08	48.91	51.28	52.13	50.23	51.52	51.60	48.90
Lysine (%)	3.40	3.42	3.34	3.50	3.33	3.30	3.27	3.22	3.39	3.43	3.23	3.19	3.29	3.23
Methionine (%)	0.62	0.68	0.70	0.79	0.67	0.65	0.64	0.64	0.62	0.67	0.66	0.65	0.63	0.64
Threonine (%)	2.21	2.15	2.06	2.18	2.07	2.13	2.11	1.94	2.15	2.08	2.12	2.09	2.11	2.11
Tryptophan (%)	0.70	0.69	0.56	0.75	0.70	0.66	0.67	0.64	0.61	0.71	0.61	0.66	0.62	0.63
Protein solubility (%)	95.16	94.20	89.22	94.65	89.68	94.53	97.45	96.82	90.50	90.34	93.28	89.67	91.66	96.00
Urease (mg/g/min)	0.03	0.00	0.00	0.06	0.00	0.08	0.06	0.02	0.19	0.00	0.02	0.37	0.11	0.06

Table 3: Ingredient compoistion and nutrient content of the diets used to determine DE and ME in dehulled and regular soybean meals

				Trail 1								Trail 2		
	D1	D2	D3	D4	D5	R1	R2	R3	D6	D7	R4	R5	R6	R7
Ingredient (% as fed)														
Corn starch[a]	62.25	62.75	62.1	62.65	62.50	60.45	59.25	59.72	59.85	60.55	60.65	61.05	62.05	62.05
Soybean meal	33.40	32.90	33.55	33.00	33.25	35.30	36.50	36.03	35.80	35.00	35.00	34.60	33.50	33.50
Soybean oil	1.00	1.00	1.00	1.00	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	0.30	0.30	0.40	0.40	0.40	0.30	0.30	0.30	0.40	0.40	0.40
Dicalcium phosphorus	1.70	1.70	1.70	1.70	1.50	1.50	1.50	1.50	1.70	1.70	1.70	1.70	1.70	1.70
Sodium cholride	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin-mineral Premix[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nutrient content (% dry matter)														
Crude protein	18.13	18.37	18.66	18.21	18.57	18.44	17.72	17.48	18.02	18.07	17.32	17.26	17.28	17.14
Gross energy (MJ/kg)	17.59	17.77	17.38	17.46	17.31	17.49	17.72	17.32	17.54	17.49	17.62	17.54	17.62	17.54
Calcium	0.67	0.67	0.65	0.70	0.67	0.67	0.68	0.64	0.67	0.68	0.68	0.68	0.68	0.67
Total Phosphorus	0.73	0.76	0.67	0.70	0.80	0.71	0.69	0.66	0.76	0.80	0.78	0.77	0.78	0.80
Neutral detergent fiber	3.52	3.38	3.14	4.30	2.80	4.41	4.72	5.52	4.23	4.18	6.16	5.01	4.51	5.56
Crude fiber	1.82	1.43	1.67	1.50	1.49	2.30	2.15	2.04	1.25	1.03	1.65	1.51	1.62	1.59

Notes: [a]Purchased from Beijing Red Star Starch Company, with gross energy 3.81 kcal/g, crude protein 0.44%, calcium 0.074% and total phophate 0.074%; bPremix provided the following per kg of complete diet: vitamin A, 55121U; vitamin D3, 2200 IU; vitamin E, 6.1 IU; vitamin B 12, 27.6 ug; riboflavin, 5.5 mg; D-pantothenic acid, 13.8 mg; niacin, 30.3 mg; choline chloride, 551 mg; Mn 100 g; Fe, 100 mg; Zn, 100 mg; Cu, 234 mg; I, 1.4 mg; Se, 0.3 mg; Co, 1.0 mg.

determined using high performance liquid chromatography (Shimadzu LC-10A, Japan) after lithium hydroxide (4.2 N LiOH) hydrolysis (20 h at 110°C) according to method GB/T18246-2000 of the Chinese Quality Technical Supervisory Bureau (2000). All chemical analyses were performed in duplicate.

Calculation of DE and ME: Cornstarch was assumed to be 100% digestible (Zhang, 2001; Noblet and Perez, 1993) and metabolisable and therefore its DE and ME values were assumed to be the same and a value of 15.06 MJ/kg was used in all calculations. For soybean oil, DE and ME values of 36.65 MJ/kg and 35.15 MJ/kg, respectively were used (NRC, 1998). The DE and ME concentrations of the soybean meal samples were calculated by difference (Ragland *et al.*, 1998) as follows:

DE (MJ/kg) = (intake of diet x GE of diet) – (output of feces x GE of feces x 60°C % DM of feces) – (15.06 x intake of diet x level of cornstarch) – (36.65 x intake of diet x level of soybean oil)/(intake of diet /level of soybean meal in diets).

ME (MJ /kg) = (intake of diet x GE of diet) – (output of feces x GE of feces x 60°C % DM of feces) – (output of urine x GE of urine) – (15.06 x intake of diet x level of cornstarch) – (35.15 x intake of diet x level of soybean oil)/(intake of diet /level of soybean meal in diets).

Statistical Analysis: The statistical analysis was conducted generating means and standard deviations for all chemical analysis data. Analysis of variance was conducted using the General Linear Model Procedure as described in the statistical package (SPSS 10.0, 2000). The analysis of variance was conducted using the model ($Y = \mu + P$), where P is the processing (dehulled and regular) effect and μ is a correction factor on ME due to individual animal

Table 4: Digestibility of dry matter and the balance of energy and nitrogen in dehulled and regular soybean meals

□	Trail 1								Trail 2					
	D1	D2	D3	D4	D5	R1	R2	R3	D6	D7	R4	R5	R6	R7
Dry matter														
Dry matter intake (g/d)	1350.1	1189.1	1545.6	1514.1	1568.5	1307.5	1196.2	1531.3	1854.5	1521.4	1483.5	1552.9	1643.6	1722.6
Dry matter in feces (g/d)	71.74	83.63	85.13	87.71	71.49	95.79	87.90	100.16	121.24	94.13	132.47	115.47	130.45	178.03
Dry matter digestibility (%)	94.68	92.97	94.48	94.16	95.44	92.67	92.67	93.37	93.35	93.83	91.05	92.57	91.99	93.03
Nitrogen balance														
Nitrogen intake (g/d)	39.18	34.94	46.14	44.13	46.6	38.57	33.91	42.31	53.48	44.24	41.83	44.64	45.54	46.34
Nitrogen in feces (d/g)	2.88	3.01	3.09	3.18	2.55	3.49	3.40	3.84	4.41	3.84	4.75	4.65	5.28	4.79
Nitrogen in urine (g/d)	12.07	10.51	13.19	13.63	16.45	12.16	11.44	12.44	18.79	15.5	12.667	13.39	14.53	14.89
Nitrogen digestibility (%)	92.64	91.41	93.32	92.78	94.54	90.93	90.06	90.94	91.67	91.35	88.67	89.69	88.39	89.41
Retained (% of intake)	62.86	61.63	64.87	62.03	59.23	59.34	56.31	61.80	56.54	56.34	58.28	59.79	56.4	57.49
Retained (% of absorbed)	67.85	67.45	69.49	67.49	62.67	65.26	62.56	67.96	61.67	61.67	65.71	66.66	63.76	64.29
Emergy balance														
Energy intake (MJ/d)	24.95	21.13	26.86	26.46	27.15	22.87	21.20	26.21	32.53	26.85	26.26	27.64	28.96	30.21
Energy infeces (MJ/d)	1.09	1.19	1.09	1.24	0.98	1.34	1.26	1.29	1.5	1.27	1.74	1.66	1.83	1.63
Energy in urine (MJ/d)	0.54	0.41	0.44	0.44	0.45	0.56	0.51	0.62	1.18	0.63	0.99	0.72	0.72	0.69
Absorbed (% of intake)	95.63	93.43	95.95	95.28	95.31	94.12	94.07	95.09	96.39	95.27	93.66	94.49	94.89	93.48
Retained (% of intake)	93.47	92.44	94.32	93.61	91.69	91.65	91.68	92.71	94.72	92.94	91.24	92.19	91.69	90.62
Retained (% of absorbed)	93.69	94.3	95.27	95.08	95.13	92.96	93.46	93.30	90.15	89.83	89.83	93.12	93.02	93.23
Digestible energy (MJ/kg)	15.55	15.34	14.84	15.05	14.78	15.03	15.11	14.42	15.85	15.003	15.03	14.79	15.6	15.11
Metabolisable energy (MJ/kg)	14.57	14.46	14.14	14.31	14.06	13.97	14.12	13.46	14.29	13.98	13.98	13.79	14.16	13.81
ME/DE ratio (%)	93.69	94.3	95.27	95.08	95.13	92.96	93.46	93.3	90.15	93.02	93.23	93.23	90.74	91.38

Table 5: Average nutrient content of dehulled and regular

□	Dehulled Soybean meal				Regular soybean meal				
	Mean	SD	Min	Max	Mean	SD	Min	Max	P
Gross energy (MJ/kg)	19.41	0.32	19.00	19.95	19.23	0.11	19.07	19.42	0.19
DE (MJ/kg)	16.94	0.46	16.41	17.55	16.79	0.35	16.19	17.34	0.60
ME (MJ/kg)	15.85	0.34	15.34	16.41	15.54	0.22	15.10	15.74	0.06
ME/DE (%)	93.84	1.83	90.20	95.3	92.58	1.07	90.70	93.50	0.14
Organic mater (%)	93.40	0.44	92.85	94.26	93.32	0.13	93.17	93.54	0.66
Ether extract (%)	1.30	0.73	0.62	2.43	1.61	0.59	0.77	2.38	0.40
Ash (%)	6.59	0.45	5.73	7.15	6.67	0.12	6.46	6.83	0.66
Calcium (%)	0.34	0.02	0.30	0.37	0.36	0.09	0.29	0.57	0.57
Phosphorus (%)	0.77	0.03	0.72	0.82	0.74	0.06	0.67	0.83	0.36
Crude fiber (%)	4.29	0.7	3.10	5.42	5.09	0.78	4.39	6.56	0.08
NDF (%)	10.77	1.73	8.22	12.82	14.73	2.00	12.70	17.85	0.01
ADF (%)	4.89	0.68	4.03	5.77	6.75	0.76	5.69	7.61	0.01
Hemicellulose (%)	5.88	1.64	4.15	8.10	7.94	1.89	5.57	10.70	0.05
Cellulose (%)	4.68	0.69	3.86	5.67	6.39	0.93	4.77	7.28	0.01
ADL (%)	0.19	0.07	0.10	0.31	0.36	0.30	0.12	1.03	0.18
NFE (%)	46.47	1.18	45.26	48.65	48.53	1.47	46.98	51.36	0.01
Soluble carbohydrate (%)	28.45	1.59	25.83	30.14	27.01	2.24	23.25	29.51	0.19
Crude protein (%)	52.46	0.94	51.28	54.03	49.95	1.18	48.90	51.60	0.01
Lysine (%)	3.40	0.06	3.30	3.5	3.24	0.03	3.20	3.30	0.01
Methionine (%)	0.68	0.05	0.62	0.79	0.64	0.08	0.63	0.66	0.16
Threonine (%)	2.12	0.06	2.06	2.21	2.08	0.06	1.94	2.13	0.24
Tryptophan (%)	0.67	0.06	0.60	0.80	0.64	0.02	0.90	0.70	0.26
Proten solubility (%)	92.00	2.62	89.22	95.15	94.20	2.84	89.67	97.45	0.16
Urease activity (mg/g/min)	0.04	0.06	0.00	0.19	1.10	0.12	0.02	0.37	0.27

difference and treatment, respectively. The t-student test was used to detect differences among data sets. The correlation coefficients between the DE and ME values and chemical constituents in soybean meals were calculated according to the procedure of SPSS10.0 (2000). Linear regression equations for predicting DE and ME values of soybean meals from chemical components were calculated according to the stepwise procedure using backward step and forward step procedures. Equations with the lowest residual standard deviation (RSD) or those indicating the limits of some chemical criteria were presented. The residuals for each cell were determined and any data that differed by more than 3.4 standard deviations from its expected value was removed and the RSD re-estimated from the remaining data.

Results and Discussion

DE and ME of Dehulled and Regular Soybean Meals: Digestible energy and metabolisable energy of seven dehulled and seven regular soybean meals were evaluated by nitrogen and energy balance (Table 4). There were differences in DE and ME values among the different sources of soybean meal ($P<0.05$), with energy values higher for dehulled compared with regular soybean meal (Table 5). For the dehulled varieties of soybean meal, the DE ranged from 16.41 to 17.55 MJ/kg DM, while ME ranged from 15.34 to 16.41 MJ/kg DM. For the regular varieties of soybean meal, the DE ranged from 16.19 to 17.34 MJ/kg DM, while the ME ranged from 15.10 to 15.74 MJ/kg DM.

The average values of DE and ME were 16.91 MJ/kg DM and 15.85 MJ/kg DM for dehulled soybean meals, 16.79 MJ/kg DM and 15.54 MJ/kg DM for regular soybean meals, respectively (Table 5). These results are similar to NRC (1998) values, but differ from the results of Rudolph *et al.* (1983) and Ragland *et al.* (1998). According to NRC (1998), DE and ME values of dehulled soybean meal with 47.5% crude protein were 17.13 MJ/kg DM and 16.22 MJ/kg DM, and those of regular soybean meal with 43.8% crude protein were 15.88 MJ/kg DM and 14.94 MJ/kg DM, respectively.

Rudolph *et al.* (1983) reported that the DE and ME values were 15.55 MJ/kg and 15.47 MJ/kg DM for dehulled soybean meals with 48.5% crude protein, and those of regular soybean meals with 44.0% crude protein were 15.47 MJ/kg DM and 15.10 MJ/kg DM (based on 88% dry matter in soybean meals). In the study of Rudolph *et al.* (1983), 6% cellulose was added and the crude protein levels were 12% for the semi-purified diets. Therefore, the lower values reported may be related to the levels of cellulose and crude protein in the diets. A higher protein level in the diets would improve the digestibility of energy and therefore increase the DE as well as the ME values. Furthermore, higher cellulose levels in diets would reduce the digestibility of nutrients (Morgan *et al.*, 1984).

Ragland *et al.* (1998) reported that the DE and ME values in dehulled soybean meal with 49.5% crude protein were 18.10 MJ/kg DM and 17.57 MJ/kg DM, respectively. This was higher than both NRC (1998) and the current study. However, in Ragland *et al.* (1998), their cornstarch-soybean meal diet had crude protein levels of 17% and they added 15% dextrose. The crude protein level and palatability of diets are important factors for the digestibility of nutrients. Adding dextrose would improve the palatability of the diet, which may have caused the difference.

In the current research, the average DE and ME values of dehulled soybean meals were higher (0.12 MJ/kg DM and 0.31 MJ/kg DM) than for regular soybean meals. There were significant differences between dehulled soybean meals and regular soybean meals in ME ($P<0.1$), but no significant difference in DE ($P>0.05$). These differences may be related to the higher crude fiber content in regular soybean meals than in dehulled soybean meals, which were 5.09% and 4.29%, respectively. The fiber fraction of the diet would have a significant negative effect on the digestibility of nutrients. The correlation coefficient between DE and NDF was -0.550; and for ME, it was -0.799 (Table 6). King and Tavernier (1975) reported that the correlation coefficient between DE and NDF was -0.770. The study of Ma (2001) indicated that the fiber fractions were mostly insoluble, which accelerated the rate of digesta transit through the gut and could reduce the digestibility and metabolism of nutrients (including energy). The mechanism of the effects of fiber on nutrient digestibility appears to be an increase in the viscosity of the digesta, which reduces reaction rates between enzymes and their substrates (Ehle *et al.*, 1982).

Establishment of Prediction Equations from Chemical Components of Soybean Meals: Prediction regression equations of the DE and ME values from chemical components in the varieties of soybean meals were established using multiple regression analysis with the stepwise and backward step procedure. The R^2 coefficient and residual standard deviation (RSD) of the equations are presented (Table 7). RSD indicates the equation accuracy when adding a chemical constituent. The R^2 was a decision coefficient and over statement could be avoided by the coefficient r (Noblet and Perez, 1993; Fernandez and J?rgensen, 1986). The RSD was useful for regression judgment and choice of predictors. The smaller the RSD value, the higher the accuracy for the regression equation (Noblet and Perez, 1993; Morgan and Whittemore, 1987; Zhang and Wu, 1981). According to this principal, four equations (No. 1 to No. 4) for predicting DE values and four equations (No. 5 to No.8) for predicting ME values were confirmed, which had an R^2 higher than 0.9 and RSD values less than 0.1 (Table 7).

Our results indicated that use of the fiber fractions, minerals, crude protein and protein solubility in soybean meal could improve the accuracy in predicting DE and ME values. The numbers and integration fashion of dependent variables, which were adopted, can affect the accuracy of the prediction equation (Fernandez and Jorgensen, 1986). Interestingly, the PS value as a predictor could be used to predict DE values through equations No. 2. and No. 3 (Table 7). Therefore, the PS values, as an indicator of overcooking in soybean meal (Araba and Dale; 1987), could suggest the effect of heat processing on soybean meal DE and ME. Araba and Dale (1987) reported that over-heating could increase the excretion of amino acids and peptides in the urine and negatively effect the energy utilization.

Table 6: Correlation coefficients between chemical components of soybean meals and their DE and ME values

	OM	SCHO	CP	ASH	CA	P	CF	EE	PS	NDF	ADF	ADL	NFE	DE	ME
OM	-	.108	.675	-.192	-.484	-.596	-.600	.094	.083	-.454	-.779*	.295	-.525	.432	.610
SCHO		-	.104	-1.08	.084	-.109	.506	-.265	-.442	-.399	.160	-.323	-.500	.315	.280
CP			-	-.367	-.338	-.415	-.602	-.099	-.455	-.789	-.720*	-.342	-.815*	.493	.771*
ASH				-	.099	.597	-.059	.499	-.033	.214	-.013	.179	.088	-.549	-.483
CA					-	-.136	.710	.302	.076	.116	.684	.068	-.082	.326	.063
P						-	-.081	-.379	.155	.501	.197	-.148	.524	-.626	-.685
CF							-	-.014	.130	.217	.882**	.352	.252	.292	-.027
EE								-	-.033	-.069	-.138	.312	-.361	-.117	-.035
PS									-	.791*	.355	.611	.514	-.051	-.307
NDF										-	.562	.271	.846*	-.550	-.799*
ADF											-	.205	.496	.020	-.328
ADL												-	.085	.242	.085
NFE													-	-.601	-.827*
DE														-	0.914**
ME															-

Table 7: Predicition equations for digestible and metabolisable energy (MJ/kg DM) in soybean meals

No.	Prediction equations	R^2	RSD
1	DE=11.46+0.13CP + 0.33CF - 0.43 ASH	0.918*	0.094
2	DE = 0.22CP + 0.41CF + 0.05 PS - 1.37	0.935**	0.075
3	DE = 0.25OM + 0.18CP + 0.37CF + 0.37CF + 0.037PS - 20.71	0.955*	0.051
4	DE = 25.30 = 0.70 ASH + 2.59 CA - 0.22 EE + 0.41 ADL - 0.099 NFE	0.980**	0.025
5	ME = 4.28 + 0.19CP + 0.29 CF	0.916**	0.840
6	ME = 6.18 + 17CP + 0.26CF-0.19 ASH	0.938**	0.626
7	ME = 8.17 + 0.17CP + 0.255 CF - 3.02P	0.951**	0.049
8	ME = 24.9 - 0.653 ASH + 0.123 ADF- 0.155 NFE - 0.058 SCHO	0.981**	0.019

* F-testing of R^2 ($P<0.05$) **F-testing of R^2 ($P<0.01$)

Comparison of the Determined DE of Soybean Meals in Trial 2 with Predicted DE from Current and Published Equations: The DE values of six varies of soybean meals were determined in Trial 2. The predicted DE values were calculated by using the equations (No. 1, 2, 3 and 4, Table 7) generated in the present study and three equations (Ewan, 1989; Noblet and Perez, 1993), which were recommended by NRC (1998) (Table 8).

The predicted DE values of the six soybean meal samples by equation No.1, 2, 3 and 4 were lower than their determined DE values in this research ($P<0.05$). However, the difference between the predicted and determined DE values in this study were 3.21, 4.13, 3.93 and 3.46%, respectively (Table 8) for the different equations, which are less than the differences using NRC equations (9.40, 9.10 and -5.39% respectively by NRC1, NRC2 and NRC3). In this study, the difference between predicted DE and determined DE values may be caused by the difference in trial conditions (mainly due to difference in the age of animals). Nevertheless, there were significant correlations between predicted DE values and the determined DE values calculated using equation No.4 and No.2, with the correlation coefficients being 0.712 and 0.652 respectively. Correlation coefficients between determined DE and predicated DE using equations No.1 and No.3 were 0.479 and 0.554, respectively. They were not used for predication purpose.

The correlation equations between the current and published predicted DE values and determined DE in trial 2 were established as follows:

DE (Determined) = -0.3428 (PDE –NRC3) + 23.688, r = 0.848;

DE (Determined) = 0.3287 (PDE 4) + 10.80, r = 0.719;

PDE 4 = -0.5206 (PDE-NRC3) + 26.399, r = 0.589;

PDE 2 = -0.565 (PDE-NRC3) +27.063, r = 0.716;

Data generated in this study suggested that predicted DE of different soybean sources by equation No.2 and No.4 were closely related with the predicated values by equation NRC3. The smaller difference between predicated DE and determined DE of this investigation in comparison with those generated by NRC method indicated that prediction equations No.4 and No.2 (Table 7) could be used to predict DE value in different soybean meal sources more specifically and precisely in practical situations.

Comparison of the Determined ME of Soybean Meals in Trial 2 with Predicted ME from Current and Published Equations: The predicted ME values of six soybean meals in Trial 2 (Table 9) were calculated by equations No. 5, 6, 7 and 8 (Table 7) and three published equations from Noblet and Perez (1993).

Table 8: Predicted digestible energy (MJ/kg DM) of soybean meals in trial 2

□	□	□	Predicted DE (MJ/kg DM)			□	□	□
	Determine DE		Using current equations				Using published equations	
□	(MJ/kg)	PDE1	PDE2	PDE2	PDE4	NRC1[A]	NRC2[b]	NRC3[c]
D6	17.55	16.47	16.30	16.32	16.56	15.72	15.54	17.74
D7 •	16.51	15.97	15.91	15.87	16.05	15.66	15.84	18.10
R4	16.78	16.45	16.32	16.36	16.37	15.32	14.90	17.81
R5	16.62	16.62	16.27	16.39	16.47	15.27	15.42	18.07
R6	17.34	16.62	16.56	16.55	16.51	15.33	15.65	17.73
R7	16.94	16.36	16.20	16.27	16.28	15.36	15.15	17.80
CV	0.024	0.015	0.013	0.014	0.011	0.013	0.022	0.009
Mean	16.96	16.41	16.26	16.29	16.37	15.36	15.42	17.87
MJ/kg Difference		0.55	0.70	0.67	0.59	1.60	1.54	(0.91)
% Difference		3.21	4.13	3.93	3.46	9.40	9.10	-5.39
T-test								
P values		0.015	0.003	0.005	0.005	0.004	0.001	0.010
r		0.479	0.652	0.554	0.712	0.640	0.092	0.849
R^2		0.918	0.935	0.955	0.980	0.880	0.920	0.850
RSE		0.094	0.075	0.051	0.025			
N	□	3	3	4	5	4	4	3

[a]NRC1: DE = 0.848 GE + 2 SCHO% - 16 ADF% - 174, R^2=0.87; Ewan (1989(

[b]NRC2: DE = 949 + 0.789 GE - 43 ASH % - 41 NDF %, R^2 = 0.91; Noblet and Perez (1993)

[c]NRC3: DE = 4151 - 122 ASH % + 23 CP% + 38 EE% - 64CF%, R^2 = 0.89; Noblet and Perez (1993)

Table 9: Predicted metabolisable energy (MJ/kg DM) of soybean meals in trial 2

□	□	□	□ Predicted ME (MJ/kg DM)				□	□
	Determined ME		Using current equations			Using published equations		
	(MJ/kg)	PME5	PME6	PME7	PMER8	Noblet1[a]	Noblet2[b]	Noblet3[c]
D6	15.81	15.59	15.52	15.79	15.56	15.91	15.31	15.11
D7	15.34	15.35	15.24	15.53	14.94	16.23	15.34	15.67
R4	15.61	15.46	15.43	15.70	15.40	16.04	14.78	15.27
R5	15.49	15.61	15.61	15.95	15.57	16.24	15.33	15.36
R6	15.74	15.75	15.67	15.96	15.79	15.90	15.30	15.21
R7	15.48	15.22	15.23	15.58	15.44	16.10	15.00	15.34
CV	0.012	0.012	0.011	0.011	0.018	0.009	0.015	0.012
Mean	15.58	15.50	15.45	15.75	15.45	16.07	15.18	15.33
MJ/kg Difference		0.08	0.13	(0.17)	0.13	(0.49)	0.40	0.25
% Difference		0.53	0.84	-1.12	0.83	-3.15	2.58	1.62
T-test								
P values		0.254	0.083	0.047	0.161	0.013	0.020	0.150
R		0.663	0.671	0.579	0.760	0.920	0.006	0.932
R2		0.916	0.938	0.951	0.981	0.870	0.910	0.890
RSD		0.840	0.626	0.049	0.019	0.343	0.292	0.385
N	□	2	3		3	3	3	4

[a]Noblet1: ME = 4168 - 123 ASH % +14 CP% + 41 EE% - 61CF %, R^2=0.8, RSD = 82; Noblet and Perez (1993)

[b]Noblet2: ME = 4194 - 92 ASH % + 10CP% + 41 EE - 35 NDF %, R^2 = 0.392, RSD = 70; Noblet and Perez (1993)

[c]Noblet3: ME = 1255 + 0.712GE (MJ/kg DM) - 85 ASH % - 66CF % R^2 = 0.85, RSD = 92; Noblet and Perez (1993)

The results (Table 9) showed that a significant relationship between the determined ME and the predicted ME values ($P<0.05$). The correlation equations between the current predicted ME values as well as the published and the determined ME values in Trial 2 were established as follows:

ME (Determined) =33.001 - 1.084 (PME - Noblet 1), r = 0.920;

ME (Determined) = 28.608 - 0.850 (PME - Noblet 3), r = 0.932;

ME (Determined) = 6.250 + 0.602 (PME5), r = 0.663;
ME (Determined) = 5.8029 + 0.6327 (PME6), r = 0.671;
ME (Determined) = 8.2961 + 0.4713(PME8), r = 0.760;
ME (PME 7) =2.2974 + 0.8682(PME5); r = 0.918;
ME (PME 7) = 0.8592 + 0.9639(PME6); r = 0.982;
ME (PME 6) = 0.9857 + 0.9334(PME5); r = 0.939;
ME (PME 8) = 0.8592 + 0.9639(PME7); r = 0.982;
ME (PME 6) = 7.3586 + 0.5237(PME8); r = 0.804;
PME-Noblet 3 = 25.165 - 0.6368 (PME 6); r = 0.617;
PME-Noblet 3 = 24.178 - 0.5729 (PME 8); r = 0.852.

The determined ME values were very closely related with the four current predicted ME values with the differences ranging from -0.08 ~ 0.17 MJ/kg DM, with none of the differences being significant ($P>0.05$; Table 9). This result also suggested that ME values could be predicated more accurately than DE values. Currently, not much research data is available predicting ME in feedstuffs. One of the few studies showed that the difference between the determined ME values and three published predicted ME values by Noblet 1, Noblet 2 and Noblet 3 were -0.49~0.25 MJ/kg DM (about -3.15%~2.58% of the determined ME values). There were no significant differences among the determined ME, the current predicated ME and the published predicated ME ($P>0.05$). Three published predicted ME values were closely related to the determined ME values and were similar to the four current predicted ME values. The results showed the current predicted equation for ME using chemical composition in soybean meals could be used to the predicted ME in soybean meals in practice.

Selecting the Best Equation: The effectiveness of a predication equation largely depends on its accuracy and feasibility. In this research, the predication equations were established by using 2-5 predictors (Table 7).
The following criteria for selecting the best equation were considered. Firstly, there should be no significant differences between the predicted and the determined values of DE and ME value. Secondly, the correlation coefficient between the determined values and predicted values must be high. Thirdly, a constituent was retained in an equation only if its inclusion reduced the residual standard deviation (RSD) by a minimum of 0.02 (Wainman *et al.*, 1981). Fourth, the R^2 value had to be increased by 0.02 with addition of a predictor. In general, a good prediction equation should also include chemical constituents that could be easily measured and analyzed (Zhang and Wu, 1981; Yang, 1979).
According to these criterion and comparison of predicted DE values with determined values, the best prediction equation (No. 4) was achieved when ASH, CA, EE, ADL, and NFE were considered. The correlation coefficients were 0.652 and 0.5887 for predicated DE with determined DE values and the predicted NRC3 DE values (equation No. 1 and No. 3) respectively. The best DE prediction equation was equation No.4 (R^2 0.980; RSD, 0.025).
The measurement of ME seems to be a better evaluation indicator over DE by accounting for urinary losses (Morgan and Whittemore, 1982). Equations for estimating ME values from chemical components were showed in Table 7 (Equation No.5 to No.8). Based on the criteria, the predicting equation of ME values (Equation No.8; R^2, 0.981; RSD, 0.019) which included ASH, ADF, NFE, and SCHO, was considered suitable for practical uses in the field.

Implications: The DE and ME values of different varieties of soybean meals were affected by the dehulling process. The ME values of the dehulled soybean meal were higher than those of the regular soybean meal ($P<0.1$). More accurate prediction equations for DE ($R^2>0.90$ and RSD<0.10) and ME were established based upon chemical composition. There was no significant difference between the determined and predicted DE and ME values ($P>0.05$). This indicates that prediction equations are suitable to replace animal trials to predict DE and ME values in soybean meal for practical purposes.

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