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NUTRIENT CONTENT OF SOYBEAN MEAL FROM DIFFERENT ORIGINS BASED ON NEAR INFRARED REFLECTANCE SPECTROSCOPY

Kandungan Nutrisi dari Bungkil Kedelai Berasal dari Negara Berbeda Berdasarkan Near Infrared Reflectance Spectroscopy

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ABSTRACT

Near infrared reflectance spectroscopy (NIRS) has become common techniques to estimate chemical composition of feed ingredient for poultry. Two experiments were performed: first was to compare the capability of NIRS system from three laboratories (E, A and T) to measure nutrient composition of soybean meal (SBM); and the second was to evaluate nutrient composition and quality of 59 samples of SBM from Argentine, Brazil and US using NIRS from T-laboratory. Thirty samples of SBM was used in the first study and the result showed that all NIRS systems were able to estimate proximate, amino acids, metabolizable energy (ME) and carbohydrate components. The second experiment indicated that there were some differences in proximate composition (especially protein), total amino acids and digestible amino acids among SBM from different origins. Brazilian SBM had 2% higher protein and amino acid compared to US or Argentine SBM ($P<0.05$). However, US SBM had slightly higher ME (20 and 40 kcal kg^{-1}) compared to Brazilian and Argentine SBM, respectively. ME is positively correlated with protein (0.50) and fat content (0.58) but negatively correlated with fiber (-0.74) and NSP (-0.61). Stepwise regression analysis demonstrated that ME can be estimated using equation ME (kcal kg^{-1}) = 75.7 – 21.0 x Fiber + 87.4 x Fat + 32.9 x Protein + 17.6 x NFE with reasonable accuracy (R^2 = 0.995). In conclusion NIRS can be used to estimate nutrient content of SBM. Brazilian SBM has higher protein and amino acids, but US SBM has slightly higher ME content.

[**Keywords**: energy value, NIRS, nutrient composition, soybean meal]

ABSTRAK

Near infrared reflectance spectroscopy (*NIRS*) *merupakan metode umum untuk mengukur komposisi kimia bahan pakan unggas. Dua percobaan telah dilakukan dengan tujuan percobaan pertama untuk membandingkan kemampuan NIRS dari tiga perusahaan* (*E, A, dan T*) *untuk mengukur komposisi gizi bungkil kedelai* (*BK*), *dan percobaan kedua untuk membandingkan komposisi gizi dan kualitas 59 contoh BK dari Argentina, Brasil, dan Amerika Serikat* (*AS*) *dengan NIRS laboratorium T. Tiga puluh contoh BK digunakan dalam percobaan pertama dan hasilnya menunjukkan bahwa tiga sistem NIRS yang diuji mampu menganalisis kandungan proksimat, asam amino, energi metabolis, dan komponen karbohidrat BK dengan perbedaan yang relatif kecil. Sementara hasil penelitian percobaan kedua dengan menggunakan NIRS dari laboratorium-T menunjukkan terdapat perbedaan komposisi proksimat* (*terutama protein*)*, asam amino total dan tercerna pada BK dari tiga negara. BK Brasil mempunyai protein dan asam amino 2% lebih tinggi daripada BK AS dan Argentina* ($P<0.05$). *Namun, BK AS mempunyai kandungan energi metabolis* (*ME*) *lebih tinggi* (*20 dan 40 kkal* kg^{-1}) *dibandingkan BK Brasil dan Argentina. Kandungan ME BK berkorelasi positif dengan kandungan protein* (*0,50*) *dan lemak* (*0.58*)*, tetapi berkorelasi negatif dengan kandungan serat* (*-0.74*) *dan NSP* (*-0.61*)*. ME BK dapat dihitung dengan persamaan regresi ME* (*kkal* kg^{-1}) *= 75,7 – 21,0 x Serat + 87,4 x Lemak + 32,9 x Protein + 17,6 x NFE dengan* R^2 *= 0,995. Sebagai kesimpulan NIRS dari tiga laboratorium mampu menganalisis kandungan gizi BK. BK Brasil mempunyai protein dan asam amino lebih tinggi sedangkan BK AS mempunyai ME lebih tinggi.*

[**Kata kunci**: bungkil kedelai, komposisi gizi, nilai energi, NIRS]

INTRODUCTION

Soybean meal (SBM) is one of major feed ingredients for feeding livestock particularly for monogastric animal, such as poultry and swine. Soybean meal chemical composition is affected by two major factors including the origin of soybean and processing conditions at the crushing plant where soybean is processed to produce oil and SBM. Chemical composition of soybean would be affected by many factors including bean genotype, planting area, soil type, agricultural practices, and environmental conditions during the growing season and storage of soybeans (Westgate et al. 2000; Karr-Lilienthal et al. 2004) and consequently the crude protein (CP), fiber, sugars and mineral content and the nutritive value of the SBM (Grieshop et al. 2003; Ravindran et al. 2014; García-Rebollar et al. 2016). Processing condition at crushing plants such as separation of hulls, completeness of extraction and temperature of toasting would influence not only chemical composition but also protein qualities (Waldroup et al. 1985; Parsons et al. 1992).

The United States (US), Brazil (BRA), and Argentina (ARG) are the dominant suppliers in the global SBM market. Variations of SBM composition and quality from different origins in terms of CP, proximate analysis, and *in vitro* protein quality measurements have been reported by several publications (Thakur and Hurburgh 2007; De Coca-Sinova et al. 2008; Frikha et al. 2012). Although the CP and nutrient composition data are useful in identifying differences between SBM samples, they are not directly related to animal growth. Metabolizable energy (ME) and amino acid (AA) digestibility are parameters that have a large effect on animal performance and therefore it is essential for nutritionists to ensure that the apparent metabolizable energy (AME) and digestible AA contents are considered in the selection of SBM to meet the desired specifications. Losada et al. (2010) attempted to estimate quality of oilseed and meal using chemical composition and *in vitro* method and may provide reliable data on value of SBM for animals.

Most of chemical composition of SBM can be measured by wet chemistry system in the laboratories. However, with the advancement of technologies, near-infrared reflectance spectroscopy (NIRS) has been the method of choice in feed mill and export laboratories to provide a quick and reliable analysis without chemical. Consequently, it can reduce cost and time of feed evaluation with respect to *in vivo* trials. However, its capability to estimate feed energy contents must be validated with *in vivo* determined values. Previous studies have shown that NIRS allows for successful estimation of major chemical constituents of feeds and the digestion efficiency in several animal species (Farrell 1999; Roberts et al. 2004). The NIRS method can also predict the energy values of complete poultry feeds (Valdes and Leeson 1992a), feed ingredients (Valdes and Leeson 1992b), starch- and fiber-concentrated ingredients including fat (Valdes and Leeson 1994). NIRS method is also able to estimate ME and calibrated not only for cockerels (Losada et al. 2010) but also for broiler chickens (Owens et al. 2009). However, the AME values of several raw materials were not well predicted from NIRS, neither when using specific equations nor when extrapolating equations derived from complete diets (Valdes and Leeson 1992b; Valdes and Leeson 1994).

Most large end users mainly feed mills have been analyzing incoming ingredients including SBM using NIR system placed on site. The machines can analyze proximate composition of various ingredients as they are calibrated locally. However, feed mills still have to rely upon commercial companies (E, A and T) to analyze amino acids and metabolizable energy of samples as only those companies are able to provide calibration while feedmill NIRS do not have capacity to develop a calibration to measure such components. Most of feed mills believe that amino acids analysis provided by service companies are reliable and can be used in their feed formulation. However, there is no report on the accuracy of service laboratories and comparison among them.

Nutrient composition data on SBM are critical to determine its acceptance in ration formulation. Therefore, following comparison of NIRS system from three different laboratories, a survey has been conducted to collect all SBM imported to Indonesia. These samples were analyzed for complete nutrient contents by NIRS and were evaluated based on their origin.

MATERIALS AND METHODS

Experiments were conducted in two stages. First experiment was designed to compare capability of NIRS laboratories belong to feed additives companies (E, A and T) to measure nutrient composition of SBM samples, while the second experiment was performed to measure nutrient composition and qualities of SBM from different origins imported to Indonesia.

Experiment I. Comparison of Three Different NIRS to Measure SBM Composition

Sample Collection

Every shipment of SBM delivered to Indonesia in 2018 had been collected either from the port on arrival or when SBM was delivered from the port to feedmills and importer warehouses. The SBM shipment could be from bulk or containers shipment. The samples were collected by quality assurance personnel of feed mills or importers according to their existing techniques. Half kilogram samples were put in a plastic bag and split into two portions, one portion for analysis and other portion was kept in freezer as reference samples. There were 62 samples of SBM collected from March to September 2018 comprised 23 samples from Argentina, 20 samples from Brazil, 16 samples from US and 3 samples from Paraguay.

NIRS Analysis

Thirty samples of SBM collected from imported SBM were analyzed by NIRS system of E, A and T laboratories. The samples were ground to pass 0.75 mm screen. Samples sent to A and E laboratory were analyzed using Foss machine model NIRS DS2500, while samples sent to T were analyzed using Foss machine model XDS.

Experiment II. Nutritional Composition of SBM from Different Origins

Following the evaluation of NIRS from different service laboratories, SBM collection was continued by taking sample in every shipment to Indonesia. A total of 62 samples of SBM was collected and stored in a freezer (-18°C) until ready for analysis. SBM samples were identified based on origin of SBM including USA, Brazil, Argentina and Paraguay. Since number of samples from Paraguay was too small, its result was not included in this report.

All SBM samples were analyzed by Master Laboratory of T and NIRS system has been calibrated by T. The samples were ground to pass 0.75 mm screen using Retsch grinder type ZM 200. The analysis was done for proximate (moisture, crude protein, crude ash, crude fat, crude fiber), nitrogen free extract (NFE), neutral detergent fiber (NDF), starch, sugar, non-starch polysaccharide (NSP), total amino acids, digestible amino acids (poultry), and metabolizable energy (ME) for poultry.

Statistical Analysis

Analytical data from experiment I were subjected to analysis of variance using SAS 9.1 (SAS Institute 2009) with the laboratories as the independent factor. When significant differences were observed, further analysis was conducted using Least Square Differences.

In the second experiment, the SBM composition data analyzed by NIR system from T were analyzed statistically using Proc GLM SAS 9.1 to differentiate the origin. Any significant difference among the origin was further analyzed using Duncan multiple range test. Chemical composition data of soybean meal including proximate composition (protein, fat, ash, crude fiber), carbohydrate components such as starch, sugars, NDF, NSP, and NFE were correlated with ME for poultry using Pearson correlation and all data were subjected to regression analysis using PROC REG by SAS 9.1 (SAS Institute 2009) to develop prediction equation of ME for poultry. A stepwise regression technique was used for variable selection method to determine the relationship between nutrient composition and AMEn described by the following model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon,$$

where y is the response variable, AMEn; (x_1, x_2, …, x_k) is the set of k regressor variables corresponding to each analyzed nutrient; the parameters β_j, j = 0, 1, …, k are the partial regression coefficients representing the expected change in response y per unit change in x_1 when all the remaining regressor variables, x_1 ($i \neq j$), are held constant; and ε is an independent and normally distributed random error component. The stepwise selection procedure begins by first including the regressor variable with the highest simple correlation to the dependent variable and the resultant best fit equation was chosen based upon the prediction coefficient of determination (R^2 Pred.).

RESULTS AND DISCUSSION

Comparison of Three Different NIRS Systems for Analyzing SBM

Results on proximate and AME content among three different NIR systems are presented in Table 1. Protein content was not different among the laboratories but there was a slight difference for dry matter, ash, fat, fiber and AME for poultry. E NIRS reported a lower dry matter but higher fat and AME value ($P<0.05$), while A NIRS showed a lower fiber and ash content compared to other NIRS from E and T. Protein is the main component of SBM, and it seems that all NIRS are capable to measure protein accurately and there is no difference in the result of protein measurement.

It is interesting to note that E NIRS showed higher AME (2.365 kcal kg^{-1}) compared to that of A and T at 2.208 and 2.218 kcal kg^{-1}, respectively. AME of SBM analyzed by E had a higher value (around 150 kcal) compared to that analyzed by NIRS from A and T. E estimated the ME value of an ingredient based on calculation from chemical composition rather than using NIRS that has been calibrated with *in vivo* trial using animal. On the other side, A reported (Liu, personal communication) that the machine has been calibrated *in vivo*, but other laboratories may use an equation to estimate ME value based on chemical composition as reported by World‘s Poultry Science Association (1989) which heavily depend upon protein, fat and NFE content. If E laboratory estimated AME by chemical composition, it was possible

Table 1. Proximate composition of soybean meal (SBM) measured by three different NIR systems.

NIRS system	Dry matter (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	ME Poultry (kcal kg^{-1})
A-laboratory	88.12[a1)]	6.21[b]	46.96	1.75[b]	3.02[b]	2208[b]
E-laboratory	88.01[b]	6.48[a]	47.11	2.46[a]	3.69[a]	2365[a]
T-laboratory	88.41[a]	6.56[a]	47.25	1.79[b]	3.75[a]	2218[b]
SEM[2)]	0.09	0.03	0.18	0.06	0.11	9
P-value	0.005	<.0001	0.48	<.0001	<.0001	<.0001

[1)]Different superscript in the same column indicates significantly different ($P<0.05$).

[2)]SEM = standard error for means.

that higher AME would be related with higher fat content in SBM because protein content was not different among the laboratories (P>0.48). Report from Ravindran et al. (2014) based on *in vivo* study indicated that AME content of SBM is negatively correlated with fiber content (r = -0.64) and ash content (r = -0.63) but positively correlated with higher fat and sucrose content, although correlation value is relatively low at 0.38 and 0.33, respectively. On the other hand, García-Rebollar et al. (2016) reported that energy content of SBM is heavily affected also by quality of protein fraction, which may be shown by digestibility of protein especially the amino acids.

Comparison between NIRS laboratories to analyze total amino acid content in SBM is presented in Table 2. There were differences among the NIRS systems on the capability to measure amino acids content. A NIRS gave significantly (P<0.05) higher result of lysine (2.98%) compared to E and T at 2.90% and 2.93%, respectively, however the difference is considered small only at second decimal point of the value. Similarly, A gave a higher result of valine (2.32%) and isoleucine (2.27%) content compared to E reported at 2.25% and 2.16% and T reported 2.27% and 2.17%, respectively. But there was no difference on methionine, cystine and threonine content among the NIRS systems. The differences on the level of valine, isoleucine and arginine were also relatively small. The large significant difference (P<0.05) was found in histidine level, being T NIRS provided highest level at 1.28% compared to E at 1.2% and A at 1.17%.

Results on digestible amino acids measurement from three different NIRS systems is presented in Table 3. The result showed significant difference among the NIRS systems for digestible amino acids value of SBM except for digestible arginine. NIRS system from A gave a lower result for digestible lysine (2.54%) compared to E at 2.58% and T at 2.57% and there was no difference between the result from the later two laboratories. Similarly, digestible cystine, TSAA, valine, histidine, phenylalanine, and leucine result from A was significantly lower that the result from E and T. A however gave a higher result for digestible tryptophan and isoleucine compared to that from E and T. Generally, there was little difference between the result of analysis of digestible amino acids between E and T NIRS systems. Similar to the total amino acids content, the results on digestible amino acids content among the NIRS systems were relatively small, only at second decimal point.

All laboratories (T, E and A) are capable of estimating proximate analyses, however there are different results on crude fat content in SBM, being E give higher value. On the total and digestible amino acids content, all NIRS systems provided by the feed additive companies gave similar value although statistically, there was a significant difference for certain amino acids at second decimal point. Measurement of ME content in SBM can also be performed using NIRS system, but NIR from E gave a higher value (150 kcal kg^{-1}) compared to NIRS system from A and T. Considering availability of NIRS system in the country and small differences on the result between the NIRS systems, further analysis of SBM nutrient composition is performed using T laboratory.

Table 2. Total amino acids content of soybean meal measured by three different NIRS systems.

NIRS system	Amino acid content (%)											
	LYS	MET	CYS	TSAA	THR	VAL	ILE	ARG	TRP	HIS	PHE	LEU
A-laboratory	2.98$^{a1)}$	0.62	0.66	1.30	1.86	2.32^{a}	2.27^{a}	3.43^{b}	0.67	1.17^{c}	2.38^{b}	3.57^{b}
E-laboratory	2.90^{b}	0.62	0.67	1.30	1.82	2.25^{b}	2.16^{b}	3.46^{b}	0.62	1.23^{b}	2.43^{a}	3.58^{b}
T-laboratory	2.93^{b}	0.73	0.78	1.42	1.87	2.27^{b}	2.17^{b}	3.56^{a}	0.69	1.28^{a}	2.46^{a}	3.64^{a}
SEM$^{2)}$	0.01	0.05	0.05	0.03	0.03	0.01	0.01	0.02	0.05	0.00	0.01	0.02
P-value	<.0001	0.14	0.15	0.01	0.26	<.0001	<.0001	<.0001	0.60	<.0001	<.0001	0.00

$^{1)}$Different superscripts in the same column indicate significantly different (P<0.005).
$^{2)}$SEM = standard error for means.

Table 3. Digestible amino acids content of soybean meal measured by three different NIRS systems.

NIRS system	Digestibe amino acid content (%)											
	LYS	MET	CYS	TSAA	THR	VAL	ILE	ARG	TRP	HIS	PHE	LEU
A-laboratory	2.54$^{b1)}$	0.57^{b}	0.51^{c}	1.08^{c}	1.54^{a}	1.92^{b}	1.98^{a}	3.16	0.58^{a}	1.03^{c}	2.13^{b}	3.13^{b}
E-laboratory	2.58^{a}	0.56^{b}	0.54^{b}	1.10^{b}	1.52^{b}	1.96^{a}	1.88^{b}	3.18	0.56^{b}	1.11^{b}	2.16^{a}	3.15^{ab}
T-laboratory	2.57^{a}	0.58^{a}	0.58^{a}	1.16^{a}	1.56^{a}	1.96^{a}	1.90^{b}	3.16	0.54^{c}	1.13^{a}	2.18^{a}	3.19^{a}
SEM$^{2)}$	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01
P-value	0.01	0.00	<.0001	<.0001	<.0001	<.0001	<.0001	0.47	<.0001	<.0001	0.00	0.01

$^{1)}$Different superscripts in the same column indicate significantly different (P<0.005).
$^{2)}$SEM = standard error for means.

Nutrient Composition and Quality of SBM from Different Origins

Proximate composition analysis of SBM from different origins received in Indonesia is presented in Table 4. There were differences in protein content of SBM among various origins. For example, Brazilian SBM had the highest protein content (48.6%) compared to other origins, however, there was no difference in protein content between US and Argentine SBM (46.5%). Fat content was detected to be significantly higher in US SBM (2%) compared to Brazil and Argentine SBM at 1.6%. In addition, ash content was the lowest in US SBM (6.3%) compared to Argentine SBM at 6.8 and Brazilian SBM at 6.5%. Although statistically there was no difference in crude fiber content among SBM from different origins, numerically, US SBM had the lowest fiber content (3.6%) as compared to Brazilian SBM (4%) and Argentine SBM at 3.8%.

Higher protein content in Brazilian SBM is likely to be related with original soybean (genetic) rather than processing condition during crushing of soybean to produce SBM. Difference in residual fat content in Brazil, US or Argentine SBM was relatively small only 0.4% and would not influence the protein level with the difference of around 2% between Brazilian SBM from other SBM origins. Karr-Lilienthal et al. (2004) reported that Brazilian soybean has higher protein content compared to US soybean. Besides genotype, factors such as planting area, soil type, agricultural practices, and environmental conditions during the growing season and storage, may affect the chemical composition of the soybeans (Westgate et al. 2000) and consequently affecting chemical composition of the SBM (Grieshop et al. 2003; Ravindran et al. 2014; García-Rebollar et al. 2016). Contribution of climate especially temperature during growing, and cultivar to geographic variability of CP content in soybeans have been demonstrated in a number of studies (Wolf et al. 1982; Breene et al. 1988; Piper and Boote 1999; Grieshop and Fahey 2001) and recent studies by Miller-Gravin and Naeve (2018) reported that within US, geographical origin may have different protein and fat contents of soybean.

Level of fat in SBM is mostly affected by conditions at crushing plant although origin of soybean had different acid hydrolyzed fats as reported by Karr-Lilienthal et al. (2004). Most of oil extraction was done using solvent, therefore completeness of solvent extraction may influence residual fat content in SBM. Plant manager at crushing plant would be able to adjust the crushing conditions to adjust residual oil in SBM. Higher fat content in US SBM (2%) compared to 1.6% from other origins may be related with conditions at crushing plant. On the other side, US SBM had significantly ($P<0.05$) lower ash content (6.29%) compared to SBM from other origins (Argentina at 6.84% and Brazil at 6.46%). A lower ash content may be associated with origin of the bean. Karr-Lilienthal et al. (2004) reported that US soybean has a lower potassium level (2.07%) compared to Argentine soybean at 2.71% and Brazilian soybean at 2.46%. However, it should be bear in mind that soil contamination of original bean may also influence the level of ash in SBM. Low level of fiber in all SBM (~4%) indicated that soybean hull may have been removed during crushing as most of fiber is found in hull but there is possibility that some amount of hull may be added back to the meal (Karr-Lilienthal et al. 2005).

Total amino acid composition of SBM from different origins is presented in Table 5. There were differences in some amino acids of SBM from different origins. Among the essential amino acids important for monogastric animals, five most important amino acids are lysine, methionine, methionine + cystine, threonine and tryptophan. The only significant difference ($P<0.05$) in those amino acids is lysine. The highest lysine content (3.01%) was found in Brazilian SBM, while in US and Argentine SBM not different at 2.89% and 2.88%, respectively. A higher lysine content in Brazilian SBM may be related to the higher protein level found in this SBM (48.6%) compared to other origin (US and Argentina) at 46.5%. Higher lysine content of SBM would be positively correlated with higher lysine (García-Rebollar et al. 2016). A higher protein content also resulted in higher other amino acids such as arginine, isoleucine, phenylalanine, histidine,

Table 4. Proximate composition of soybean meal from different origins.

SBM origin	No of samples	Moisture (%)	Dry matter (%)	Crude ash (%)	Crude protein (%)	Crude fat (%)	Crude fiber (%)
Argentina	23	$11.15^{a1)}$	88.85^{a}	6.84^{a}	46.47^{a}	1.56^{a}	3.81
Brazil	20	11.54^{c}	88.46^{c}	6.46^{b}	48.57^{c}	1.58^{a}	4.04
USA	16	11.31^{b}	88.68^{b}	6.29^{c}	46.59^{b}	2.01^{b}	3.58
SEM[2)]		0.11	0.16	0.044	0.21	0.08	0.12
P value		0.043	0.043	0.0001	0.0001	0.0004	0.0527

[1)]Different superscripts in the same column indicate significantly different ($P<0.05$).

[2)]SEM = standard error for means

Table 5. Total amino acids content of soybean meal (SBM) from different origins.

SBM origin	No of samples	Total amino acid content (%)												
		LYS	MET	CYS	MET+CYS	THR	TRP	ILE	ARG	PHE	HIS	LEU	TRY	VAL
Argentina	23	2.88[a]	0.75	0.79	1.42	1.86	0.71	2.14[a]	3.48[a]	2.42[a]	1.25[a]	3.58[a]	1.72[a]	2.23[a]
Brazil	20	3.01[b]	0.68	0.73	1.41	1.89	0.63	2.23[b]	3.64[b]	2.52[b]	1.31[b]	3.74[b]	1.80b	2.33[b]
USA	16	2.89[a]	0.65	0.70	1.35	1.82	0.60	2.14[a]	3.49[a]	2.42[a]	1.26[a]	3.39[a]	1.72[a]	2.23[a]
SEM		0.020	0.090	0.090	0.070	0.050	0.100	0.014	0.020	0.015	0.008	0.023	0.011	0.014
P value		0.000	0.571	0.580	0.594	0.317	0.558	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[1)]Different superscripts in the same column indicate significantly different (P<0.05).
[2)]SEM = standard error for means.

leucine, tyrosine and valine. If the ratio between lysine and protein content is calculated, the ratio for Argentine, Brazil and US SBM would be same at 6.2%. This result is in contrary with previous data from Ravindran et al. (2014) that US SBM would have higher lysine to protein ratio at 6.10 compared to Argentine SBM at 6.05 while Brazilian SBM was the lowest at 5.79%. Stein (2019) reported that ratio of lysine to protein of good quality SBM should be maintained at >6%. In this current study, all SBM imported to Indonesia from different origins has lysine to protein ration at 6.2 and may be considered all good quality.

Digestible amino acids content of SBM from different origins is presented in Table 6. Similar to total lysine and non-essential amino acid content, Brazilian SBM has significantly higher digestible amino acid contents compared to US or Argentine SBM. In contrast, there was no difference in digestible amino acid contents between US and Argentine SBM. Table 6 shows that average digestible lysine content of SBM ranged from 2.53% to 2.63%. In general, digestible amino acids content of Brazilian SBM was higher that digestible amino acids of SBM from US and Argentina and this is mainly attributed by higher level of protein content in Brazilian SBM.

Digestible lysine can be an indicator for the quality of SBM considering processing effect and agronomic background. Previous report from García-Rebollar et al. (2016) indicated that US SBM contain higher lysine to CP ratio. However, in this study when lysine to CP ratio was calculated, there was no difference observed among SBM with value around 5.42% to 5.43%. Almeida et al. (2014) reported that heat damaged SBM would contain lysine to CP ratio at 5.4 compared to 6.1 in undamaged SBM. Stein (2019) reported that over processing SBM may result in a decrease in digestible lysine but further damage in SBM may result to a decrease in total lysine, therefore the ratio between total and digestible lysine to protein content would decrease significantly.

Carbohydrate components such as starch, sugar, NFE, NDF, NSP and ME for poultry of SBM from different origins are presented in Table 7. There were some differences on the content of carbohydrate components among SBM from different origins. In general, carbohydrate components of US SBM were almost similar to that of Argentine SBM. Brazilian SBM had lower sugar and NFE contents, but slightly higher NDF level compared to US SBM. Higher level of sugar in US SBM was also reported by García-Rebollar et al. (2016), but in this study sugar content of US SBM was similar to Argentine SBM.

Energy content of SBM from different origins based on estimation for poultry is presented in Table 7. It is clearly indicated that US SBM had significantly higher ME content (2237.4 kcal kg^{-1}) compared to Argentine SBM (2188 kcal kg^{-1}) while Brazilian SBM (2212 kcal/kg) was in between US and Argentine SBM. The data indicated that US SBM contained around 40 and 25 kcal kg^{-1} higher ME compared to that of Argentine and Brazilian SBM, respectively. This result is consistent with previous finding reported by Ravindran et al. (2014) and Mateos (2017) who suggested that US SBM generally contain higher ME level compared to SBM from South America. García-Rebollar et al. (2016) reported that higher ME in US SBM would probably relate with sugar level, higher sugar level would increase ME content of SBM. However, further statistical analysis of SBM based on Pearson correlation between different components of SBM (Table 8) indicated that there was a positive correlation between ME with protein and fat level with the value at 0.50 and 0.58, respectively. Table 8 shows that there was a negative correlation between ME value with NSP and fiber level in SBM. The negative correlation was also reported by Ravindran et al. (2014) based on *in vivo* trial.

Considering the relationship between ME level with other components in SBM, it would be of interest to look at prediction on ME value based on chemical composition. Several equations have been proposed in poultry to estimate the AME values of compound feeds from their chemical composition (Carpenter and Clegg 1956; Sibbald et al. 1980; Fisher 1982; Carré et al. 1984; CVB 2004; NRC 1994). However, these equations are of limited value when extrapolated to predict the energy

Table 6. Digestible amino acids content (poultry) of soybean meal (SBM) from different origins.

SBM origin	No of samples	Digestible amino acids (%)												
		LYS	MET	CYS	TSAA	THR	VAL	ILE	ARG	TRP	HIS	PHE	LEU	LYS
Argentina	23	2.53[a1)]	0.57[a]	0.57[a]	1.14[a]	1.54[a]	0.54[a]	1.88[a]	3.10[a]	2.15[a]	1.11[a]	3.14[a]	1.52[a]	1.93[a]
Brazil	20	2.63[b]	0.59[b]	0.59[b]	1.18[b]	1.60[b]	0.56[b]	1.95[b]	3.24[b]	2.24[b]	1.16[b]	3.27[b]	1.59[b]	2.01[b]
USA	16	2.54[a]	0.57[a]	0.57[a]	1.14[a]	1.54[a]	0.54[a]	1.88[a]	3.11[a]	2.15[a]	1.12[a]	3.15[a]	1.52[a]	1.94[a]
SEM[2)]		0.018	0.006	0.005	0.010	0.011	0.005	0.014	0.020	0.016	0.008	0.023	0.013	0.016
P value		0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[1)]Different superscripts in the same column indicate significantly different (P<0.05).
[2)]SEM = standard error for means.

Table 7. Carbohydrate component and metabolizable energy of soybean meal (SBM) from different origins.

SBM origin	No of samples	Starch (%)	Sugar (%)	NFE (%)	NDF (%)	ME poultry (kcal kg^{-1})
Argentina	23	0.82	10.43[ab1)]	30.17[a]	9.07[ab]	2188.0[a]
Brazil	20	0.80	9.88[a]	27.81[b]	10.14[b]	2212.3[ab]
USA	16	0.80	10.83[b]	30.23[a]	8.56[a]	2237.4[b]
SEM[2)]		0.01	0.35	0.23	0.57	13
P value		0.465	0.039	0.000	0.028	0.002

NFE = nitrogen free extract, NDF = neutral detergent fiber, NSP = non-starch polysaccharide, ME poultry = metabolizable energy for poultry
[1)]Different superscripts in the same column indicate significantly different (P<0.05).
[2)]SEM = standard error for means.

Table 8. Pearson correlation coefficients between chemical composition and metabolizable energy for 62 soybean meal (SBM).

Item[1)]	Protein	Fat	Fiber	Starch	Sugar	NFE	NDF	NSP	ME poultry
Protein (%)	1.000								
Fat (%)	-0.240	1.000							
Fiber (%)	-0.379	-0.131	1.000						
Starch (%)	-0.055	-0.127	0.019	1.000					
Sugar (%)	-0.181	0.105	-0.162	-0.753	1.000				
NFE (%)	-0.824	0.030	0.038	-0.024	0.381	1.000			
NDF (%)	-0.078	0.081	0.502	-0.075	-0.508	-0.209	1.000		
NSP (%)	-0.805	-0.020	0.576	-0.049	-0.010	0.721	0.460	1.000	
ME poultry (kcal kg^{-1})	0.504	0.575	-0.735	-0.171	0.137	-0.303	-0.258	-0.611	1.000

[1)]NFE = nitrogen free extract, NDF = neutral detergent fiber, NSP = non-starch polysaccharide, ME poultry = metabolizable energy for poultry.

concentration of single feeds, with different chemical compositions than that of complete diets. Furthermore, prediction equations for feed ingredients in poultry are scarce and its validity is limited to the conditions in which they were obtained (Dolz and de Blas 1992). In addition, this approach is also limited by the time required for the chemical analyses and its repeatability. In the current experiment, an attempt has been made to develop a regression equation to estimate ME value of SBM based on the chemical components and the results are presented in Table 9.

The results showed that fiber is the most important component affecting ME of SBM for poultry followed by fat, protein and NFE. When all those four chemical components are included in setting up regression equation, the best estimate for ME prediction for SBM is "ME (kcal kg^{-1}) = 75.7 – 21.0 x Fiber + 87.4 x Fat + 32.9 x Protein + 17.6 x NFE (R^2 = 0.995)". In this study, no other chemical components significantly (P>0.05) influenced the energy value including sugar, NDF and NSP. This result is in contrary to the report by Mateos (2017) in which sugar content is the most important component affecting the energy value of SBM. However, the current result is in agreement with study conducted by Ravindran et al. (2014) that fiber is the most important component affecting energy level in SBM. The higher fiber level in SBM resulted in a lower energy value. However, Ravindran et al. (2014) reported only fiber while in the current report, other component such as residual fat, protein and NFE would positively affect the energy value of SBM. Energy content of feed is currently the most expensive nutrient compared to protein. Therefore, evaluation of energy content is critical to reduce cost of feed during feed formulation. Advancement of NIRS

Table 9. Prediction equation of AMEn soybean meal.

ME equation for poultry	P value	R^2	R^2 adjusted
ME, kcal kg^{-1} = 2431.4 – 57.6 x Fiber	<0.0001	0.540	
ME, kcal kg^{-1} = 2319.0 – 52.6 x Fiber + 55.4 x Fat	<0.0001	0.773	
ME, kcal kg^{-1} = 1506.3 – 37.0 x Fiber + 71.3 x Fat + 15.4 x Protein	<0.0001	0.948	
ME, kcal kg^{-1} = 75.7 – 21.0 x Fiber + 87.4 x Fat + 32.9 x Protein + 17.6 x NFE[1)]	<0.0001	0.995	0.995

[1)]NFE = nitrogen free extract

system provided by all laboratories (A, E and T) is able to provide measurement of ME in feed ingredients, however the basis of calibration of NIRS would differ among the laboratories. A claimed that the calibration is based on *in vivo* trials (Liu et al. 2012), while E and T are likely based on the equation reported by World's Poultry Science Association (1989).

CONCLUSION

NIRS systems provided by feed additives companies (E, A, and T) are able to estimate proximate composition, total and digestible amino acids and metabolizable energy of SBM, but there are small differences on the result for fat and amino acids at second decimal value. Laboratory E estimates a slightly higher ME value (150 kcal) compared to that from other laboratories (A and T). Comparison between SBM showed that Brazilian SBM has higher protein (2%) and amino acids (total and digestible) content compared to US or Argentine SBM. However, US SBM had slightly higher AME content (20 and 40 kcal kg^{-1}) compared to Brazilian and Argentine SBM, respectively. Furthermore, a prediction equation was developed based on other nutrients (fiber, fat, protein and NFE) to estimate energy content of SBM.

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