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Regional and processor variation in the ileal digestible amino acid content of soybean meals measured in growing swine[1]

T. A. T. G. van Kempen*[2], I. B. Kim*, A. J. M. Jansman†, M. W. A. Verstegen‡, J. D. Hancock§, D. J. Lee§, V. M. Gabert¶, D. M. Albin¶, G. C. Fahey, Jr.¶, C. M. Grieshop¶, and D. Mahan#

*Department of Animal Science, North Carolina State University, Raleigh 27695; †ID-TNO Animal Nutrition, P.O. Box 65, 8200 AB Lelystad, The Netherlands; ‡Department of Animal Science, Agricultural University Wageningen, Wageningen, 6700 AH, The Netherlands; §Department of Animal Science, Kansas State University, Manhattan 66506; ¶Department of Animal Science, University of Illinois, Urbana 61801; and #Department of Animal Science, Ohio State University, Columbus 43210

ABSTRACT: To assess differences in soybean meal quality related to region of production, researchers in Illinois, Kansas, North Carolina, The Netherlands, and Ohio collected four soybean meal samples processed locally at least 15 d apart. These samples were assayed for ileal amino acid digestibility by pigs using a common soybean meal and a soy protein concentrate as references, and a low-protein casein diet for determination of endogenous amino acid losses. Digestibility was determined at each university using seven barrows surgically fitted with ileal cannulas in a 7 × 7 Latin square design. The experimental diets contained 17% CP from the test material except for the low-protein casein diet. Animals were fed twice daily, 12 h apart, at a level of 45 $g \cdot kg^{-0.75}$ BW for each meal. Following a 5-d adaptation period, ileal digesta were collected for two 12-h periods for 2 d to be used for determination of ileal digestibility. Variation in amino acid digestibility was very small among and within sites and was much smaller than variation in the concentration of amino acids. Among sites, samples from The Netherlands had less total and thus digestible lysine and methionine than the U.S. samples ($P < 0.05$). The soybean meals tested in this experiment were approximately 4% higher in amino acids than that reported in the NRC (1998). True (standardized) digestibilities, however, were very similar to NRC values except for cysteine and threonine, which were 5 and 3 percentage points lower in this experiment, respectively. In conclusion, soybeans grown in the United States and locally processed into soybean meal were very similar in nutritional composition. Soybean meals produced in The Netherlands were lower in lysine and methionine ($P < 0.05$) but had a digestibility similar to that produced in the United States.

Key Words: Amino Acids, Digestibility, Pigs, Soyabeans, Soybean Meal

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Introduction

Soybean meal is the major protein ingredient used in swine feeds in the United States and throughout the world. Its amino acid profile, high digestibility, and relatively low price make soybean meal an excellent protein source for feeding swine and poultry (American Soybean Association, 2000).

Many studies have investigated the nutritional value of soybean meal; however, few have addressed location of soybean production as a variable that may affect its nutritional value. Although the genetic variability in soybeans within the United States is very limited (10 plants are responsible for 80% of the gene pool), the location of production can affect growth characteristics and the yield (Palmer et al., 1996). According to USDA-NASS (2001), major differences in yield exist between Illinois and Ohio, having high yields (3.0 tons/ha), and North Carolina and Kansas with low yields (1.8 and 2.0 tons/ha, respectively). As yield is inversely related to protein content (Palmer et al., 1996), the region of production may affect the nutritional value of soybeans processed into meal.

Processing conditions may add further variation to the quality of soybean meal. Balloun (1980) reviewed

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[2]Correspondence: 123 Polk Hall (phone: 919-515-4016; fax: 919-515-7780; E-mail: t_vankempen@ncsu.edu).

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the impact of processing conditions and noted that processing method and characteristics, such as processing temperature, time, and moisture content, greatly influenced the nutritional value of the meal. Within the United States, however, processing conditions have been standardized over the last 20 yr and are not expected to contribute greatly to product variation.

The objectives of this experiment were 1) to evaluate the degree of variation in nutritional value of soybean meal, processed within a single plant over a 45-d period, and 2) to evaluate the degree of variation that exists among various production locations.

Material and Methods

Five universities participated in an experiment that evaluated the consistency of soybean meal samples processed and collected from within their regions at four time periods. These research institutions were North Carolina State University (**NC**); Wageningen University, in The Netherlands (**NL**); Kansas State University (**KS**); the University of Illinois (**IL**); and The Ohio State University (**OH**). Approved animal care procedures were used at each University.

Animals and Diets

At each site, nine barrows were surgically fitted with cannulas at the distal ileum. Following a recovery period, seven of the cannulated pigs were used in a 7×7 Latin square design experiment. Pigs were fed twice daily, 12 h apart. Feed allowance for each meal was calculated at 45 g/kg BW. Water was provided for ad libitum consumption.

Experimental diets were calculated to be isonitrogenous, except for the low-protein casein (**LPC**) diet (Table 1). A common source soybean meal (48%) and a common soy protein concentrate were provided by The Ohio State University and served as the reference standard at each site. At each location, test soybean meal samples were obtained from one regional soybean processor at four different periods at least 15 d apart. These samples are referred to as the *test soybean meal samples* and are identified by location code and day of collection (e.g., OH d45). The LPC diet was formulated to contain 5% casein and was used to estimate endogenous losses of amino acids from one pig within each collection period. Chromic oxide (0.5%) was included in each diet as an indigestible marker and was used to calculate digestibility values.

Each 7-d experimental period consisted of a 5-d adaptation and a 2-d collection period. Digesta collection was started immediately after the morning feeding and terminated at the beginning of the evening feeding. Ileal digesta were collected continuously from the cannula into an attached plastic container and transferred at frequent intervals to a freezer where they were pooled by pig within each period.

Additional information on site specifics is presented in Table 2.

Chemical Analyses

The N, Cr, and amino acid analyses of feed and freeze-dried digesta samples for all investigators were conducted by a common laboratory to reduce analytical variations (Experimental Station Chemical Laboratories, University of Missouri, Columbia). Amino acids were analyzed according to AOAC procedures (AOAC, 1995). Dry matter, CP, organic matter (AOAC, 1995), total dietary fiber (**TDF**, Prosky et al., 1984), and total nonstructural carbohydrates (**TNC**, Smith, 1969) were determined in the test soybean meal samples at the University of Illinois. At The Ohio State University, selenium (Se) apparent digestibilities were determined after freeze-dried digesta samples were wet-ashed in perchloric and nitric acids, with Se analyzed by the fluorometric method (AOAC, 1995). At NC, energy digestibility was determined after the energy content of feed and ileal digesta (oven-dried at 60°C) were determined using an oxygen bomb calorimeter (IKA Model C5000, IKA, Wilmington, NC).

Calculations

Apparent digestibility coefficients were calculated using the following equation:

$$\text{Apparent digestibility, \%} = 100 - [(M_d \cdot AA_I)/(AA_d \cdot M_I)] \cdot 100$$

where

M_d = chromium concentration in the diet (mg/kg)
AA_I = amino acid concentration in ileal digesta (g/kg)
AA_d = amino acid concentration in the diet (g/kg)
M_I = chromium concentration in the ileal digesta (mg/kg)

Endogenous amino acids losses (g/kg feed intake) were determined using the LPC diet that was assumed to be 100% (true) digestible. Using these endogenous losses, LPC standardized digestibilities were calculated using the following equation:

$$\text{LPC standardized digestibility, \%} = 100 \cdot \{AAd - [AAd \cdot (1 - AD/100) - AAe \cdot DMt/DMc]\}/AAd$$

where

AAd = amino acid concentration in diet (g/kg feed)
AD = apparent digestibility (%)
AAe = endogenous loss (g/kg feed)
DMt = dry matter content of test diet (%)
DMc = dry matter of LPC diet (%)

Table 1. Composition of the experimental diets (%, as-fed basis)

Ingredient	Treatment			
	Common SBM[a]	Common SPC[a]	Test SBM	Casein
Cornstarch	38.10	46.00	39.55	61.60
Sucrose	20.00	20.00	20.00	20.00
Soybean meal	35.25	—	—	—
Test soybean meal[b]	—	—	33.80	—
Soy protein concentrate	—	27.00	—	—
Solka floc (cellulose fiber)	—	—	—	5.00
Casein (food grade)	—	—	—	5.00
Corn oil	2.00	2.00	2.00	2.00
Salt	0.35	0.35	0.35	0.35
Dicalcium phosphate	3.00	3.00	3.00	3.00
Limestone	0.45	0.45	0.45	0.60
Chromic oxide	0.50	0.50	0.50	0.50
Potassium carbonate (55% K)	—	0.35	—	1.40
Magnesium oxide (58% Mg)	—	—	—	0.15
Vitamin premix[c]	0.30	0.30	0.30	0.30
Mineral premix[d]	0.05	0.05	0.05	0.05

[a]The common soybean meal (SBM) and soy protein concentrate (SPC) were provided by The Ohio State University.
[b]The soy samples were included in the feed to provide approximately 17% CP (at the expense of cornstarch).
[c]Provides per kilogram of diet: 2,000 IU vitamin A; 300 IU vitamin D_3; 20 IU vitamin E; 1.0 mg vitamin K (menadione); 4 mg thiamine; 15 mg niacin; 4 mg riboflavin; 12 mg pantothenic acid; 15 μg vitamin B_{12}; 2 mg pyridoxine; 0.1 mg D-biotin; 0.5 mg folic acid; and 0.6 g choline.
[d]Provides per kilogram of diet: 90 mg Fe (ferrous sulfate); 5 mg Mn (manganese oxide); 8 mg Cu (copper sulfate); 0.20 mg I (potassium iodate); 0.21 mg Se (sodium selenite), and 90 mg Zn (Zinc sulfate).

"NRC true" Digestibility, %. Because the LPC diet was observed to augment endogenous secretions compared with a protein-free diet, digestibility coefficients were also calculated using values for endogenous losses obtained with a protein-free diet as reported by Tran et al. (1999), in line with the NRC (1998) guidelines.

Statistical Analyses

At NC, data from one animal during one period were excluded from the analysis because the animal had a poor feed intake (Diet NC d30). At NL, no ileal fluid was collected from one animal on diet NL d0 due to ileal diarrhea. This observation was replaced with one using a spare animal in a subsequent period. Diets NL d0 and NC d30 thus yielded higher SEM values (results not given).

All data were analyzed using the GLM procedure of SPSS 8.0 (SPSS Inc., Chicago, IL) using animal as the experimental unit. The model included location, location × animal, location × period, and diet, and the results listed are based on unconditional analyses. Using this model, location effects are determined based on the digestibility of the common soybean meal and soy protein concentrate. This location effect then corrects the digestibility of the test samples for site effects such that these samples can be compared among sites. Low-protein casein digestibility values were not corrected for site effects because these values were used to apply for a site-specific endogenous losses correction.

Relationships among samples and data obtained were investigated with principal component analysis using Unscrambler 7.5 (Camo, Trondheim, Norway) because the data set generated in this experiment contain many variables that are not independent. In principal component analysis, data are reorganized such that new variables are generated to describe the original variables, but with each new variable (principal component) being orthogonal (independent). These new variables can subsequently be used with multiple linear

Table 2. Site specification details and deviations from the generic protocol

Item	Location				
	Illinois	Kansas	N. Carolina	Netherlands	Ohio
Cannula	T	T	T	PVTC[a]	T
Pig BW at d 0, kg	27	25	28	65	28
Diet form	Meal	Meal	Meal	Pellet[b]	Meal[c]

[a]The postvalvular T-cecum (PVTC) cannula was placed at the site of the ileocecal valve.
[b]Diets were cold-pelleted using a die with 2.5-mm openings.
[c]Selenium was deleted from the trace mineral mixture for determining the apparent digestibility of Se.

Table 3. Chemical composition of the soybean meal samples averaged within location

	Location					
Item	Illinois	Kansas	N. Carolina	Netherlands	Ohio	SEM
Dry matter, %, as fed	89.1^{a}	90.1^{b}	89.7^{ab}	91.0^{c}	91.7^{c}	0.3
Crude protein, % of DM	55.2^{ab}	55.0^{a}	56.2^{b}	54.7^{a}	54.8^{a}	0.3
Organic matter, % of DM	92.5^{c}	91.7^{a}	92.6^{c}	92.1^{b}	93.0^{d}	0.1
Total dietary fiber, % of DM	16.9^{b}	16.6^{ab}	15.6^{a}	16.3^{ab}	16.0^{ab}	0.4
Total nonstructural carbohydrates, % of DM	21.6^{c}	19.5^{a}	21.6^{c}	20.5^{b}	20.4^{ab}	0.3

[a,b,c]Means in the same row lacking a common superscript letter are different ($P < 0.05$).

regression because they are independent (Esbensen et al., 1996). A major advantage of this method is that it allows for the rapid evaluation of relationships among dependent and independent variables, and this analysis is the method of choice for complicated multivariate problems. This statistical method, though, does not result in statistics such as probability values and confidence intervals.

Results and Discussion

The results presented and the ensuing discussion will focus on LPC-standardized digestibility data for Lys, Met, Cys, Thr, and Trp (the nutritionally dispensable amino acid Cys is listed with the indispensable amino acids because it plays an important role in feed formulation). Data for other nutritionally indispensable amino acids are provided in tables.

The chemical composition of the test samples provided in Table 3 showed that, although small statistical differences existed among different locations attributed to a small SEM, the samples can be considered as being very similar in their chemical composition. This observation is consistent with the suggestion of Palmer et al. (1996) that genetic variation is small within soybeans grown in the United States. This observation also suggests that processing conditions were uniform, as they did not introduce variation among locations.

The amino acid concentrations of the test soybean meal samples are provided in Table 4. Principal component analysis of these data indicated that Trp and Val were negatively correlated and that Cys, His, and Met co-varied strongly, as did Arg and Thr (Figure 1). This graph shows NL samples as distinct from U.S. samples, being higher in Val and Trp but lower in other indispensable amino acids. The NL samples were also substantially more variable than the U.S. samples. Samples collected in NC and OH were lower in Trp, Met, and Cys than were samples collected in KS and IL.

Casein included at 5% of the diet had an apparent ileal digestibility of 88.6% for Lys, 91.9% for Met, 71.4% for Thr, and 82.5% for Trp (data not shown). This diet was included on the assumption that casein was 100% digestible, and thus amino acids collected at the end of the ileum could be used for estimating endogenous losses (Nyachoti et al., 1997). This method was chosen because protein-free diets were considered physiologically abnormal (Low, 1980). Feeding protein-free diets may result in an abnormally high Pro excretion. According to Stein et al. (1999), this may be related to a higher excretion of mucin proteins in young pigs (< 120 d old), which are high in Pro. In our experiment, high secretions of Pro, Gly (data not shown), and Cys (Table 5) were observed with the LPC diet as well, resulting in apparent digestibility coefficients that were negative for 11% of the animals for Pro, 23% of the animals for Cys, and 49% of the animals for Gly (data not shown). Only the pigs that were used in NL had LPC digestibility data that ap-

Table 4. Indispensable amino acids of test soybean meal samples averaged within location (%, DM basis)

	Location					
Amino acid	Illinois	Kansas	N. Carolina	Netherlands	Ohio	SEM
Arg	4.10^{a}	3.96^{b}	4.16^{ac}	3.94^{b}	4.20^{c}	0.03
Cys	0.82^{b}	0.92^{d}	0.90^{d}	0.78^{a}	0.86^{c}	0.01
His	1.55^{c}	1.52^{b}	1.50^{ab}	1.48^{a}	1.50^{ab}	0.01
Ile	2.35^{a}	2.40^{ab}	2.46^{b}	2.41^{ab}	2.44^{ab}	0.03
Leu	4.23^{ab}	4.18^{a}	4.35^{b}	4.21^{a}	4.23^{ab}	0.04
Lys	3.48^{bc}	3.45^{b}	3.53^{c}	3.16^{a}	3.47^{b}	0.02
Met	0.85^{c}	0.80^{b}	0.79^{b}	0.73^{a}	0.77^{b}	0.01
Phe	2.80	2.85	2.85	2.81	2.83	0.03
Thr	2.07^{b}	2.05^{ab}	2.17^{c}	2.02^{a}	2.14^{c}	0.02
Trp	0.81^{ab}	0.85^{b}	0.78^{a}	0.80^{a}	0.80^{a}	0.01
Val	2.53^{a}	2.51^{a}	2.57^{ab}	2.65^{b}	2.59^{ab}	0.03

[a,b,c,d]Means in the same row lacking a common superscript letter are different ($P < 0.05$).

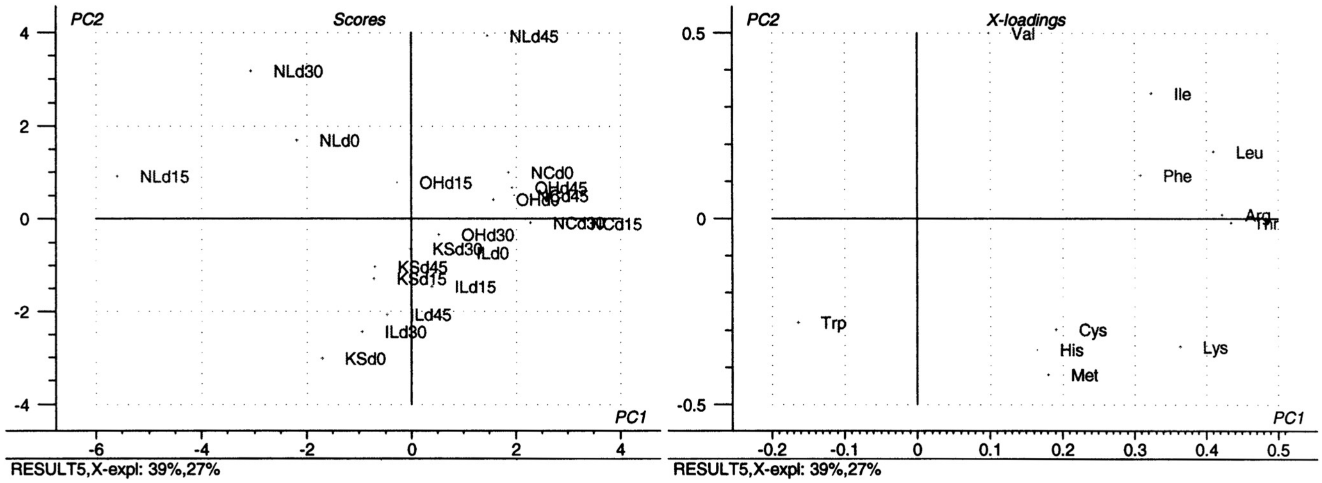

Figure 1. Principal component analysis of the amino acid composition of the test soybean meal samples. Component 1 explained 39% of the total variation, and Component 2 explained 27% of the variation. Left panel: orientation of the test samples relative to the principal components. Right panel: orientation of the amino acid concentrations relative to the principal components.

peared normal for these amino acids: 90.2% for Pro, 61.3% for Gly, and 62.6% for Cys. These results are consistent with the suggestion of Stein et al. (1999) that endogenous secretions including mucin but possibly also bile are more pronounced in younger pigs.

Low-protein casein-standardized ileal digestibilities for lysine and CP for common soybean meal and soy protein concentrate demonstrated site differences in digestibility as large as 7 percentage units for Lys and CP (Figure 2, top panel). These same differences were also apparent in the digestibility of the test soybean meal samples when calculated without site correction (Figure 2, center panel). The reason for these differences is unknown. Statistically, site effects could be removed through the use of the common soybean meal and soy protein concentrate as site-independent variables, and the site-corrected data are provided in Figure 2, bottom panel.

The top panel of Figure 2 suggests that an anomaly occurred with the NL soy protein concentrate. For soy protein concentrate, U.S. sites had a lysine digestibility that was greater than the CP digestibility (ratio of 1.014 ± 0.004), but the NL soy protein concentrate had a much lower lysine digestibility than CP digestibility (ratio of 0.934 ± 0.009, $P < 0.05$). Also, the NL soy protein concentrate had less lysine as a percentage of total CP (5.8 vs. 6.4%), a drop similar to that observed in overprocessed vs normal soybean meal (Chang et al., 1987). These data suggest that a portion of the lysine in soy protein concentrate may have been chemically altered to the extent that it was lower in digestibility and such that a portion was not recognized as lysine when assayed, in line with what is observed in the Maillard reaction. Other amino acids in the NL soy protein concentrate sample were apparently not affected. Lysine in NL soy protein concentrate was, therefore, excluded from further statistical analyses.

Table 5. Estimated endogenous losses of crude protein and amino acids determined with the low-protein casein diet (g/kg dry feed)

Item	Illinois	Kansas	N. Carolina	Netherlands	Ohio	SEM
CP	20.87^{a}	16.93^{b}	13.83^{c}	7.36^{d}	9.73^{d}	0.98
Arg	0.70^{c}	0.59^{bc}	0.47^{b}	0.21^{a}	0.23^{a}	0.06
Cys	0.26^{c}	0.20^{b}	0.22^{b}	0.12^{a}	0.14^{a}	0.01
His	0.27^{c}	0.21^{b}	0.21^{b}	0.12^{a}	0.14^{a}	0.02
Ile	0.65^{bc}	0.50^{ab}	0.58^{b}	0.42^{a}	0.42^{a}	0.05
Leu	0.82^{d}	0.65^{bc}	0.76^{cd}	0.41^{a}	0.52^{ab}	0.05
Lys	0.65^{d}	0.45^{ab}	0.49^{bc}	0.40^{ab}	0.36^{a}	0.04
Met	0.16^{b}	0.12^{ab}	0.16^{b}	0.11^{a}	0.10^{a}	0.01
Phe	0.45^{d}	0.34^{bc}	0.42^{cd}	0.21^{a}	0.29^{ab}	0.03
Thr	0.82^{c}	0.64^{b}	0.73^{bc}	0.43^{a}	0.49^{a}	0.05
Trp	0.19^{c}	0.13^{ab}	0.17^{bc}	0.09^{a}	0.09^{a}	0.02
Val	0.73^{c}	0.55^{ab}	0.63^{bc}	0.47^{a}	0.46^{a}	0.05

[a,b,c,d]Means in the same column lacking common superscript letters are different ($P < 0.05$).

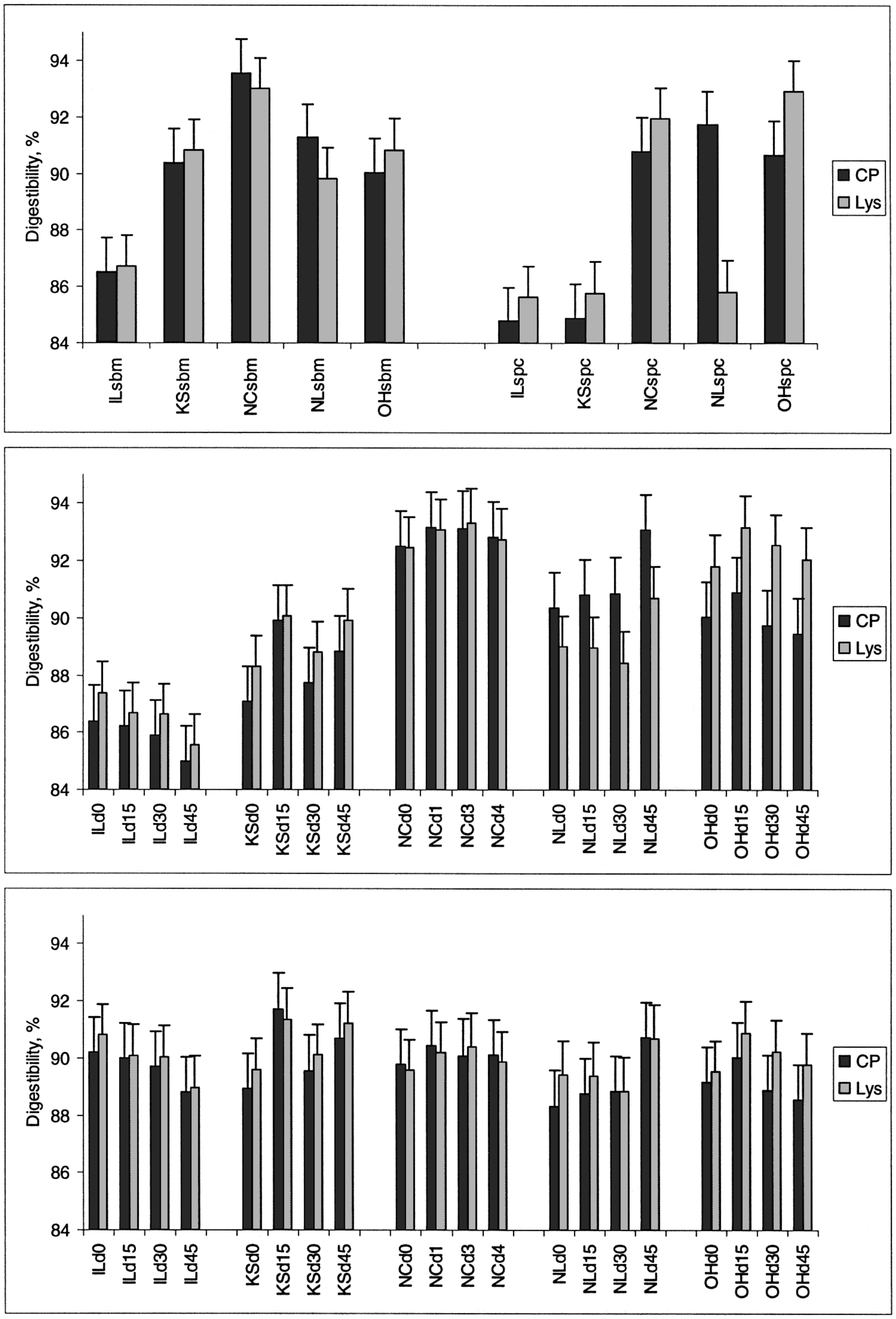

Figure 2. The top panel is the low-protein casein (LPC)-standardized digestibility coefficients for CP and lysine for the common soybean meal (SBM) and soy protein concentrate (SPC). The center panel is the LPC standardized digestibilities (uncorrected for location effects) for the test soybean meal samples. Significant differences were observed in digestibilities for the common SBM samples due to site, and these differences also were apparent in the digestibility of the test SBM samples. The bottom panel is the LPC standardized digestibility coefficients corrected for location effects using the statistical model as outlined in the text. Notice that the NL SPC sample had an abnormally low lysine digestibility. To avoid having these lysine data confound the observations, they were deleted from the statistical analysis used for generation of the bottom panel.

Using the LPC diet supplemented with Solka floc, "basal endogenous secretions" (Table 5) were calculated to be, on average, 37% higher than with a protein-free diet as reported by Tran et al. (2000). This finding is in line with Butts et al. (1993), who observed a 56% increase in endogenous secretions with an enzyme-hy-

Table 6. Low-protein casein-standardized digestibility coefficients (%) of crude protein and the indispensable amino acids

Item	CP	Arg	Cys	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Soybean meal	90.3[a]	95.4	84.3[a]	92.0[a]	91.9	89.3	90.2[a]	92.4[a]	89.9	86.8[a]	92.2[a]	90.2[a]
Soy protein concentrate	88.6[b]	95.2	79.2[b]	90.2[b]	91.3	88.8	89.0[b]	90.9[b]	90.3	85.0[b]	90.1[b]	88.8[b]
SEM	0.5	0.5	1.3	0.3	0.4	0.4	0.4	0.3	0.3	0.5	0.5	0.4
Illinois d0	90.2	95.4	85.1	92.4[cd]	91.6	88.8[cd]	90.8	93.4[cd]	89.5[cde]	85.7[cd]	90.1[cd]	90.1
Illinois d15	90.0	95.3	84.1	92.1[cd]	91.0	89.0[cd]	90.1	93.1[cd]	89.5[cde]	85.8[cd]	91.0[cd]	90.0
Illinois d30	89.7	95.6	84.7	92.6[cd]	92.2	89.6[cd]	90.0	93.8[cd]	89.8[cde]	87.2[cd]	91.3[cd]	90.7
Illinois d45	88.8	94.7	83.4	92.0[cd]	90.4	88.1[cd]	89.0	92.2[cd]	88.7[cd]	85.6[cd]	90.3[cd]	88.5
Kansas d0	88.9	95.5	83.8	92.5[cd]	91.3	88.8[cd]	89.6	92.6[cd]	90.3[cde]	86.1[cd]	92.6[cdef]	89.7
Kansas d15	91.7	96.3	86.5	93.3[d]	92.8	90.7[d]	91.4	94.5[d]	91.4[e]	88.3[cd]	94.3[def]	91.2
Kansas d30	89.6	95.5	83.6	91.4[cd]	91.3	89.0[cd]	90.1	92.7[cd]	89.7[cde]	86.1[cd]	90.7[cd]	89.5
Kansas d45	90.7	95.9	85.0	92.4[cd]	91.7	89.4[cd]	91.2	92.9[cd]	90.2[cde]	85.9[cd]	92.4[cdef]	90.2
North Carolina d0	89.8	95.5	80.7	91.1[cd]	90.8	88.5[cd]	89.6	92.2[cd]	89.1[cde]	86.0[cd]	91.6[cdef]	88.7
North Carolina d15	90.4	95.8	82.6	91.6[cd]	91.2	88.8[cd]	90.2	92.4[cd]	89.4[cde]	86.6[cd]	91.9[cdef]	89.2
North Carolina d30	90.1	95.1	83.1	91.7[cd]	90.9	88.9[cd]	90.4	92.4[cd]	89.7[cde]	86.1[cd]	92.9[cdef]	88.8
North Caroina d45	90.1	95.3	83.7	91.7[cd]	91.0	88.8[cd]	89.9	92.5[cd]	89.4[cde]	86.5[cd]	92.7[cdef]	89.1
Netherlands d0	88.3	94.7	80.8	90.2[c]	90.3	87.8[c]	89.4	91.5[c]	88.6[c]	84.7[c]	90.6[cd]	88.5
Netherlands d15	88.8	94.7	82.5	90.2[c]	90.4	87.9[c]	89.4	91.7[c]	88.6[c]	85.5[cd]	91.7[cdef]	88.8
Netherlands d30	88.8	95.3	81.2	90.5[c]	90.6	88.3[cd]	88.8	91.7[c]	89.2[cde]	85.5[cd]	91.1[cd]	88.7
Netherlands d45	90.7	95.7	83.7	92.0[cd]	92.4	90.2[d]	90.7	93.5[cd]	90.9[de]	88.2[d]	92.1[cdef]	90.6
Ohio d0	89.2	95.3	83.6	91.7[cd]	91.5	89.1[cd]	89.5	92.8[cd]	90.0[cde]	87.2[cd]	93.9[cdef]	89.5
Ohio d15	90.0	95.6	84.2	92.7[cd]	92.7	90.2[cd]	90.9	93.6[cd]	90.7[d]	88.5[cd]	95.6[f]	91.1
Ohio d30	88.9	95.3	82.6	91.6[cd]	91.2	89.0[cd]	90.3	93.1[cd]	90.0[cde]	87.3[cd]	93.5[cdef]	89.1
Ohio d45	88.6	95.5	81.7	91.4[cd]	91.7	88.9[cd]	89.8	92.3[cd]	90.0[cde]	86.5[cd]	92.0[cdef]	89.3
SEM	1.2	1.3	3.5	0.9	1.1	0.9	1.1	0.9	0.9	1.4	1.4	1.1

[a,b]Means in the same column lacking common superscript letters are different ($P < 0.05$).
[c,d,e,f]Means in the same column lacking common superscript letters are different ($P < 0.05$).

drolyzed casein or a zein diet compared with either a protein free-diet or a synthetic amino acid-supplemented diet. These findings support the hypothesis that the CP content of the diet induces endogenous losses (cellulose has minimal effects on endogenous losses; Furuya and Kaji, 1992), and digestibility data corrected with endogenous loss data obtained with animals fed a protein-supplemented diet should not be compared with data obtained with a protein-free diet (NRC, 1998 is based on correction with a protein-free diet).

Significant location effects were observed on endogenous secretions, with NL and OH having low endogenous secretions, and IL having high endogenous secretions (Table 5). Within location, applying the LPC correction on an animal basis increased variation in digestibility coefficients (on average, a 5% increase in variation was noted when the animal served as its own control). This suggests that the repeatability of the digestibility assay within animals is no better than among animals within location, or that animals respond differently to the LPC diet than to the test diets.

In contrast to expectations (e.g., based on NRC, 1998), soy protein concentrate feeding resulted in lower digestibility of most amino acids compared with soybean meal (except for lysine, Table 6). As this concerns only a single sample of soy protein concentrate, no conclusions about the digestibility of amino acids in soy protein concentrate can be made.

Differences in the digestibility among the test soybean meal samples were relatively minor (Table 6). Only samples KS d15 and NL d45 had higher digestibilities for several of the amino acids than samples NL d0 and NL d15 ($P < 0.05$). Other statistical differences observed were for single amino acids and did not indicate clear trends for generally higher or lower digestibilities.

The lack of variation in the digestibility of the soybean meal samples within location but collected at different time points suggests that processing conditions affect digestibility little over time. These data also suggest that such processing conditions vary little among the different processing sites, in line with our expectation as samples were obtained from large processing plants all using similar technologies (Balloun, 1980).

The LPC standardized digestible amino acid content of the test soybean meal samples averaged per location are provided in Table 7. Nutritionally relevant differences were observed for Lys and Met, which were low in the NL samples ($P < 0.05$), and in Thr, for which NC and OH samples were higher ($P < 0.05$) than for the other locations. The KS samples had higher Trp levels than NC, IL, and NL ($P < 0.05$).

The principal component analysis of total and digestible Lys, Met, Cys, Thr, and Trp, and OM, CP, TNC, and TDF (Figure 3) demonstrated that the total and digestible amino acids co-vary strongly. Total Met and digestible Met and total Lys and digestible Lys effectively had the same loadings on the first and second components, whereas the other three amino acids had very small differences. This suggests that for the sam-

Table 7. Low-protein casein-standardized digestible amino acid content of the test soybean meal samples by site (%, DM basis)

Amino acid	Illinois	Kansas	N. Carolina	Netherlands	Ohio	SEM
Arg	3.90[a]	3.79[b]	3.97[a]	3.74[b]	4.01[a]	0.034
Cys	0.73[c]	0.78[d]	0.68[b]	0.64[a]	0.74[c]	0.010
His	1.43[c]	1.40[bc]	1.37[ab]	1.34[a]	1.38[ab]	0.013
Ile	2.14	2.20	2.24	2.19	2.24	0.032
Leu	3.76	3.74	3.86	3.73	3.77	0.046
Lys	3.13[b]	3.12[b]	3.17[b]	2.83[a]	3.12[b]	0.024
Met	0.79[c]	0.75[b]	0.73[b]	0.67[a]	0.72[b]	0.011
Phe	2.50	2.58	2.55	2.52	2.55	0.033
Thr	1.79[a]	1.77[a]	1.87[b]	1.74[a]	1.87[b]	0.018
Trp	0.73[a]	0.78[b]	0.72[a]	0.73[a]	0.75[ab]	0.014
Val	2.27	2.26	2.29	2.36	2.33	0.033

[a,b,c]Data in the same row lacking common superscript letters are different ($P < 0.05$).

ple population tested, measuring digestibility added little value over simply measuring the amino acid concentration and using a fixed digestibility coefficient. The principal component analysis also showed that samples with high CP, TNC, and OM contained less total and digestible Trp. Tryptophan also proved to be a rather "independent" amino acid, not co-varying at all with Lys, and having a negative correlation with CP.

Interestingly, TDF did not have a strong negative correlation with the digestible amino acid content of the samples. This is in contrast with the findings of van Kempen and Simmins (1997), who showed that NDF and ADF were good predictors of the digestible amino acid content of soybean meal, having a strong negative relationship with the digestible amino acid content. These authors, however, had access to a larger database with many extreme samples (but all analyzed using the same procedures), whereas in the present study, the samples were rather homogeneous.

Regression of digestible vs total Met (Figure 4), Lys, Cys, Thr, and Trp confirmed that the digestible amino acid content of the soybean meal samples could be derived easily from the total amino acid content. The prediction equations obtained are provided in Table 8. Negative intercepts for Met, Cys, Thr, and Trp are likely related to the correction for endogenous losses, with Thr having relatively high endogenous losses compared with the CP composition of soybean meal (i.e., the ratio between Thr in endogenous losses and Thr in soybean meal is higher than those for the other amino acids).

Extrapolating the digestible amino acid content from the CP content of the samples was not successful (using cross-validation). For Met, Cys, and Trp, no variation could be explained based on CP, whereas for Lys and Trp, less than 5% of the variation could be explained. These findings are consistent with results of van Kempen and Simmins (1997), who suggested that measuring CP does not provide insight into the nutritional

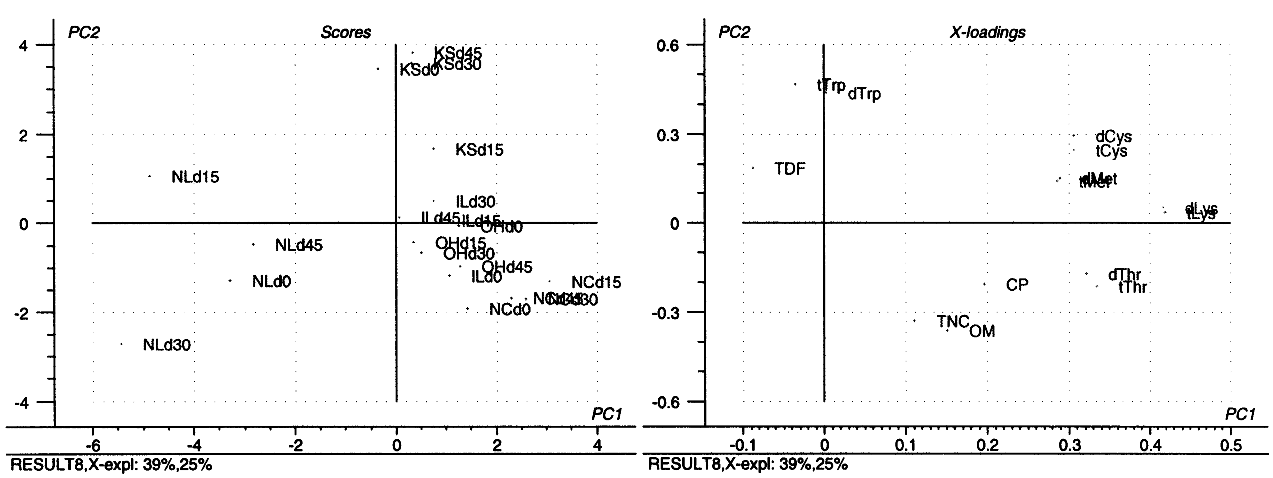

Figure 3. Principal component analysis on total (t) and digestible (d) Lys, Met, Cys, Thr, and Trp, and OM, CP, TNC (total nonstructural carbohydrates), and TDF (total dietary fiber). Component 1 explained 39% of the variation and Component 2 explained 25% of the variation. Left panel: orientation of the samples relative to the principal components. Right panel: orientation of the parameters relative to the principal components.

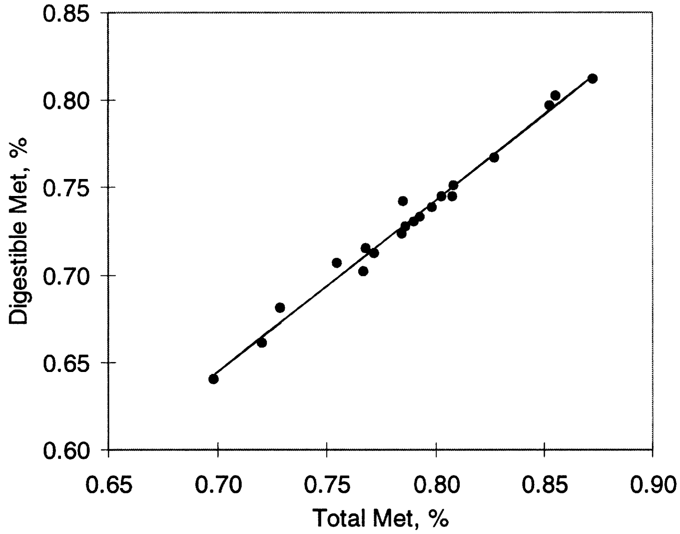

Figure 4. Digestible methionine content extrapolated from total methionine content of the test samples.

value of feedstuffs such as corn and soybean meal. Adding other components did not aid in explaining variation for Lys, Cys, and Met, likely resulting from the lack of variability in chemical components in the present experiment. For Thr and Trp, adding chemical components allowed for 18 and 6%, respectively, of the variation to be explained, whereas TDF had a negative regression coefficient for Thr and a positive coefficient for Trp.

Selenium digestibility was determined in the OH samples only (Table 9). Because Se in grain is largely in the form of selenomethionine or one of its analogs, the apparent absorption of Se in our trial would be expected to be similar to that of methionine. Selenium apparent digestibilities were high in all OH samples, ranging from 95.7 to 97.8%. Selenium concentrations in the test soybean meal samples are presented in Table 10. Selenium concentrations are consistent with previously reported Se values from soybean meal samples collected from each region (Cromwell et al., 1999). In general, the east coast and the eastern part of the Midwest have areas that are low in Se, whereas areas in the western part of the Corn Belt have higher Se concentrations. The samples obtained from NL were variable, which may be attributed to the soybeans being imported from different regions of the world.

Apparent ileal energy digestibility was determined only in NC samples (Table 9), using the assumption that the digestibility of the excipients in the test diets equaled that of the LPC diet (Scott et al., 1976). The ileal energy digestibility ranged from 72.1% for the common soybean meal to 78.7% for soy protein concentrate. The energy digestibility of the NC test soybean meal samples ranged from 75.6 to 78.5%, and NC d45 tended to be different from common soybean meal ($P < 0.06$). Uncorrected for the digestibility of the LPC diet, apparent energy digestibility of the test soybean meal samples averaged 84%, which is similar to the values reported by Chang et al. (1987).

The amino acid concentrations and amino acid digestibility results of this experiment are compared with NRC (1998) data in Table 11. Numerically, the samples tested in this experiment had a higher amino acid content and a higher apparent digestibility than the NRC data, except for Cys and Thr. The NRC is a compilation of digestibility data collected from several countries and thus is more likely to include batches of soybean meal that were produced under poor conditions.

For true digestibility data calculated according to NRC (1998) guidelines, differences between the current data set and that of the NRC (1998) were negligible for all amino acids except Cys and Thr. The basal endogenous correction applied in this study was derived from Tran et al. (1999), whose data are based on approximately 110 tests with protein-free diets. National Research Council (1998) relied strongly on the same data set for its true digestibility data, which makes this difference surprising. The explanation for this difference may lie in high endogenous secretions rich in Cys and Thr due to the use of young pigs in this trial, which is not corrected properly compared with an endogenous correction based on a different set of (older) pigs. This observation deserves further study because it impacts nutrient evaluations and requirements.

In conclusion, LPC-standardized digestibility of samples was strongly affected by research site, with a difference of 7 percentage units between the site with the highest and the site with the lowest overall CP and Lys digestibilities (based on common soybean meal and soy protein concentrate, Figure 2). The reason for this difference is unknown.

Table 8. Regression equations for predicting digestible amino acids (%, DM basis) from total amino acids (%, DM basis)

Amino acid	Intercept	Slope	r^2	RMSEP[a]
Lys	0.227	0.834	0.96	0.025
Met	−0.040	0.979	0.98	0.006
Cys	−0.056	0.899	0.94	0.013
Thr	−0.192	0.957	0.90	0.022
Trp	−0.023	0.950	0.89	0.012

[a]RMSEP = root mean squared error of prediction.

Table 9. Selenium digestibility of OH and energy digestibility of NC soybean meal and soy protein concentrate samples

Item	Selenium (Ohio only)	Energy (N. Carolina only)
Soybean meal	97.8[a]	72.1[a]
Soy protein concentrate	97.0[b]	78.7[b]
D0	96.8[b]	75.7[ab]
D15	96.2[bc]	75.6[ab]
D30	95.7[c]	75.6[ab]
D45	97.3[ab]	78.5[ab]
SEM	0.2	2.2

[a,b,c]Values in the same column lacking common superscript letters are different.

Table 10. Selenium content (mg/kg) of the test soybean meal samples

	Location				
Item	Illinois	Kansas	N. Carolina	Netherlands	Ohio
d0	0.136	0.599	0.087	0.186	0.074
d15	0.170	0.577	0.078	0.345	0.103
d30	0.146	0.628	0.117	0.064	0.103
d45	0.150	0.548	0.086	0.023	0.101
Average	0.151[a]	0.588[b]	0.092[a]	0.155[a]	0.095[a]

[a,b]Data in the "average" row lacking common superscript letters are different ($P < 0.05$; SEM = 0.033).

Table 11. Summary of the results of the current experiment as compared with the values of NRC (1998)

	Total amino acids, %, DM basis		Apparent digestibility, %		NRC true digestibility, %		Low-protein casein-corrected digestibility, %
Item	Current	NRC	Current	NRC	Current	NRC	Current
Arg	4.07	3.87	92.5	90	94.8	94	95.4
Cys	0.85	0.82	77.3	79	82.4	87	83.3
His	1.51	1.42	88.3	86	90.7	91	91.8
Ile	2.41	2.40	85.5	84	88.7	89	91.4
Leu	4.24	4.07	84.9	84	88.0	89	89.0
Lys	3.42	3.36	86.3	85	89.4	90	90.0
Met	0.79	0.74	88.2	86	91.1	91	92.7
Phe	2.83	2.66	86.5	84	89.5	89	89.7
Thr	2.09	2.02	78.3	78	83.7	87	86.5
Trp	0.81	0.72	87.6	81	90.6	90	92.1
Val	2.57	2.52	83.5	81	87.5	88	89.6

Within the United States, the location of soybean production and the processing of the meal seemed to have minor effects on the chemical composition and the digestibility of the soybean meal, suggesting greatly standardized growing and processing conditions. Regional differences in total amino acid composition were observed, suggesting that growing practices affect the amino acid composition of soybeans.

Soybean meal samples obtained in NL were lower in Lys, Met, and Thr than were U.S. samples and were more variable, which might be due to NL soybeans being imported from countries where growing conditions may not be optimal. Digestibility, however, was very similar to that of the U.S. samples, suggesting that the effects of Dutch processing techniques on digestibility were similar to those of the United States.

The digestible amino acid content of soybean meal can be extrapolated from the total amino acid content; the total amino acid content explained 89 to 98% of the variation in the digestible amino acid content. Crude protein, however, explained an inconsequential amount of variation in the digestible amino acid content of soybean meal.

The selenium content of soybean meal samples was in line with expectations based on regional origin of the samples, with OH and NC having 0.09 mg/kg; IL, 0.15 mg/kg; and KS, 0.59 mg/kg. Samples from NL were variable, the lowest being 0.02 mg/kg and the highest, 0.35 mg/kg, in line with the fact that NL imports soybeans from different parts of the world, thus leading to a more variable product.

Finally, the digestibility results obtained in this experiment are in good agreement with the findings for soybean meal published in the NRC (1998), except for Cys and Thr, for which lower digestibilities were observed in this experiment.

Implications

Soybean meal collected in four regions within the United States varied little in nutrient content and digestibility. Samples collected in The Netherlands, which is an importer of soybeans, were more variable, and, due to a lower amino acid content, had a lower nutritional value. Thus, within the United States, quality control of soybean meal can be limited to checking for amino acid composition and processing errors. A fixed digestibility coefficient can be used for the determination of digestible amino acids if the soybean meal is processed by a large processor.

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