

Soybean Meal – An Exceptional Protein Source

Gary L. Cromwell, PhD
Emeritus Professor
Animal and Food Sciences Department
University of Kentucky

Soybean meal has long been considered an outstanding source of supplemental protein in diets for livestock and poultry. In fact, soybean meal is sometimes referred to as the "gold standard" because other protein sources are often compared to it. Soybean meal is rich in highly digestible protein, and the protein is composed of a superior blend of amino acids, the building blocks of body protein for livestock and poultry.

A Brief History of Soybeans

Soybean meal, obviously, comes from soybeans, a crop that has a very interesting background. The soybean is thought to have originated in China as many as 5,000 or more years ago. In 1804, sailors first brought soybeans from China to the United States as inexpensive ballast for their ships. The soybeans were dumped at U.S. ports to make room for cargo returning to China.

Soybeans were first grown in the United States in 1829 and used for a variety of purposes including production of soy sauce, as an inexpensive substitute for coffee by soldiers during the Civil War, as a "green manure" crop, and as forage for cattle. The pioneering research with soybeans by George Washington Carver at Tuskegee Institute in 1904 opened new avenues for usage of soybeans as a source of protein and oil rather than simply for forage.

Crushing of soybeans for oil production began on a small scale in 1918. In 1929, approximately 10,000 soybean varieties were imported from China for U.S. researchers to study which laid the foundation for the rapid ascension of the United States as a world leader in soybean production.

A major event that boosted the use of soybeans was World War II. Before the war, the United States imported nearly one-half of its edible fats and oil. At the onset of the war, oil supplies to the United States were cut off, so processors and users had to turn to other sources of oil, mainly soybean oil. Also, the increased demand for meat and meat products during the war was a contributing factor to increased use of alternative protein sources in foods and feeds.

Other factors also contributed to the expansion of soybean usage. Discoveries of technologies that improved the quality of soybean oil for human use and the development of solvent processing to more efficiently remove the oil and produce a higher quality meal with less heat-damaged protein were contributing factors. Finally, with the discovery in 1948 of vitamin B₁₂, the "animal protein factor" found in meat scraps, fish meal, and other high-protein meals of animal origin, production of vitamins allowed the swine and poultry industries to use this supplement in all-plant, grain-soybean meal diets. All of these discoveries resulted in an explosive expansion of the soybean industry in the United States.

Additional information on the history of soybeans can be found at www.soymeal.org/factsheets/.

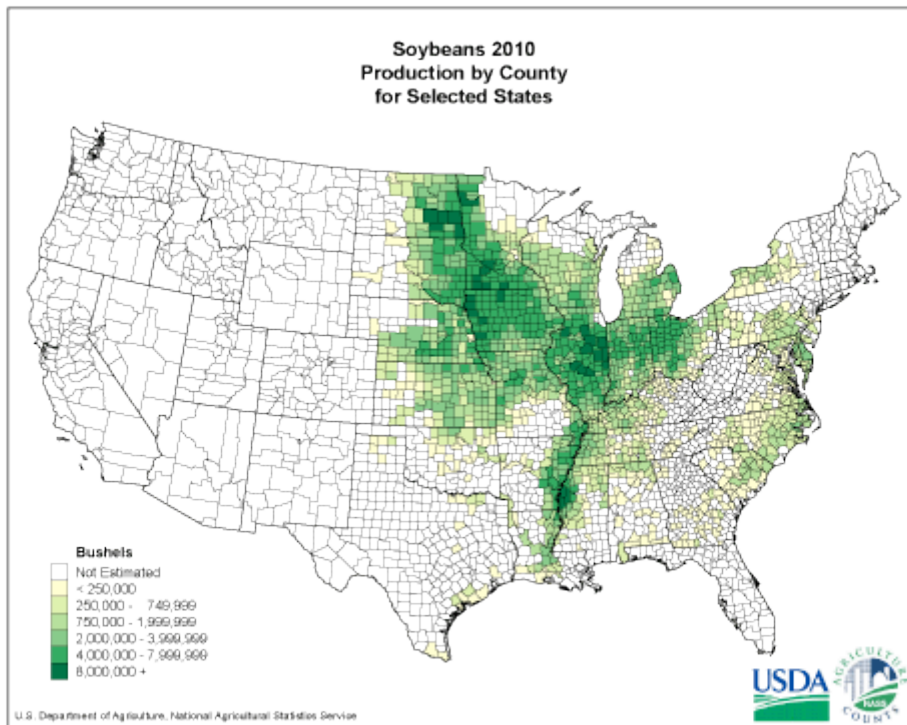
World Production of Soybeans and Soybean Meal

Soybeans are by far the most popular oilseed crop produced in the world today. Soybeans represent 55% of the total global production of oilseeds followed by rapeseed (14%), cottonseed (10%), peanut (8%), sunflower (9%), palm kernel (3%), and copra (1%).

The United States leads the world in soybean production. The U.S. produces approximately 34% of the world's soybeans, followed by Brazil (29%), Argentina (19%), and China (6%). In 2011, the United States produced 3.06 billion bushels of soybeans worth \$38 billion dollars. During the past 40 years, acreage devoted to soybean production has increased from 43.5 million acres in 1971 to 73.6 million acres in 2011. The 73.6 million acres of

soybeans harvested in 2011 compares with 91.1 million acres of corn and 45.7 million acres of wheat. Soybean acreage far exceeds the acreage harvested from sunflowers (1.4 million acres) and other oilseeds. Yield of soybeans has increased from about 25 bushels per acre to over 41.5 bushels per acre during the past 40 years.

Soybean production by county for crop year 2010 is shown in the following illustration. .



Approximately 1.3 billion bushels of soybeans are crushed annually in the U.S. In the 2010/2011 crop year, the U.S. produced nearly 36 million metric tons of soybean meal which represents approximately 20% of the world's soybean meal production, ranking second only to China (25%). Other major producers of soybean meal are Argentina (17%), Brazil (16%), the European Union (6%), and India (4%).

Domestic use of soybean meal differs considerably among countries. China uses essentially all of the soybean meal that they produce (43.4 million metric tons used versus 43.6 million metric tons produced); whereas the United States uses about three-quarters of the soybean meal that is produced domestically (27.5 million metric tons used versus 35.6 million metric tons produced). Brazil uses 48%, India uses 40%, and Argentina uses 2.5% of the meal that they produce. The European Union uses over three times as much soybean meal as it produces, indicating that a large percentage of their soybean meal usage is imported. Nearly one-fourth (23%) of the soybeans produced in the United States is exported as whole soybeans or soybean meal.

Globally, soybean meal accounts for nearly 69% of all protein sources used in animal feeds followed by rapeseed (canola) meal (13%), cottonseed meal (6%), sunflower meal (5%), fish meal (2%), and peanut meal (2%). However, in the U.S. soybean meal accounts for approximately 92% of the total oilseed meals fed to livestock and poultry. Approximately 48% of the soybean meal is used in poultry feeds followed by 26% in swine feeds, 12% in beef cattle feeds, 9% in dairy cattle feeds, 3% in fish feeds, and 2% in pet foods.

Popularity of Soybean Meal

One might ask the question – why is soybean meal such a popular source of protein for livestock and poultry? The answer is actually quite simple. Not only does soybean meal have a high concentration of protein (44% to 49%), the

protein is highly digestible, and the amino acids that are released from the protein following digestion consist of a blend that is ideal for nonruminants – swine and poultry. In other words, the digestible amino acid profile of soybean protein more closely matches the amino acids requirements of these species than any other oilseed meal. Soybean meal is a rich source of lysine, tryptophan, threonine, isoleucine, and valine – the amino acids that are seriously deficient in corn, grain sorghum, and other cereal grains that are commonly fed to swine and poultry. However, the amino acids are not perfectly balanced; they tend to be low in methionine and cystine.

One way of comparing the quality and nutritional value of the protein in soybeans and soybean meal to that of other oilseeds is to compare their lysine content as a percentage of the protein. The reason for using lysine as the comparator is that lysine is generally considered the first limiting amino acid for swine and most other nonruminant animals (poultry is an exception; methionine is first limiting and lysine is second). Soy protein contains approximately 6.5% lysine which is not greatly different from the lysine content of muscle protein (it ranges from 6.5 to 7.0% lysine). Other oilseed meals have considerably less lysine in their protein. For example, the lysine content of canola meal protein is 5.8%. The lysine content of the protein in cottonseed meal, peanut meal, and sunflower meal is even lower – only 4.2%, 3.4%, and 2.8%, respectively.

Table 1. Relative amount of lysine in soybean protein and in protein of other feedstuffs of plant origin (as fed basis)^a

Feedstuff	Protein %	Lysine %	Lysine % of protein	Relative to SBM ^b
Plant protein sources				
Soy protein concentrate	64.0	4.20	6.6	102
Soybean meal, dehulled	47.5	3.02	6.4	100
Soybean meal	43.8	2.83	6.4	100
Soybeans, full-fat, heat processed	35.2	2.22	6.3	98
Soy protein isolate	85.8	5.26	6.1	95
Canola meal	35.6	2.08	5.8	91
Cottonseed meal	41.4	1.72	4.2	65
Linseed meal	33.6	1.24	3.7	57
Peanut meal	49.1	1.66	3.4	53
Sunflower meal, dehulled	42.2	1.20	2.8	44
Safflower meal, dehulled	42.5	1.17	2.8	43
Coconut (copra) meal	21.9	0.58	2.6	41
Sesame meal	42.6	1.01	2.4	37
Cereal grains				
Barley	0.41	3.6	56	
Oats	11.5	0.40	3.5	54
Wheat, soft	11.5	0.38	3.3	51
Corn	8.3	0.26	3.1	49
Triticale	12.5	0.39	3.1	49
Grain sorghum	9.2	0.22	2.4	37
Grain byproducts				
Wheat bran	15.7	0.64	4.1	63
Brewers grains	26.5	1.08	4.1	63
Wheat middlings	15.9	0.57	3.6	56
Corn gluten feed	21.5	0.63	2.9	46
Distillers grains with solubles	27.7	0.62	2.2	35
Corn gluten meal	60.2	1.02	1.7	26

^aProtein and lysine levels in feedstuffs from NRC (1998).

^bRelative to the lysine as percent of protein in soybean meal.

Types of Soybean Meal

The two major kinds of soybean meal available for use in the livestock and poultry industry are conventional soybean meal (43-44% protein) and dehulled soybean meal (47-49% protein). Today, in modern soybean processing plants, soybeans, which contain approximately 35% protein and 18% oil, are processed using a solvent extraction process which removes most of the oil. The oil-extracted residue consists of protein, carbohydrates (sucrose, oligosaccharides, and fibrous components), minerals and vitamins. This residue is then heated to drive off the solvent and carefully toasted to a prescribed temperature. Time is factored in to deactivate the trypsin inhibitors and some of the other undesirable anti-nutrients leaving a high quality soybean meal. Soybean hulls are either blended back with the meal to standardize the crude protein to 44%, or they are not left out which results in dehulled soybean meal.

Care must be taken to sufficiently heat the soybean meal, not to overheat it. Overheating will cause the binding of the amino acids with carbohydrates causing reduced digestibility of the amino acids, especially lysine. Other amino acids can be damaged by overheating. The urease test is commonly used to test for proper heating. It is based on the premise that the naturally occurring urease enzyme in soybeans is destroyed at a comparable rate as the trypsin inhibitor. A properly heated meal should contain no more than 0.2 pH rise in urease activity, but a complete lack of urease could indicate overheating. Solubility of the soybean protein in a 0.2% KOH solution can be used to test for overheating. Using this test, the solubility index should be 80 to 85% in properly heated meal.

The various steps in producing a high quality, solvent-extracted soybean meal are described in more detail and several flow schematics are shown in Soybean Meal INFOcenter fact sheet on Soybean Processing www.soymeal.org/factsheets/.

Composition of Soybean Meal

Numerous tables are available that summarize the composition of conventional and dehulled soybean meal. Tables 2 and 5 are from the *Nutrient Requirements of Swine* and are based on summaries of exceptionally large databases from the feed industry and university laboratories. The composition of other soy products that are less commonly used (e.g., heat-processed, full-fat soybeans, soy protein concentrate, and soy protein isolate) are also included.

Nutrient Soybean	Dehulled Meal	Heated Full-fat Soybean Meal	Soy Protein Soybeans	Soy Protein Concentrate	Isolate
Metab. energy, Mcal/kg	3.382	3.294	3.938	3.50	3.56
Crude protein, %	43.9	47.7	37.6	64.0	85.8
Fat, %	1.24	1.52	20.18	3.0	0.6
Fiber-NDF, %	9.52	5.28	10.00	-	-
Fiber-ADF, %	6.66	1.10	6.17	-	-
Minerals					
Calcium, %	0.35	0.33	0.31	0.35	0.15
Phosphorus, %	0.64	0.71	0.53	0.81	0.65
Sodium, %	0.01	0.08	0.03	0.05	0.07
Chloride, %	0.05	0.05	0.03	-	0.02
Potassium, %	1.96	2.24	1.64	2.20	0.27
Magnesium, %	0.29	0.27	0.28	0.32	0.08
Sulfur, %	0.39	0.40	0.30	-	0.71
Copper, ppm	17	15	16	13	14
Iron, ppm	225	98	80	110	137
Manganese, ppm	41	35	30	-	5

Selenium, ppm ^b	0.32	0.27	0.11	-	0.14
Zinc, ppm	50	49	39	30	34
Vitamins					
Biotin, mg/kg	0.27	0.26	0.24	-	0.30
Choline, g/kg	2.79	2.73	2.31	-	2.00
Folacin, mg/kg	1.37	1.37	3.60	-	2.50
Niacin, mg/kg	34	22	22	-	6
Pantothenic acid, mg/kg	16.0	15.0	15.0	-	4.2
Riboflavin, mg/kg	2.9	3.1	2.6	-	1.7 ^d
Thiamin, mg/kg	4.5	3.2	11.0	-	0.3 ^d
Vitamin B ₆ , mg/kg	6.0	6.4	10.8	-	5.4 ^d
Vitamin B ₁₂ , µg/kg	0	0	0	-	0
Vitamin E, mg/kg ^c	2.3	2.3	18.1	-	-
β-carotene, mg/kg ^d	.2	.2	1.9	-	-

^aNRC (2012); a "-" indicates the value is unknown.

^bExtremely variable; dependant on the region where soybeans were grown.

^cAs α-tocopherol.

^d1 mg of all-trans β-carotene = 267 IU of vitamin A or 80 µg of vitamin A alcohol (retinol) or 92

Soybean meals also contain relatively small amounts of minerals and vitamins compared to the quantities of these nutrients required by swine and poultry (Table 2). Some of the minerals, especially phosphorus, are poorly available to swine and poultry. Most of the phosphorus in soybeans is organically bound as phytic acid and its salts (phytate) and these species lack the necessary enzymes in their digestive tract to degrade phytate and release the phosphorus for absorption.

Of the various minerals and vitamins in soybean meal, selenium is the most variable. The amount of selenium in soybean meal is highly dependent on the area where the soybeans were produced. In one study, soybean meal from Michigan, Indiana, Ohio and Kentucky contained 0.12 to 0.18 ppm selenium compared with 0.65 to 0.85 ppm selenium in soybean meal from Nebraska, Iowa, and the Dakotas (Cromwell et al., 1999).

The concentrations of amino acids in soybean meal and other soy products are closely related to the amount of crude protein in the meal or product. For example, conventional soybean meal contains approximately 2.83% lysine compared with 3.02% lysine in the higher protein, dehulled soybean meal. This relative difference is found for the other amino acids as well. In a study involving 31 sources of soybean meal from 15 universities over a 2-year period, the lysine content of soybean meals was closely correlated with crude protein content of the meals ($r = 0.90$; Cromwell et al., 1999).

Regression analysis indicated that lysine increased by 0.063 of a percentage point for each one percentage point increase in crude protein. According to equations developed from extensive analysis of a large number of soybean meal samples over many years by the Degussa Corporation, lysine increases by 0.064 percentage unit, threonine by 0.038 unit, tryptophan by 0.012 unit, methionine by 0.014 unit, and methionine + cystine by 0.026 percentage unit for each one percentage unit increase in crude protein (Fickler et al., 1995; NRC, 1998).

As mentioned previously, soybean protein is highly digestible meaning that, in pigs, the individual amino acids released from the digesta at the end of the small intestine (i.e., terminal ileum) result in relatively high digestibility coefficients. For example, the standardized digestibility coefficients (SID) in pigs for lysine (listed as true digestibility coefficients in the NRC publication), are approximately 90% for soybean meal. The SID coefficients for the other essential amino acids range from 85 to 94%. The SID coefficients for lysine (89 to 90%) are higher in soybean meal than for other oilseed meals (canola meal (78%), cottonseed meal (64%) or sunflower meal (83%); or for cereal grains (corn (78%), barley (79%), wheat (81%)) (Table 5).

Table 3. Amino acid composition of soybean products (as fed basis)^a

Amino acid	Soybean Meal	Dehulled Soybean Meal	Heated Full-fat Soybeans	Soy Protein Concentrate	Soy Protein Isolate
Total Amino Acids. %					
Arginine, %	3.17	3.45	2.60	5.79	6.87
Histidine, %	1.26	1.28	0.96	1.80	2.25
Isoleucine, %	1.96	2.14	1.61	3.30	4.25
Leucine, %	3.43	3.62	2.75	5.30	6.64
Lysine, %	2.76	2.96	2.22	4.20	5.26
Methionine, %	0.60	0.66	0.53	0.90	1.01
Cystine, %	0.68	0.70	0.55	1.00	1.19
Phenylalanine, %	2.26	2.40	1.83	3.40	4.34
Tyrosine, %	1.55	1.59	1.32	2.50	3.10
Threonine, %	1.76	1.86	1.41	2.80	3.17
Tryptophan, %	0.59	0.66	0.48	0.90	1.08
Valine, %	1.93	2.23	1.68	3.40	4.21
Apparent Ileal Digestibility Coefficients, %					
Arginine	90	92	84	91	
Histidine	84	87	78	95	88
Isoleucine	84	87	75	93	90
Leucine	83	86	75	92	
Lysine	85	87	79	93	88
Methionine	85	88	75	91	-
Cystine	76	79	70	-	
Phenylalanine	85	86	77	94	88
Tyrosine	83	84	77	89	
Threonine	78	80	71	90	85
Tryptophan	85	88	79	89	-
Valine	79	83	73	91	86
True (Standardized) Ileal Digestibility Coefficients, %					
Arginine	92	94	87	-	
Histidine	86	90	81	97	-
Isoleucine	88	89	78	95	-
Leucine	86	88	78	-	
Lysine	88	89	81	95	-
Methionine	89	90	80	94	-
Cystine	84	84	76	-	
Phenylalanine	87	88	79	97	-
Tyrosine	86	88	81	-	
Threonine	83	85	76	94	-
Tryptophan	90	91	82	93	-
Valine	84	87	77	94	

^aNRC (2012); a "-" indicates the value is unknown.

Table 6. Ileal digestibility of lysine for swine in soybeans, soybean meal, and other feedstuffs of plant origin^a

Feedstuff	Ileal Digestibility of Lysine, %	
	Apparent	True (Standardized)
Plant protein sources		
Soy protein concentrate	93	95
Soybean meal, dehulled	85	90
Soybean meal	85	89
Soybeans, heated, full-fat	81	86
Soy protein isolate	88	-
Canola meal	74	78
Cottonseed meal	61	64
Linseed meal	70	-
Peanut meal	78	88
Sunflower meal, dehulled	74	83
Safflower meal, dehulled	-	-
Coconut (copra) meal	51	-
Sesame meal	76	85
Cereal grains		
Oats	70	76
Barley 68	79	
Wheat, soft	73	81
Corn	66	78
Triticale	76	81
Grain sorghum	62	81
Grain byproducts		
Wheat bran	69	71
Brewers grains	69	82
Wheat middlings	75	89
Corn gluten feed	51	66
Distillers grains with solubles	47	59
Corn gluten meal	75	80

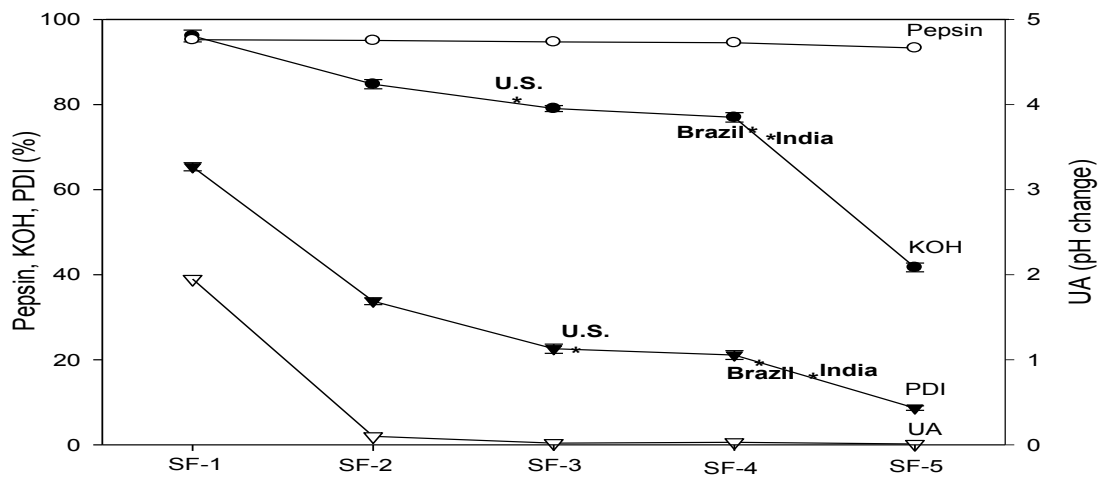
^aNRC (1998); a "-" indicates that the value is unknown.

Soybean Meal Quality Differences

Several studies have been conducted to determine quality differences between soybean meals. One study compared both quality assays and the quality of commercial soybean meal available to the Korean feed manufacturer. In this experiment raw soy flakes steam were processed for different periods of time with levels of heat to produce meals differing in heat treatment. Meals of different origins were also subjected to the various quality assays.

They reported that the protein digestibility index (PDI) is a sensitive soybean meal quality. PDI values changed linearly with the amount of heat processing; urease levels (UA) had value in measuring soybean meals with insufficient heat-treatment, but was not a good measurement of over-toasting or heat damage; protein solubility in KOH was a sensitive measure of over-heating process; and pepsin digestibility (PD) was not sensitive enough to measure differences in heat-treatment. Their conclusion was to use combination of PDI and KOH to predict protein quality of soybean meals.

Figure 1. Quality indexes of soy flakes heat-treated for various time periods and soybean meals from various origins



Treatments included: Protein quality measurements of heat-treated soy flakes. SF1: Raw soy flake; SF2: Steamed at 95 °C for 5 min; SF3: Steamed at 110 °C for 5 min; SF4: Steamed at 110 °C for 15 min; SF5: Steamed at 110 °C for 60 min. U.S.: and quality measurement for U.S. dehulled soybean meal; Brazilian soybean meal; and Indian soybean meal.

Soybean meal quality assays included: 1) Urease Activity Index, evaluated by method of AOAC (1980); 2) Protein soluble in KOH, evaluated by a method of Araba and Dale (1990); 3) Pepsin digestibility, evaluated by method of AOAC (1990); and 4) Protein Dispersibility Index, evaluated by method of AOAC. (1980).

(* *Reference: Kwang-Youn Whang. 2003. Nutritional value of U.S. dehulled soybean meal and Non-dehulled Soybean Meals from Brazil and India in pigs. American Soybean Association-International Marketing. Contact #4310-092003-0020 with Kwang-Youn Whang, Department of Animal Science, Korea University.*

Soybeans and soybean meal from different regions of the world have been shown to differ significantly. Analysis of 71 soybean meal samples collected from nine countries indicated that soybean meal processed in the United states was superior to the other major meals in terms of their absolute content of the top five key amino acids as well as their estimated digestible amino acids (Baize, 2000). This study also reported the KOH protein solubility indexes were highest in the U.S. samples indicating superior processing of the soybean meal.

In October, 1999 John C. Baize and Associates contracted with Smith Bucklin& Associates (SBA) to undertake to carry out a global soybean meal sampling and analysis project (USB Project # 0586) on behalf of the Quality Committee of the United Soybean Board. With the decision by the USB to eliminate the Quality Committee in December 1999 management of the project was subsequently transferred to the American Soybean Association (ASA), the USB's international marketing contractor.

Sample Collection. The project was begun in October 1999 with requests being sent to ASA's foreign office directors in Beijing, Tokyo, Seoul, Singapore, Brussels, Vienna, and Istanbul. These offices were selected because they are responsible for countries where US soybean meal is imported and must compete with soybean meal exported by Argentina, India, Brazil, and the European Union.

A total of 71 soybean meal samples were collected from the following meal origins:

USA	17 samples	India	17 samples	Argentina	10 samples
China	1 sample	Brazil	14 samples	EU	8 samples
Syria	1 sample	Malaysia	1 sample	Philippines	2 samples

It is important to note that it was not possible to collect samples of soybean meal using methodologies that assured the samples were representative of the overall meal shipments. Instead, samplers attempted to collect samples that appeared as much as possible to represent the overall shipments. It is assumed that was done.

Analysis Methodology. All samples collected by ASA foreign staff were sent to John C. Baize where they were assigned a number provided by the Grain Quality Laboratory at Iowa State University. At this time the samples' origin and country of collection were entered into a database. All samples were then sent by UPS to the Grain Quality Laboratory at Iowa State University.

When the staff at the Iowa State Grain Quality Laboratory received the samples, all were thoroughly mixed and ground and then split into 4 sub-samples. In the case of a few samples the volume was insufficient to create 4 sub-samples and only 2 were created. Two of the sub-samples were sent at different times to Woodson-Tenent Laboratories in Des Moines, Iowa where all were analyzed for moisture, crude protein, crude fiber, and fat/oil content. One of the sub-samples was analyzed for protein solubility (KOH method). The Iowa State Grain Quality Laboratory sent the remaining two sub-samples to the University of Missouri where each was analyzed for amino acids. This procedure resulted in all but a few samples being analyzed in duplicate for crude protein, crude fiber, fat/oil, and amino acids and once for protein solubility.

Once the results of laboratory analyses by Woodson-Tenent and the University of Missouri were received by the ISU Grain Quality Laboratory, all analysis results data were corrected mathematically to a 12% moisture basis to allow a fair comparison of the various samples for the various factors analyzed. The data were then sent to John C. Baize and Associates for compilation and statistical analysis.

Results of Sample Analysis. The following are the average moisture, protein, fiber, fat, amino acid, and KOH protein solubility levels of the soybean meals analyzed:

The only factor utilized to classify a soybean meal as low-pro (non-dehulled) or high-pro (dehulled) was the crude fiber content of the meal. If the average crude fiber content of a sample was 4% or lower it was classified as high-pro meal while samples over 4% were classified as low-pro meal. This is an arbitrary dividing line. However, it is generally recognized that any dehulled soybean meal should have a fiber content of less than 4%.

If one multiplies the average crude protein of the major types of soybean meal samples analyzed by the average KOH protein solubility level (to estimate likely digestible protein) then one finds that US high-pro and low-pro soybean meals stand out far above the other meals. The following is an indication of the estimated digestible protein levels of the major meal types.

It would appear that US high-pro soymeal may supply as much as 5.8% more digestible protein than Brazilian high-pro soymeal and 16.6% more digestible protein than Argentine high-pro soymeal. US low-protein soymeal would appear to provide more digestible protein than all of the meals analyzed except US high-protein soymeal and EU soymeal. The worst soybean meal in terms of likely digestible protein was Argentine low-pro meal.

The tables below shows the average total amino acid levels of the major meals analyzed as well as the total of the five most important amino acids provided by soybean meal to swine and poultry rations. In addition, the table shows the KOH protein solubility level for each meal and an estimated amino acid digestibility derived by multiplying the amino acid levels times the KOH level.

Summary of Soymeal Analysis Data

Characteristic	US Hi-Pro	US Low-Pro	Argentine Hi-Pro	Argentine Low-Pro	Brazilian Hi-Pro	Brazilian Low-Pro	Indian Meal	EU Meal
# Samples	14	2	2	8	5	9	17	8
Moisture	11.04	11.71	11.82	11.63	11.87	9.80	11.61	10.89
Protein	48.61	45.44	46.83	44.81	48.91	46.94	46.98	47.79
Fat	1.45	1.77	2.26	1.72	1.65	1.56	1.03	1.40
Fiber	3.66	5.38	3.49	5.86	3.75	5.90	6.09	3.89
KOH Solubility	84.08	85.50	74.87	76.82	78.98	80.64	80.96	82.32
Lysine	3.04	2.91	2.86	2.85	2.95	2.82	2.92	2.88
Methionine	0.69	0.65	0.64	0.61	0.67	0.61	0.64	0.67
Threonine	1.85	1.75	1.81	1.73	1.86	1.76	1.81	1.81
Cystine	0.75	0.72	0.72	0.66	0.76	0.68	0.68	0.75
Tryptophane	0.70	0.66	0.64	0.63	0.70	0.67	0.66	0.69
Taurine	0.05	0.07	0.06	0.05	0.04	0.04	0.05	0.03
Hydroproline	0.05	0.05	0.07	0.08	0.07	0.10	0.09	0.06
Aspartic Acid	5.36	5.07	5.19	4.97	5.48	5.15	5.33	5.26
Serine	2.14	1.96	2.25	2.04	2.33	2.12	2.24	2.13
Glutamine	8.70	8.19	8.53	8.01	9.02	8.43	8.72	8.72
Proline	2.32	2.18	2.29	2.12	2.43	2.27	2.29	2.36
Lanthionine	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Glycine	1.98	1.92	1.91	1.88	1.98	1.89	1.95	1.92
Alanine	2.07	1.99	2.01	1.93	2.08	1.97	2.03	2.02
Valine	2.29	2.21	2.25	2.19	2.23	2.16	2.24	2.21
Isoleucine	2.12	2.02	2.05	1.98	2.09	2.02	2.09	2.04
Leucine	3.70	3.51	3.62	3.47	3.74	3.56	3.66	3.60
Tyrosine	1.71	1.63	1.62	1.61	1.70	1.65	1.68	1.68
Phenylalanine	2.45	2.33	2.37	2.30	2.49	2.37	2.41	2.39
Hydroxylysine	0.02	0.02	0.00	0.02	0.01	0.01	0.01	0.01
Histidine	1.29	1.23	1.23	1.22	1.27	1.22	1.25	1.25
Ornithine	0.03	0.04	0.04	0.05	0.04	0.03	0.04	0.03
Arginine	3.51	3.33	3.43	3.29	3.58	3.40	3.41	3.46
Total Amino Acids	46.83	44.47	45.59	43.69	47.49	44.93	46.20	45.76

Summary of Digestibility Data for Soymeal Samples

Characteristic	US Hi-Pro	US Low-Pro	Argentine Hi-Pro	Argentine Low-Pro	Brazilian Hi-Pro	Brazilian Low-Pro	Indian Meal	EU Meal
	84.08	85.50	74.87	76.82	78.98	80.64	80.96	82.32
Crude Protein	48.61	45.44	46.83	44.81	48.91	46.94	46.98	47.79
Est. Digestible Protein Content	40.87	38.85	35.06	34.42	38.63	37.85	38.04	39.34
Rank	1	3	7	8	4	6	5	2

Summary of the Key Amino Acid Content of Soymeals

Characteristic	US Hi-Pro	US	Argentine	Argentine	Brazilian	Brazilian	Indian	EU Meal
		Low-Pro	Hi-Pro	Low-Pro	Hi-Pro	Low-Pro	Meal	
Lysine	3.04	2.91	2.86	2.85	2.95	2.82	2.92	2.88
Methionine	0.69	0.65	0.64	0.61	0.67	0.61	0.64	0.67
Threonine	1.85	1.75	1.81	1.73	1.86	1.76	1.81	1.81
Cystine	0.75	0.72	0.72	0.66	0.76	0.68	0.68	0.75
Tryptophan	0.70	0.66	0.64	0.63	0.7	0.67	0.66	0.69
Total of above	7.03	6.69	6.67	6.48	6.94	6.54	6.71	6.80
Total Amino acids	46.83	44.47	45.59	43.69	47.49	44.93	46.20	45.76
KOH Solubility	84.08	85.5	74.87	76.82	78.98	80.64	80.96	82.32
Est. Digestible Total Amino Acids	39.37	38.02	34.13	33.56	37.51	36.23	37.40	37.67
Digestible 5 Key Amino Acid Coefficient	5.91	5.72	4.99	4.98	5.48	5.27	5.43	5.60

The above table clearly shows that US high-pro and low-pro soymeal appear to be superior to the other major meals in terms of their absolute content of the top 5 key amino acids as well as estimated digestible total and key amino acids. This is a likely a key reason that animals fed US soybean meal perform better than animals fed competing soybean meals. In short, US soymeal appears to have higher levels of the key amino acids as well as a higher availability of those amino acids to animals.

In another study involving 15 samples of soybean meals from the U.S., India, Argentina, and Brazil, protein solubility index was highest (78%) for the U.S. meals and ranged from 20% to 72% for meals from the other countries. The standardized ileal digestibility of all amino acids by broilers was 87.0% for the U.S. soybean meal compared with 83.2, 86.6, and 86.1% for the meals from the other three countries.

Table 5. Nutrient Analysis, Metabolizable Energy and Digestible Amino Acids of Soybean meals of Different Origin for Broilers

	U.S.	India	Argentina	Brazil
Number of Samples	3	4	4	4
Dry Matter	88.2±0.14	88.5±0.59	88.5±0.53	88.2±0.40
Crude Protein	54.0±0.68	51.4±1.72	51.8±1.08	52.0±0.69
Crude Fat	1.6±0.15	1.1±0.36	2.1±0.25	2.2±0.11
Crude Fiber	4.3±0.25	6.3±1.44	4.1±0.42	4.3±0.09
Ash	7.5±0.16	7.7±0.36	8±0.14	6.7±0.12
NFE	34.5±3.40	33.6±0.51	35.2±1.46	34.9±0.55
NFE	7.9±0.16	12.3±3.37	8.10±0.92	7.40±0.40
Urease Index	0.11±0.11	0.07±0.07	0.01±0.01	0

Protein Solubility	78.1±1.65	20.2±0.75	69.6±1.24	72.6±1.77
Total Amino Acids Concentration (expressed on a percent as received basis)				
Aspartic Acid	5.52±0.05	5.71±0.21	5.60±0.08	5.64±0.33
Threonine	1.84±0.02	1.69±0.07	1.76±0.06	1.76±0.04
Serine	2.17±0.05	2.14±0.13	2.15±0.03	2.13±0.06
Glutamic Acid	7.93±0.21	8.37±0.20	8.28±0.23	8.00±0.18
Proline	2.20±0.07	2.19±0.12	2.11±0.15	2.22±0.06
Glycine	1.87±0.03	1.95±0.06	1.92±0.10	1.94±0.06
Alanine	1.90±0.02	1.80±0.02	1.94±0.03	2.04±0.07
Valine	2.44±0.07	2.11±0.06	2.21±0.04	2.18±0.15
Isoleucine	2.63±0.07	2.17±0.10	2.19±0.07	2.12±0.04
Leucine	3.63±0.07	3.35±0.17	3.38±0.08	3.54±0.06
Tyrosine	1.76±0.09	1.69±0.12	1.76±0.08	1.76±0.18
Phenylalanine	2.45±0.06	2.39±0.06	2.55±0.05	2.58±0.21
Histidine	1.30±0.05	1.25±0.08	1.29±0.04	1.22±0.08
Lysine	3.09±0.10	2.80±0.08	2.81±0.10	2.86±0.09
Arginine	3.42±0.05	3.29±0.14	3.40±0.13	3.31±0.06
Cysteine	0.79±0.03	0.68±0.03	0.70±0.03	0.72±0.07
Methionine	0.70±0.03	0.54±0.03	0.62±0.03	0.62±0.05
Standardized Ileal Amino Acid Digestibility (Percent)				
Crude Protein	86.3±0.66	82.2±1.35	85.4±1.98	85.5±1.43
Aspartic Acid	86.1±0.70	81.8±2.34	85.0±2.09	84.9±0.35
Threonine	83.3±0.05	79.8±1.09	83.4±1.57	83.1±0.59
Serine	86.6±1.41	82.9±1.72	86.6±1.50	85.8±0.30
Glutamic Acid	89.6±1.10	86.8±1.47	89.5±1.67	89.2±0.64
Proline	87.2±1.68	82.5±1.68	85.0±0.96	85.3±0.65
Glycine	86.3±0.72	81.6±2.05	85.3±1.88	85.8±0.93
Alanine	87.2±1.16	84.3±0.73	87.3±1.44	86.7±1.02
Valine	96.5±1.25	84.0±0.62	87.0±1.29	86.1±1.02
Isoleucine	87.5±1.26	84.8±0.72	87.8±1.30	87.0±0.77
Leucine	87.4±1.14	84.6±0.74	87.6±1.36	86.6±1.09
Tyrosine	89.0±1.15	86.1±0.80	89.2±1.41	88.5±1.47
Phenylalanine	88.0±1.64	85.0±2.00	88.6±1.28	86.4±3.05
Histidine	86.5±3.47	83.0±3.01	85.6±2.31	86.1±1.05
Lysine	91.0±0.74	87.4±0.77	90.9±1.28	89.9±2.30
Arginine	91.1±1.24	89.8±0.24	91.5±1.33	91.3±0.80
Cysteine	76.3±1.90	62.9±9.11	71.4±3.94	70.6±7.81
Methionine	89.5±0.91	87.2±0.97	89.7±1.88	89.9±1.85
Average of All AA	87.0±1.22	83.2±1.09	86.6±1.58	86.1±1.23
<i>Reference: Preliminary Report on a Contract Research Project Conducted by the Monogastric Research Centre, Massey University, Palmerston North, NEW ZEALAND; October 2011</i>				

Anti-Nutritional Factors in Soybeans and Soybean Meal

Most all of the oilseeds possess a certain amount of anti-nutritional factors, and soybeans are no exception. Several of these factors are known to cause depressed growth performance in swine. Some of these factors can be reduced or eliminated by various processing methods and by plant breeding programs.

Trypsin Inhibitors. Soybeans contain several factors that inhibit the activity of trypsin, one of the major protein-digesting enzymes in the intestinal tract of pigs. Fortunately, these inhibitors are destroyed by moist heat, so they are

routinely destroyed during the normal processing steps in preparing soybean meal. If unprocessed, the feeding of diets with whole, unprocessed soybeans to young pigs will severely depress growth due to the trypsin inhibitors. Older pigs seem to tolerate the inhibitors better than young pigs. Generally, full-fat soybeans should be roasted or heated in some way to destroy the enzyme inhibitors.

Plant breeders have successfully produced soybeans with reduced amounts of trypsin inhibitors. Research conducted at the University of Kentucky with low-trypsin inhibitor soybeans showed that they were significantly better than normal soybeans when fed as whole unprocessed beans to growing pigs. The study showed that the low-trypsin soybeans still required some heat processing to maximize their nutritional value. About half as much heat was required with low-trypsin inhibitor soybeans as with normal soybeans (Herkelman et al., 1992).

Phytate Phosphorus. Most of the phosphorus in soybeans is in an indigestible form called phytic acid or phytate. Pigs do not have the digestive enzymes to degrade this phytate into a form of phosphorus that can be utilized by pigs. To overcome this problem, additional inorganic phosphorus (in the form of mono- or dicalcium phosphate) must be added to the diet. The end result of the poor phosphorus utilization and the additional inorganic phosphorus that must be included in the diet is that excessive phosphorus is excreted in the manure which contributes to environmental pollution.

Genetically modified soybeans with low phytate content have been developed and experiments at the University of Kentucky have shown that the bioavailability of phosphorus in low- phytate soybean meal is several times greater than in normal soybean meal. The use of low-phytate soybeans also reduce phosphorus in pig manure. This type of soybean, however, is not yet commercially available.

Oligosaccharides. Raffinose and stachyose are two types of short-chained carbohydrates that make up about 5-7% of the soybean. These oligosaccharides are not digested and are generally thought to cause digestive disturbances especially in early-weaned pigs when soybean meal is fed at too high a level in the diet. However, a study at the University of Illinois with growing pigs (35 kg body weight) demonstrated that soy oligosaccharides did not have a large effect on the digestibility of dry matter, protein or amino acids in soybean meal.

Soybean oligosaccharides can be removed by special processing, resulting in a product called soy protein concentrate. Also, mutant genes have now been identified that eliminate or greatly reduce the oligosaccharides in soybeans. Incorporation of these genes into commercial soybean varieties should have a positive impact on the nutritional value of soybean meal for young, early-weaned pigs.

Antigenic Factors. Young pigs are hypersensitive to certain immunologically active soybean proteins, glycinin and β -conglycinin (Stokes et al., 1984), resulting in the development of an inflammatory response in the intestine when high levels of soybean meal are included in the diet. Typically, intestinal morphology is altered and absorption of nutrients is depressed. The allergenicity of soybean protein apparently is greater if pigs are exposed to soybean meal during the nursing phase (Li et al., 1990). Soy protein concentrate and soy protein isolate produce less of an allergic response than soybean meal according to studies by Li et al. (1991) and Sohn et al. (1994). Because of the antigenicity of soybean meal, other protein sources and amino acids are often included in diets for early-weaned pigs so that soybean meal is not the only source of supplemental protein.

Other Factors. Soybeans contain compounds called lectins (hemagglutinins) that bind with intestinal cells and interfere with absorption of nutrients. Fortunately, the lectins are destroyed with proper heat treatment. Other compounds such as saponins, lipoxidase, phytoestrogens, and goitrogens also exist in soybeans, but whether or not they have anti-nutritional effects in pigs is not well understood.

Other Beneficial Factors

Several factors have been identified in soybeans and soybean meal that may have beneficial effects. Various isoflavones in soybeans were found to improve growth and stimulate lean tissue synthesis in young pigs in a study at Iowa State (Cook et al., 1998). Inclusion of soy genistein in diets of pigs challenged with a harmful virus reduced

concentrations of the virus in serum and improved growth rate (Greiner et al., 1999).

Plant breeders have successfully produced soybeans with high oleic acid content using recombinant DNA strategies (Anderson, 1997). Oil from high oleic acid soybeans has potential for humans because of the perceived health benefits from monounsaturated fatty acids. Because pigs and poultry tend to alter the fatty acid composition of their body fat depending on the type of fat they consume, the feeding of high oleic soybeans could potentially be used to alter the fatty acid composition of pork or chicken toward a higher proportion of monounsaturated fatty acids.

Summary Comments

- SBM is the premium protein ingredient that complements feed grains to produce optimum livestock and poultry performance. Its amino acid balance complements the amino acid pattern of corn to produce diets to support optimum economic performance;
- SBM is a time-tested feed ingredient---SBM has been widely studied for most of the past century---No other feed ingredient has been so thoroughly studied as SBM. There are volumes of technical papers and reports that support SBM use;
- SBM's value to the feed formulator is based on its composition, price and availability; other meal benefits include being a palatable protein ingredient without toxins, residues, etc;
- SBM is a highly available source of digestible amino acids and energy—Few other protein ingredients have consistently high levels of digestible amino acids needed for optimum animal, poultry and aquaculture production;
- Soybean meal is a relatively rich source of phosphorus, important for growth and bone integrity of livestock and poultry. However, the phosphorus is only moderately available to nonruminants due to its organic nature (phytate), but the common practice of including supplemental dietary phytase renders some of this phosphorus available to swine and poultry;
- SBM is widely available to the feed formulator. Volume amounts are available year-around for long-term ration planning;
- SBM is a uniform product that the nutritionists can plan on for providing key nutrients important for least-cost computer feed formulation; and
- SBM is produced by sophisticated processing facilities that are carefully controlled to maximize a consistent quality product in both compositional and physical properties. In-plant monitoring of processing and products assure that SBM is a consistent, quality protein ingredient for the formulator of feeds.

For these results, ***SBM is clearly the protein of choice for the feed industry.***

References

- Anderson, P. C. 1997. Crop biotechnology for feed improvement. Proc. Nottingham Easter School Nutrition Conference. Nottingham University Press, Nottingham, U.K.
- Baize, John C. 2000. Global soybean meal sampling and analysis activity. United Soybean Board contract #0586 with John C. Baize, Falls Church, Virginia.
- Cook, D. R., T. S. Stahly, and P. A. Murphy. 1998. The effect of dietary soybean isoflavone on carcass muscle and body growth in pigs fed from 6 to 32 kg BW. *J. Anim. Sci.* 76(Suppl. 2):57 (Abstr.).
- Cromwell, G. L., C. C. Calvert, T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, D. C. Mahan, E. R. Miller, J. L. Nelssen, J. E. Pettigrew, L. F. Tribble, T. L. Veum, and J. T. Yen. NCR-42 Committee on Swine Nutrition. 1999. Variability among sources and laboratories in nutrient analyses of corn and soybean meal. *J. Anim. Sci.* 77:3262-3273.
- Fickler, J., J. Fontaine, and W. Heimbeck. 1995. The Amino Acid Composition of Feedstuffs. Degussa Corporation, Ridgefield Park, NJ.
- Greiner, L. L., T. S. Stahly, and T. J. Stabel. 2001. The effect of dietary soy genistein on pig growth and viral replication during a viral challenge. *J. Anim. Sci.* 79:1272-1279.
- Herkelman, K. L., G. L. Cromwell, T. S. Stahly, T. W. Pfeiffer, and D. A. Knabe. 1992. Apparent digestibility of amino acids in raw and heated conventional and low-trypsin inhibitor-soybeans for pigs. *J. Anim. Sci.* 70:818-826.
- Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blaeha, J. D. Hancock, G. L. Allee, R. D. Goodband, and R. D. Klemm. 1990. Transient hypersensitivity to soybean meal in the early-weaned pig. *J. Anim. Sci.* 68:1790-1799.
- Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blaeha, R. D. Klemm, D. W. Giesting, J. D. Hancock, G. L. Allee, and R. D. Goodband. 1991. Measuring suitability of soybean meal products for early-weaned pigs with immunological criteria. *J. Anim. Sci.* 69:3299-3307.
- NRC. 2012. Nutrient Requirements of Swine (11th ed). National Research Council, National Academy of Science. National Academy Press, Washington, DC.
- NRC. 1998. Nutrient Requirements of Swine (10th ed). National Research Council, National Academy of Science. National Academy Press, Washington, DC.
- Sohn, K. S., C. V. Maxwell, D. S. Buchanan, and L. L. Southern. 1994. Improved soybean protein sources for early-weaned pigs: I. Effects on performance and total tract amino acid digestibility. *J. Anim. Sci.* 72:622-630.
- Stokes, C. R., T. J. Newby, B. G. Miller, and F. J. Bourne. 1984. The immunological significance of transient cell mediated immunity to dietary antigens. In: P. J. Quinn (Ed.) Cell Mediated Immunity. p 249. Commission of the European Communities, Luxembourg.
- Whang, Kwang-Youn. 2003. Nutritional value of U.S. dehulled soybean meal and Non-dehulled Soybean Meals from Brazil and India in pigs. American Soybean Association-International Marketing. Contact #4310-092003-0020 with Kwang-Youn Whang, Department of Animal Science, Korea University.
- U.S. Department of Agriculture. 2012. World Agricultural Supply and Demand Estimates. WASDE-503, February 9, 2012.