Soybean meal fed to pigs (*)

Hans H Stein
University of Illinois, Urbana-Champaign

Summary

Soybeans are an important crop in the United States and toasted soybean meal is the primary source of protein in swine diets because of its favorable concentration and balance of digestible amino acids. Diets for all groups of pigs greater than 20 kg may, therefore, be formulated on the basis of cereal grains and soybean meal and no other protein source is needed in the diets. Soybean meal may be produced as dehulled soybean meal or non-dehulled soybean meal and both sources may be used in diets fed to pigs. Soybean meal of good quality contains less than 7 units of trypsin inhibitors, has a urease activity of less than 0.20 and has a lysine to crude protein ratio that is greater than 6.0%. If these quality parameters are not met, reduced performance of the pigs is expected.

In addition to amino acids, soybean meal also provides calcium and phosphorus and if microbial phytase is added to the diets, phosphorus from soybean meal is usually well digested by pigs. The concentration of metabolizable energy (ME) in dehulled U.S. soybean meal is slightly greater than in corn and it appears that the concentration of ME in the soybean meal that has been produced during the last few years is greater than in soybean meal produced 15 to 20 years ago.

Introduction

Soybeans (*Glycine max*) are produced in the United States with almost 35 million hectares planted in 2010 (USDA-NASS, 2010). The majority of soybeans are crushed and the resulting defatted soybean meal is fed to poultry, pigs, and other livestock species as de-hulled soybean meal or non-de-hulled soybean meal. In 2009, 27 million tons of soybean meal was fed to poultry and livestock in the United States (ASA, 2010).

Raw soybeans contain anti-nutritional factors that are called trypsin inhibitors, which bind to and inactivate the protein-digesting enzyme trypsin. By inactivating trypsin, amino acid digestibility is reduced (Święch et al., 2004; Goebel and Stein, 2011a) and growth performance of pigs is, therefore, impaired if raw soybeans are fed to pigs. To avoid this problem, soybean products need to be heated before being fed to swine because heating inactivates the trypsin inhibitors (Goebel and Stein, 2011a). The final step in soybean crushing, therefore, involves toasting of the defatted meal, which results in inactivation of the trypsin inhibitors in soybean meal. If full fat soybeans are fed to pigs, they need to be roasted, extruded, or otherwise heat treated to make sure the trypsin inhibitors have been inactivated. The average concentration of trypsin inhibitors in raw soybeans is more than 35 trypsin inhibitor units, but this number is reduced to less than 5 units in properly heated soybeans and U.S. soybean meal. Trypsin inhibitor concentrations may also be estimated by the so-called urease activity. A urease activity of 0.20 or less is indicative of inactivation of trypsin inhibitors and indicates that the soybeans or soybean meal has been correctly heated.

Nutritional value of soybean meal

Soybeans contain approximately 35% crude protein and 19% fat (Table 1). However, after crushing, most of the fat is removed and the resulting soybean meal contains less than 2% fat.

The raw soybeans may be dehulled before crushing and this will result in production of de-hulled soybean meal, which contains approximately 47.5% crude protein. If soybeans are not de-hulled before crushing or if the hulls are added back to the soybean meal after crushing, a non-dehulled soybean meal, which contains approximately 43% crude protein, is produced.

Protein and Amino Acids

The protein in soybeans has an excellent balance of amino acids that compares well with the requirements of pigs. Soy protein has a concentration of both lysine and tryptophan, two of the indispensable amino acids for pigs, that is greater than that of almost all other plant proteins (Table 2). The concentration of many other indispensable amino acids such as threonine, isoleucine, and valine is also relatively high in U.S. soybean meal – these are all among the limiting amino acids in corn, wheat, sorghum, and barley (Lewis, 1985). Amino acids in soybean meal, therefore, complement the concentration of amino acids in cereal grains, which makes it possible to formulate diets that meet the requirements of pigs.

The digestibility of amino acids in protein fed to pigs is best characterized by the standardized ileal digestibility. The standardized ileal digestibility of most amino acids in U.S. soybean protein is greater than that of proteins from other plant ingredients, which results in absorption of a large proportion of dietary amino acids when U.S. soybean meal is included in the diets. The favorable digestibility of amino acids in U.S. soybean meal also results in relatively low amounts of nitrogen being excreted in the manure from pigs fed diets based on soybean protein. The digestibility of amino acids in dehulled U.S. soybean meal is greater than in non-dehulled soybean meal and the digestibility of amino acids in full fat soybeans is usually greater than that of dehulled soybean meal (Baker and Stein, 2010). However, the digestibility of amino acids in soybean meal may be increased if soybean oil is added to the diet (Cervantes-Pahm and Stein, 2008).

Diets fed to pigs are usually formulated based on ideal ratios of digestible amino acids and the usefulness of a protein source as an ingredient in diets fed to pigs can, therefore, be characterized by calculating the ideal ratio of digestible amino acids in that protein source. That is accomplished by dividing the digestible concentration of each amino acid by the concentration of digestible lysine, and then comparing that ratio with the required ratio of pigs. Based on such a comparison, it is evident that soy protein has a favorable balance of digestible amino acids.

Although heating of soybean meal is necessary to inactivate the trypsin inhibitors, overheating will reduce the digestibility of lysine and other amino acids (Gonzalez-Vega et al., 2011). Over-heating results in reductions in the concentrations of the digestibility as well as the concentration of lysine. A relatively easy way to assess if a particular source of soybean meal is over heated is to calculate the concentration of lysine as a percentage of crude protein. This ratio is between 6 and 6.5 in normal, undamaged soybean meal, but if the meal is heat damaged, the ratio can be less than 6.0 (Gonzalez-Vega et al., 2011). Overheating also often results in darkening of the meal so a darker color of soybean meal is also indicative of heat damage in that source of soybean meal.

Carbohydrates

Although soybeans are used primarily as a source of protein, they also bring significant quantities of carbohydrate to the diet. Carbohydrates in soybeans and soybean meal consist of structural as well as non-structural carbohydrates (Grieshop et al., 2003). The structural carbohydrates are mainly cellulose and hemi-cellulose, which may be calculated if concentrations of lignin, ADF, and NDF are analyzed (Table 3). The non-structural carbohydrates include sugars, sucrose, oligosaccharides, and small amounts of starch. All the non-structural carbohydrates and some of the structural carbohydrates are soluble, and therefore, easily fermentable by pigs. However, some of the structural carbohydrates are insoluble, and therefore, less fermentable, which results in a reduced energy value to pigs.

Most sources of U.S. soybean meal contain 5 to 7% oligosaccharides (also called alpha-galacto-oligosaccharides; Karr-Lilienthal et al., 2005). Pigs do not secrete the digestive enzymes necessary to cleave the α-1,6 linkages in these oligosaccharides; however, they are fermented in the digestive tract. This fermentation allows the pig to utilize the energy from the oligosaccharides and in pigs above approximately 20 kg oligosaccharides do not create any problems. However, younger pigs do not handle oligosaccharides very efficiently and negative side effects, including diarrhea and gastrointestinal discomfort, may be observed in young pigs if they are fed large quantities of soybean meal (Liying et al., 2003). The inclusion of soybean meal in diets fed to weanling pigs is, therefore, usually restricted to less than 20%.

Phosphorus and Calcium

Soybeans and U.S. soybean meal contain between 0.50 and 0.70% total phosphorus, but most of the phosphorus is bound to phytate (Table 4). Pigs produce no intestinal phytase, and therefore, cannot utilize the phytate-bound phosphorus, which is instead excreted in the manure. The digestibility of phosphorus in soybean meal is, therefore, usually less than 40% (Bohlke et al., 2005; Almeida and Stein, 2010). However, if microbial phytase is added to the diet, the digestibility of phosphorus may be improved to 50 to 70% (Almeida and Stein, 2010), which will result in a reduction in the amount of phosphorus being excreted in the manure. Thus, U.S. soybean meal can contribute a relatively high proportion of the total amount of phosphorus that is needed by pigs and only small amounts of inorganic phosphorus such as dicalcium phosphate or monocalcium phosphate is needed in diets containing soybean meal and microbial phytase.

Soybeans and U.S. soybean meal usually contain between 0.25 and 0.50% calcium, but greater concentrations may sometimes be observed. The apparent total tract digestibility of calcium in U.S. soybean meal is approximately 50% (Bohlke et al., 2005).

Energy

Soybeans contain more energy than soybean meal because the oil has not been removed and dehulled soybean meal has a greater energy digestibility than non-dehulled soybean meal, because pigs have a relatively low utilization of energy in the fiber-rich hulls that are included in the non-dehulled meals. The concentration of DE and ME in dehulled soybean meal, therefore, is greater than in non-dehulled soybean meal, although both sources of soybean meal contain less energy than full fat soybeans. The dehulled soybean meal that has been produced in recent years has, however, greater concentration of DE and ME than soybean meal that was produced earlier. As an example, the average ME value in U.S. soybean meal determined at the University of Illinois during the last few years is 4,017 kcal/kg DM (Table 5). In contrast, the current book value is 3,755 kcal/kg DM. This difference in ME of more than 250 kcal per kg adds more value to U.S. soybean meal. The reason for the increase in energy in U.S. soybean meal is not clear, but it may be related to increased digestibility of the nutrients in U.S. soybeans or factors related to selection of new varieties of U.S. soybeans. It is also possible that the previous values were underestimated.

Inclusion of soybean meal in diets fed to pigs

As mentioned above, weanling pigs do not tolerate great quantities of soybean meal in their diets because of the presence of oligosaccharides and antigens in soybean meal. Inclusion of soybean meal in diets fed to weanling pigs is, therefore, most often restricted to less than 20%. However, a few weeks post-weaning, this concentration may be increased and when pigs are around 20 kg, all supplemental protein in the diet may be furnished by soybean meal. Likewise, in diets fed to all growing-finishing pigs, U.S. soybean meal may be the only protein ingredient. If growing pigs are fed corn-based diets, approximately 28 to 30% dehulled U.S. soybean meal is needed to make sure the requirement for all indispensable amino acids is met. As pigs become older, they require less amino acids in the diets and the inclusion of soybean meal may, therefore, be reduced to between 20 and 26%. Gestating sows fed diets based on corn need approximately 14% de-hulled soybean meal in the diet, but because of the greater requirement for amino acids for milk production, diets fed to lactating sows need to contain 25-28% de-hulled soybean meal. At these inclusion levels, all indispensable amino acids in the diets other than those provided by corn will be furnished by soybean meal. If wheat, barley, or sorghum is the cereal source in the diets, the inclusion of soybean meal may be slightly changed to reflect the difference in concentrations of indispensable amino acids among cereal grains.

Conclusions

Dehulled and non-dehulled soybean meals are excellent sources of protein for pigs because soy protein has an excellent balance of indispensable amino acids. The digestibility of amino acids in soy protein is also greater than in most other proteins of plant origin, and the digestibility may be increased if soybean oil is added to the diets. Soybean meal can potentially be heat damaged, but the lysine to crude protein ratio can be calculated as an indicator of heat damage. In soybean meals that are not heat damaged, this ratio should be greater than 6%. Soybean meal also provides carbohydrates to the diets, but the concentration of fat in soybean meal is low. Concentrations of calcium and phosphorus are relatively high in U.S. soybean meal and if microbial phytase is also included in the diet, the need for inorganic phosphorus is greatly reduced. U.S. Soybean meal may provide all supplemental amino acids needed by growing-finishing pigs and sows, but in diets fed to weanling pigs, the inclusion of soybean meal should be restricted to less than 20%.

Literature cited

Almeida, F. N., and H. H. Stein. 2010. Performance and phosphorus balance of pigs fed diets formulated on the basis of values for standardized total tract digestibility of phosphorus. J. Anim. Sci. 88:2968-2977.

ASA. American Soybean Association. 2010. Soy Stats: A Reference Guide to Important Soybean Facts and Figures. Am. Soybean Assoc., St. Louis, MO.

Baker, K. M., and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to growing pigs. J. Anim. Sci. 87:2282-2290.

Baker, K. M., B. G. Kim., and H. H. Stein. 2010. Amino acid digestibility in conventional, high protein, or low oligosaccharide varieties of full-fat soybeans and in soybean meal by weanling pigs. Anim. Feed Sci. Technol. 162:66-73.

Bohlke, R. A., R. C. Thaler, and H. H. Stein. 2005. Calcium, phosphorus and amino acid digestibility in low phytate corn, normal corn, and soybean meal by growing pigs. J. Anim. Sci. 83:2396-2403.

Cervantes-Pahm, S. K., and H. H. Stein. 2008. Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs. J. Anim. Sci. 86:1841-1849.

Goebel, K. P. and H. H. Stein. 2011. Ileal digestibility of amino acids in conventional and low-Kunitz soybean products fed to weanling pigs. Asian-Austr. J. Anim. Sci. 24:88-95.

González-Vega, J. C., B. G. Kim, J. K. Htoo, A. Lemme, and H. H. Stein. 2011. Amino acid digestibility in heated soybean meal fed to growing pigs. J. Anim. Sci. 89:3617-3625.

Grieshop, C. M., C. T. Kadzere, G. M. Clapper, E. A. Flickinger, L. L. Bauer, R. L. Frazier, and G. C. Fahey. 2003. Chemical and nutritional characteristics of United States soybeans and soybean meals. J. Agric. Food Chem.

Karr-Lilienthal, L. K., C. T. Kadzere, C. M. Grieshop, and G. C. Fahey. 2005. Chemical and nutritional properties of soybean carbohydrates as related to nonruminants: A review. Livest. Prod. Sci. 97:1-12.

Liying, Z., D. Li, S. Qiao, E. W. Johnson, B. Li, P. A. Thacker, and I. K. Han. 2003. Effects of stachyose on performance, diarrhea incidence and intestinal bacteria in weanling pigs. Arch. Anim. Nutr. 57:1–10.

Święch, E., L. Buraczewska, and M. Taciak. 2004. The effect of trypsin inhibitor level in soy products on *in vitro* and *in vivo* (piglets and rats) protein and amino acid digestibility. Pages 247–250 in Recent Advances of Research in Antinutritional Factors in Legume Seeds and Oilseeds. M. Muzquiz, G. D. Hill, C. Cuadrado, M. Pedrosa, and C. Burbano, ed. Wageningen Academic Publishers, Wageningen, the Netherlands.

USDA-NASS. United States Department of Agriculture – National Agricultural Statistics Service. 2010. Acreage. http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0610.pdf. Accessed March 6, 2011.

(*) Presented at the U.S. Soybean Export Council's special program on the Nutritive Value of U.S. Soybean Meal that was held at the International Poultry Expo on January 25, 2012 at the Georgia World Congress Center in Atlanta, GA.

Table 1. Nutritional composition of U.S. soybeans and U.S. soybean meal

Product	Full-fat soybeans	44% U.S. SBM, nondehulled	48% U.S. SBM, dehulled
DM %	90.7	88.7	89.6
CP %	35.4	43.3	47.8
Fat %	19.36	1.5	1.34
Carbohydrates %	30.80	37.8	34.51
Ash %	5.14	6.1	5.95

Table 2. Crude protein and amino acid concentration and digestibility in soy products (as-fed basis)

Item	Concentration, %			Standardized ileal digestibility, %		
Product	Full-fat U.S. soybeans	44% U.S. SBM, nondehulled	48% U.S. SBM, dehulled	Full-fat U.S. soybeans	44% U.S. SBM, nondehulled	48% U.S. SBM, dehulled
CP	35.38	43.34	47.26	92.1	84.7	86.9
Indispensable AA						
Arg	2.73	3.26	3.36	94.9	93.5	94.3
His	0.96	1.21	1.21	89.8	89.8	89.8
Ile	1.62	1.98	2.06	87.1	87.1	87.8
Leu	2.71	3.47	3.56	87.9	86.8	89.2
Lys	2.25	2.87	2.98	89.3	88.5	88.9
Met	0.55	0.65	0.68	88.6	89.5	89.0
Phe	1.81	2.26	2.19	89.4	87.4	88.2
Thr	1.41	1.78	1.87	84.7	84.2	84.5
Trp	0.42	0.61	0.65	85.7	85.9	90.4
Val	1.71	2.11	2.12	86.0	84.6	85.8
Dispensable AA						
Ala	1.50	1.99	2.80	91.1	82.5	83.4
Asp	4.00	5.12	5.23	89.7	85.4	85.3
Cys	0.58	0.70	0.68	82.5	82.4	83.0
Glu	6.32	8.07	8.38	90.7	86.1	87.0
Gly	1.52	1.92	1.94	89.2	80.8	81.4
Pro	1.78	2.28	2.27	153.7	112.6	112.8
Ser	1.77	2.27	2.29	88.6	85.8	86.9
Tyr	1.30	1.67	1.70	89.0	88.7	88.8

Table 3. Carbohydrates in soy products (as-fed basis)

Product	Full-fat U.S. soybeans	44% U.S. SBM, nondehulled	48% U.S. SBM, dehulled
Sucrose, %	7.30	8.14	7.55
Raffinose, %	0.73	0.99	1.12
Stachyose, %	4.07	4.51	4.98
ADF, %	7.46	9.40	4.41
NDF, %	12.80	13.30	7.42

Table 4. Calcium and phosphorus concentration in soy products and apparent (ATTD) and standardized (STTD) total tract digestibility of phosphorus (as-fed basis)

Product	Full-fat U.S. soybeans	44% U.S. SBM, nondehulled	48% U.S.SBM, dehulled
Total P, %	0.56	0.65	0.68
ATTD P, %	32	31	38
Total Ca, %	0.28	0.32	0.35

Table 5. Concentration of energy in dehulled U.S. soybean meal

Product	NRC, 1998	Univ. of Illinois
As-fed basis		
DE, kcal/kg	3685	3778
ME, kcal/kg	3380	3536
DM basis		
DE, kcal/kg	4094	4292
ME, kcal/kg	3755	4017