UTILIZATION OF CO-PRODUCTS FROM CORN AND SOYBEANS, AND ALTERNATIVE PROTEINS BY PIGS

Hans H Stein

University of Illinois

http://nutrition.ansci.illinois.edu

CORN CO-PRODUCTS

Ground corn can be fed directly to animals but may also be used to produce industrial or food products such as ethanol, corn oil, corn sweeteners, corn flour, corn grits, etc. However, only a part of the corn kernel is used in the production of these products and several co-products that may be used in animal feeding are, therefore, also generated. The composition of these co-products depends on the processing that was used to generate the primary products, i.e., dry grinding, wet milling, or dry milling (NRC, 2012).

Co-Products from the Dry-Grind Industry

The dry grinding process is used primarily in the ethanol industry and the primary co-products that are generated from this process are distillers dried grains with solubles (DDGS), high protein distillers dried grain (HP-DDG), and corn germ. Ethanol is generated by fermenting the starch in the corn grain and the co-products from the dry grind industry are, therefore, generally low in starch, but contain the majority of the corn fiber, corn protein, and corn oil. Numerous experiments have been conducted to determine the composition and the nutritional value of these products and several reviews are available with detailed descriptions of the nutritional value of each product (Stein and Shurson, 2009; Stein, 2012). In general, the concentration of digestible energy (DE) and metabolizable energy (ME) in DDGS and corn germ is similar to that of corn (Guo et al., 2004; Pedersen et al., 2007; Stein et al., 2009), whereas HP DDG contains more DE and ME than corn. In some ethanol plants, oil is removed by skimming the solubles before they are added back to the distillers grains and that results in production of DDGS that contains between 6 and 9% fat, rather than 10 to 12% fat as is the case in regular DDGS. However, the concentration of DE and ME is not greatly influenced by this procedure (Ren et al., 2011; NRC, 2012). However, it is also possible to extract the oil from the DDGS using solvent extraction, and this will result in production of de-oiled DDGS, which contains less than 5% fat and the concentration of DE and ME in this ingredient is considerably less than in conventional DDGS (Jacela et al., 2011; Anderson et al., 2012).

The digestibility of amino acids (AA) in co-products from the dry-grind industry is slightly less than in corn and in some instances, the digestibility of Lys is significantly less than in corn due to heat damage during processing(Fastinger and Mahan, 2006; Pahm et al., 2008; Kim et al., 2012). The digestibility of P is generally high in ingredients that have been fermented (DDGS and HP-DDG), but in corn germ, which has not been fermented, the digestibility of P is similar to that in corn (Widmer et al., 2007; Almeida and Stein, 2012).

Co-Products from the Wet-Milling Industry

The primary co-products from the wet milling industry include corn gluten meal, corn gluten feed, and corn germ meal. Corn gluten meal is a high-protein ingredient that results from the removal of starch, germ, and some of the fibers in corn (Stock et al., 2000). The product contains more than 60% crude protein (CP), but as is the case with all other corn proteins, the concentration of Lys and Trp is low. Corn gluten meal is, therefore, not commonly used in diets fed to swine, but if correctly balanced for indispensable AA, diets containing at least 15% corn gluten meal may be fed to weanling pigs(Mahan, 1993), and for growing finishing pigs, diets may contain up to 30% corn gluten meal. The concentration of ME is greater in corn gluten meal than in corn (Guo et al., 2004; Anderson et al., 2012; Ji et al., 2012), and the digestibility of most indispensable AA is also greater than in corn (Almeida et al., 2011; Ji et al., 2012).

Corn gluten feed is a high fiber ingredient that is produced after the starch, the gluten, and the germ has been removed from the corn grain. The concentration of CP is 10 – 25% and the digestibility of AA is similar to that in corn (Almeida et al., 2011). The nutritional value may, however, vary somewhat among different batches of the ingredient and corn gluten feed is usually not included in diets fed to pigs. However, it is believed that at least 20% can be included in diets fed to growing-finishing pigs, and for gestating sows, diets may include up to 30% corn gluten feed (Honeyman and Zimmerman, 1991). The digestibility of AA in corn gluten feed is similar to that in corn (Almeida et al., 2011), but the digestibility of energy is less than in corn (Anderson et al., 2012).

Corn germ meal is produced when corn germ is de-oiled. The product has a high concentration of fiber (> 30% NDF), and contains 22 – 24% CP. The digestibility of AA is slightly less than in corn (Almeida et al., 2012), but because of the high concentration of fiber and the low concentration of fat in corn germ meal, the concentration of DE and ME is less than in corn grain (NRC, 2012). However, as is the case for most other corn co-products from the wet-milling industry, the digestibility of P is greater than in corn. Corn germ meal is an excellent ingredient for gestating sow diets and may be used by at least 40% in these diets. For growing and finishing pigs, up to 38% may be used without reducing average daily gain, but feed efficiency will be reduced because of the reduced concentration of DE and ME in the diets (Weber, 2010).

Co-Product from the Dry-Milling Industry

Hominy feed is the primary co-product from the dry-milling industry and contains the parts of the corn grain that are left after production of corn grits or corn flour (Larson et al., 1993; Stock et al., 2000). In contrast to most of the other corn co-products, the concentration of starch is relatively high in hominy feed (>50%), and the concentration of CP, fat, and fiber is similar to that in corn grain (NRC, 2012). The concentration of DE and ME in hominy feed is also similar to that in corn grain, but the digestibility of AA is less than in corn (Almeida et al., 2011). Hominy feed may replace at least 50% of the cereal grains in diets fed to all categories of pigs if diets are correctly balanced for AA.

CO-PRODUCTS FROM THE SOYBEAN INDUSTRY

Soybean products that are available to the feed industry include products that are produced from new varieties of soybeans as well as products that are a result of novel processing technologies applied to harvested soybeans or soybean meal. New varieties of soybeans are produced by modifying the genetic make-up of soybeans using biotechnological tools ("GMO-soybeans") or by using traditional plant breeding technologies (Stein et al., 2008). Genetic modification using biotechnology has primarily focused on modifying input traits by insertion of genes that infers in planta glyphosate tolerance to soybeans ("Round-up Ready" soybeans), whereas traditional plant breeding technologies primarily have been used to enhance output traits (Parsons, 2000). Modification of input traits of soybeans does not change the composition or the nutritional value of the soybeans or the soybean meal produced from these beans (Cromwell et al., 2002). In contrast, modification of output traits may change the composition of the beans as well as the nutritional value of the soybean meal produced from these beans (Cervantes-Pahm and Stein, 2008; Baker and Stein, 2009). Likewise, enzyme treatment or fermentation of conventional soybean meal may result in changes in both composition and nutritional value of the soybean meals that are produced (Cervantes Pahm and Stein, 2010; Goebel and Stein, 2011b; Rojas and Stein, 2012a). The composition and concentration of digestible energy and nutrients in most commonly produced soybean products were recently published (NRC, 2012).

Conventional Soybean Meal and Extruded-Expelled Soybean Meal

The majority of soybeans are de-hulled and crushed and the oil is removed via solvent extraction. The resulting soybean meal is used as a protein source in diets fed to pigs and because of the rapidly increasing demand for AA in the global feed industry, production of soybeans is increasing faster than that of any other agricultural crop in the world (Goldsmith, 2008). Conventional de-hulled soybean meal contains approximately 47.5% CP, but if soybeans are not de-hulled prior to crushing, the resulting soybean meal contains only 42.5% CP (NRC, 2012). To eliminate the negative influence of trypsin inhibitors in soybeans, soybean meal – like all other soybean products – need to be heat treated. Un-heated soybean meal contains approximately 35 units of trypsin inhibitors, but in correctly treated soybean meal, this value is reduced to less than 4 units (Goebel and Stein, 2011a). A urease test may be used to confirm proper heat treatment and a pH rise of less than 0.20 on a urease test is indicative of correct heat treatment (NRC, 2012). However, care should be taken not to overheat the soybean meal, because over-heating will result in reduced digestibility of Lysine and other indispensable amino acids (Gonzales-Vega et al., 2011). Overheating of soybean meal will result in a reduction in the Lysine:CP ratio. If the Lysine:CP ratio is above 6.0, the soybean meal has likely been correctly heated, but if the ratio is less than 6.0, the soybean meal is heat damaged (Gonzales-Vega et al., 2011).

Oil may also be removed from soybeans using a mechanical expelling process and because mechanical expelling of oil is less efficient than solvent extraction, this process results in production of soybean meal that contain between 5 and 8% fat. To inactivate the trypsin inhibitors, soybeans are often extruded before oil is expelled, and the resulting meal is, therefore, called "extruded-expelled soybean meal" (Woodworth et al., 2001; Baker and Stein, 2009). The digestibility of AA in extruded-expelled soybean meal is similar to that in conventional soybean meal. Most often, the soybeans that are extruded-expelled are not de-hulled and the concentration of NDF and ADF is, therefore, greater in extruded-expelled soybean meal than in conventional soybean meal (NRC, 2012). As a consequence, the concentration of DE and ME in extruded-expelled soybean meal is not greater than in conventional soybean meal despite the greater concentrationof fat (Baker and Stein, 2009).

Soybean Meal Produced from High-Protein and Low-Oligosaccharide Soybeans

Conventional soybeans contain approximately 35% CP and 19% crude fat, but recent efforts to increase the concentration of CP in the beans have resulted in selection of high-protein soybeans that contain 45 – 48% CP (Cervantes-Pahm and Stein, 2008; Baker et al., 2010). Soybeans that have reduced concentrations of oligosaccharides have also been selected and the soybean meal produced from these varieties contain more CP but less oligosaccharides than conventional soybean meal (Baker and Stein, 2009; Baker et al., 2010). The digestibility of AA and energy in soybean meal produced from high protein or low-oligosaccharide soybeans is not different from that in conventional soybean meal (Baker and Stein, 2009). However, because of the greater concentration of AA in these soybeans, the concentration of digestible AA is greater in soybean meal produced from high-protein or low-oligosaccharide soybeans compared with conventional soybean meal. Because of the reduced concentration of oligosaccharides in the low-oligosaccharide soybean meal, it is expected that young pigs better tolerate diets containing low-oligosaccharide soybean meal than conventional soybean meal.

Enzymatically Treated andFermented Soybean Meal

Conventional de-hulled soybean meal contains 5 to 7% sucrose, 6 to 8% oligosaccharides and antigens, but both oligosaccharides and antigens may be eliminated if soybeans are enzyme treated or fermented prior to use. During enzyme treatment and fermentation, both sucrose and oligosaccharides are eliminated and the concentration of other nutrients is, therefore, increased, and these meals contain 53 to 55% CP (Hong et al., 2004; Yang et al., 2007). The primary reason for eliminating the oligosaccharides is that they are not well tolerated by young pigs (Li et al., 1990), but because enzyme treated or fermented soybean meals do not contain oligosaccharides, these meals may be included in diets for young pigs (Jones et al., 2010; Kim et al., 2010; Yan et al., 2012). The digestibility of AA in enzyme treated or fermented soybean meal is similar to or greater than in conventional soybean meal (Cervantes-Pahm and Stein, 2010). The concentration of DE and ME is also similar to that in conventional soybean meal (Goebel and Stein, 2011b). However, fermentation hydrolyzes some of the phytate bonds in soybean meal and the concentration of phytate bound phosphorus is, therefore, less in fermented or enzyme treated soybean meal than in conventional soybean meal. As a consequence, the digestibility of phosphorus in fermented or enzyme treated soybean meal is greater than in conventional soybean meal (Goebel and Stein, 2011b; Rojas and Stein, 2012a).

Soy Protein Concentrate and Soy Protein Isolate

Soy protein concentrate is produced by chemically removal of the water- or alcohol-soluble non-protein components in conventional de-hulled soybean meal (Endres, 2001). To be classified as soy protein concentrate, the resulting meal must contain at least 65% CP (DM basis; Endres, 2001). The digestibility of AA in soy protein concentrate is greater than in conventional soybean meal (Cervantes-Pahm and Stein, 2008). Like enzyme treated or fermented soybean meal, soy protein concentrate does not contain oligosaccharides and it may, therefore, replace animal protein sources in diets fed to young pigs (Lenehan et al., 2007; Yang et al., 2007).

Soy protein isolate is also produced from conventional de-hulled soybean meal by removing most of the carbohydrates in the meal and the concentration of CP in soy protein isolate is, therefore, greater than 90% (DM basis; NRC, 2012). The digestibility of AA in soy protein isolate is similar to that of casein (Cervantes-Pahm and Stein, 2010), but because of the relatively high cost of the product, soy protein isolate is usually not used in commercial diets fed to pigs.

DUCKWEED, MICRALGAE, AND SINGLE CELL PROTEIN

Duckweed

Duckweeds (Lemna spp.) are small free floating aquatic plants that are grown on open waters worldwide (Archimede et al., 2011; Radic et al., 2011). They are of the botanical family Lemnaceae (Archimede et al., 2011) and contain 35-40% CP (Olorunfemi et al., 2006; Hasan and Chakrabarti, 2009). If plants are harvested and dehydrated, the resulting dehydrated Lemna plant may be included in diets fed to poultry and fish (Haustein et al., 1994; Bairagi et al., 2002). However the protein may also be extracted to produce a Lemna protein concentrate, which contains approximately 68% CP. The concentration of most indispensable AA in Lemna protein concentrate is greater than in soybean meal, but the concentration of phosphorus is less (Rojas and Stein, 2012b). When fed to pigs, Lemna protein concentratehas a digestibility of AA that is close to that of soybean meal, whereas the digestibility of phosphorus in Lemna protein concentrate is greater than in soybean meal and the concentration of DE and ME in Lemna protein concentrate is similar to that in soybean meal (Rojas and Stein, 2012b).

The plant tissue that is left after protein has been extracted is a high fiber product that has a composition that is similar to that of alfalfa meal. This ingredient is called Lemna meal and is mainly used in feeding of dairy cows. It is, however, likely that Leman meal also may be used in the feeding of gestating sows. However, for both Lemna protein concentrate and Lemna meal, experiments to evaluate effects of including these ingredients in diets fed to pigs are needed.

Microalgae

The annual global production of microalgae was recently estimated at approximately 10.000 metric ton dry matter (Becker, 2007). However, because some species of microalgae contains more than 20% crude fat, the interest in producing microalgae and use the oil in biodiesel production is increasing and it is, therefore, expected that the production of microalgae will increase in the future. There are more than 30,000 different species of microalgae and only a few hundred have been characterized in terms of chemical composition (Christaki et al., 2011). It has, however, been demonstrated that the concentration of nutrients vary significantly among different species, but the concentration of CP in many species is greater than 50% (dry matter basis). The AA composition of microalgae protein is similar to that in soybean protein (Christaki et al., 2011; Skrede et al., 2011). The digestibility of AA has not been determined when fed to pigs, but it has been demonstrated that the when fed to mink, the digestibility of AA in microalgae is less than that of soybean meal and also variable among species (Skrede et al., 2011). The lipids in microalgae have a high concentration of polyunsaturated omega-3 fatty acids, which may contribute to improved animal health (Christaki et al., 2011). The concentration of ash is relatively high (up to 15%), but the concentration or digestibility of phosphorus has not been reported. Likewise, there are no reports on the concentration of DE and ME in microalgae fed to pigs. It has, however, been reported that inclusion of 2% microalgae in diets fed to weanling pigs has no negative effects on pig growth performance (Grinstead et al., 2000), and inclusion of microalgae in diets fed to finishing pigs may increase the concentration of long-chained polyunsaturated fatty acids in pork (Marriot et al., 2002; Sardi et al., 2006).

Single Cell Protein

Single cell protein may be produced by bacteria that utilize mainly methanol or methane as substrate. The protein has a concentration of CP between 40 and 70% and a relatively high concentration of indispensable AA. However, up to 19% of the protein may be in the form of nucleic acids, which limits the utilization of the protein in nutrition, but pigs do not seem to be negatively affected by the relatively high concentrations of nucleotides (Øverland et al., 2010). It is also possible to reduce the concentration of nucleotides in the protein by separating fractions with the greatest nucleotide content after production. The digestibility of AA in single cell protein is slightly less than in soybean meal and fish meal (Skrede et al., 1998).

The concentration of P in single cell protein is between 1 and 2% and the digestibility is greater than 75% (Kim and Stein, 2010). The concentration of gross energy in single cell protein is greater than in corn and soybean meal because of the greater concentration of ether extract in the meal. However, the digestibility of energy in single cell protein is less than in soybean meal and the concentration of DE and ME in single cell protein is not different from the concentration in soybean meal (Hellwing et al., 2007; Kim and Stein, 2010).

There is a lack of information about the quantities of single cell protein that can be used in diets fed to pigs. However, it is likely that single cell protein will mainly be used in diets fed to weanling pigs as a substitute for fish meal. However, production experiments to verify that single cell protein may replace fish meal are needed to fully evaluate this ingredient.

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.

Almeida, F. N., and H. H. Stein. 2011. Standardized total tract digestibility of phosphorus in blood products fed to weanling pigs. Rev. Colomb. Cienc.Pecu. 24:617-622.

Almeida, F. N., and H. H. Stein. 2012. Effects of graded levels of microbial phytase on the standardized total tract digestibility of phosphorus in corn and corn co-products.J. Anim. Sci. 90:1262-1269.

Anderson, P.V., B. J. Kerr, T. E. Weber, C. J. Ziemer, and G. C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn co-products fed to finishing pigs. J. Anim. Sci. 90:1242-1254.

Archimede, H., C. Regnier, C. M.-M.Chevry, J. L. Gourdine, L. Rodriguez, and E. Gonzalez. 2011. The alternatives to soybeans for animal feed in the tropics. Chapter 15 in Soybeans Application and technology, Ng Tzi-Bun (ed). ISBN: 978-953-307-207-4, In Tech.

Baker, D. H. 2000. Nutritional constraints to the use of soy products by animals. Pp. 1-12 inSoy in Animal Nutrition, J. K. Drackley, ed. Savoy, IL: Federation of Animal Science Societies.

Baker, K. M., and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from 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.

Bairagi, A., K. Sarkar-Ghosh, S. K. Sen, and A. K. Ray. 2002. Duckweed (Lemnapolyrhiza) leaf meal as a source of feedstuff in formulated diets for rohu (Labeorohita Ham.) fingerlings after fermentation with a fish intestinal bacterium. Bioresource Technol. 85:17-24.

Becker, E. W. 2007. Microalgae as a source of protein.Biotechnol. Adv. 25:207-210.

Cervantes-Pahm, 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.

Cervantes-Pahm, S. K., and H. H. Stein. 2010. Ileal digestibility of amino acids in conventional, fermented, and enzyme treated soybean meal and in soy protein isolate, fishmeal, and casein fed to weanling pigs. J. Anim. Sci. 88:2674-2683.

Christaki, E., P. Florou-paneri, and E. Bonos. 2011. Microalgae: A novel ingredient in nutrition. Int. J. Food Sci. Nutr. 62:794-799.

Cromwell, G. L., M. D. Lindemann, J.H. Randolph, G.R. Parker, R.D. Coffey, K.M. Laurent, C.L. Armstrong, W.B. Mikel, E.P. Stanisiewski, and G.F. Hartnell. 2002. Soybean meal from Roundup Ready or conventional soybeans in diets for growing-finishing swine. J. Anim. Sci. 80:708–715.

Endres, J. G. 2001. Soy Protein Products.Characteristics, nutritional aspects, and utilization.Urbana, IL: AOCS Press.

Fastinger, N. D., and D. C. Mahan. 2006. Determination of the ileal amino acid and energy digestibilities of corn distillers dried grains with solubles using grower-finisher pigs. J. Anim. Sci. 84:1722-1728.

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

Goebel, K. P., and H. H. Stein. 2011b. Phosphorus and energy digestibility of conventional and enzyme treated soybean meal fed to weanling pigs. J. Anim. Sci. 89:764-772.

Goldsmith, P. D. 2008. Economics of soybean production, marketing, and utilization. Pages 117-150 in Soybeans: Chemistry, Production, Processing and Utilization. L. A. Johnson, P. J. White, and R. Galloway, ed. AOCS Press, Urbana, IL.

Grinstead, G. S., M. D. Tokach, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2000. Effects of Spirulinaplatensis on growth performance of weanling pigs. Anim. Feed Sci. Technol. 83:237-247.

Guo, L., X. Piao, D. Li., and S. Li. 2004.The apparent digestibility of corn by-products for growing-finishing pigs in vivo and in vitro.Asian-Austral.J. Anim. Sci. 17:379-385.

Hasan, M. R., and R. Chakrabarti. 2009. Floating aquatic macrophytes - duckweeds. Pages 29-52 in Use of algae and aquatic macrophytes as feed in small-scale aquaculture.1nd ed. FAO, VialedelleTerne di Caracalla, Roma.

Haustein, A. T., R. H. Gilman, and P. W. Skillicorn. 1994. Performance of broiler chickens fed diets containing duckweed (LemnaGibba). J. Agr. Sci. 122:285-289.

Helwing, A. F. L., A.-H. Tauson, N. P. Kjos, and A. Skrede.2007. Bacterial protein meal – effects on protein and energy metabolism in pigs. Animal 1:45-54.

Honeyman, M. S., and D. R. Zimmerman. 1991. Metabolizable energy of corn (maize) gluten feed and apparent digestibility of the fibrous components for gestating sows. Anim. Feed Sci. Technol. 35:131-137.

Hong, K.J., C.H. Lee, and S.W. Kim. 2004.Aspergillusoryzae GB-107 fermentation improves nutritional quality of food soybeans and feed soybean meal. J. Med. Food. 7:430–436.

Jacela, J. Y., H. L. Frobose, J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2010. Amino acid digestibility and energy concentration of high-protein corn dried distillers grains and high-protein sorghum dried distillers grains with solubles for swine. J. Anim. Sci. 88:3617-3623.

Jacela, J. Y., J. M. DeRouchey, S. S. Dritz, M. D. Tokach, R. D. Goodband, J. M. Nelssen, R. C. Sulabo, R. C. Thaler, L. Brandts, D. E. Little, and K. J. Prusa. 2011. Amino acid digestibility and energy content of deoiled (solvent extracted) corn dried distillers grains with solubles for swine and its effects on growth performance and carcass characteristics. J. Anim. Sci. 89:1817-1829.

Ji, Y., L. Zuo, F. Wang, D. Li., C. Lai. 2012. Nutritional value of 15 corn gluten meals for growing pigs: chemical composition, energy content, and amino acid digestibility. Arch. Anim. Nutr. 66:283-302.

Jones, C. K., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, S. S. Dritz, and R. D. Goodband. 2010. Effects of fermented soybean meal and specialty animal protein sources on nursery pig performance. J. Anim. Sci. 88:1725-1732.

Kim, B. G., G. I. Petersen, R.B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grainsand their effects on growth performance of pigs. J. Anim. Sci. 87:4013-4021.

Kim, B. G., and H. H. Stein. 2010. Energy concentration and phosphorus digestibility in yeast products, fish meal, and soybean meal fed to growing pigs. J. Anim. Sci. 88 (Suppl. 3):86(Abstr.)

Kim, S. W., E. van Heugten, F. Ji, C. H. Lee, and R. D. Mateo. 2010. Fermented soybean meal as a vegetable protein source for nursery pigs: I. Effects on growth performance of nursery pigs. J. Anim. Sci. 88:214-224.

Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, and D. H. Shain. 1993. Energy value of hominy feed for finishing ruminants.J. Anim. Sci.71:1092-1099.

Li, D.F., J.L. Nelssen, P.G. Reddy, F. Blecha, 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.

Lenehan, N. A., J. M. DeRouchey, R. D. Goodband, M. D. Tokach, S. S. Dritz, J. L. Nelssen, C. N. Groesbeck, and K. R. Lawrence. 2007. Evaluation of soy protein concentrates in nursery pig diets. J. Anim. Sci. 85:3013-3021.

Mahan, D. C. 1993. Evaluation of two sources of dried whey and the effects of replacing the corn and dried whey component with corn gluten meal and lactose in the diets of weanling pigs. J. Anim. Sci. 71:2860-2866.

Marriot N. G., J. E. Garret, M. D. Sims, and J. R. Abrul. 2002. Composition of pigs fed a diet with docosahexaenoic acid. J. Muscle Foods 13:265-277.

Olorunfemi, T. O. S., F. M. Aderibigbe, B. K. Alese, and E. A. Fasakin. 2006. Utilization of duckweed (Lemnapaucicostata) in least cost feed formulation for broiler started: A liner programming analysis. Inform. Tech. J. 5:166-171.

Øverland, M., A-H.Tauson, K. Shearer, and A. Skrede. 2010. Evaluation of methane-utilizing products as feed ingredients for monogastric animals. Arch. Anim. Nutr. 64:171-189.

Pahm, A. A., C. Pedersen, D. Hoehler, and H. H. Stein. 2008a.Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs.J. Anim. Sci. 86:2180-2189.

Pahm, A. A., C. Pedersen, and H. H. Stein. 2008b. Application of the reactive lysine procedure to estimate lysine digestibility in distillers dried grains with solubles fed to growing pigs. J. Agric. Food Chem.56:9441-9446.

Parsons, C. M. 2000. Assessment of nutritional quality of soy products. Page 90-105 in Soy in Animal Nutrition. J.K. Drackley, Ed. Federation of Animal Science Societies: Savoy, IL.

Pedersen,C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in 10 samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Radić, S., D. Stipaničev, P. Cvjetko, M. MarijanovićRajčić, S. Širac, B. Pevalek-Kozlina, and M. Pavlica. 2011. Duckweed Lemna minor as a tool for testing toxicity and genotoxicity of surface waters. Ecotox. Environ. Safe. 74:182-187.

Ren, P. Z. Zhu, B. Dong, J. Zang, and L. Gong. 2011. Determination of energy and amino acid digestibility in growing pigs fed corn distillers dried grains with solubles containing different lipid levels. Arch. Anim. Nutr. 65:303-319.

Rojas, O. J., and H. H. Stein. 2012a. Digestibility of phosphorus by weanling pigs of fermented and conventional soybean meal without and with microbial phytase. J. Anim. Sci. 90:1506-1512.

Rojas, O., and H. H. Stein. 2012b. Energy, phosphorus, and amino acid digestibility in Lemna protein concentrate, fish meal, and soybean meal fed to weanling pigs. J. Anim. Sci. 90(E-Suppl. 3):467 (Abstr.)

Sardi, L., G. Martelli, L. Lambertini, P. Parisini, and A. Mordenti. 2006. Effects of a dietary supplement of DHA-rich marine algae on Italian heavy pig production parameters. Livest. Sci. 103:95-103.

Skrede, A., G. M. Berge, T. Storebakken, O. Herstad, K. G. Aarstad, and F. Sundstøl. Digestibility of bacterial protein grown on natural gas in mink, pigs, chicken, and Atlantic salmon.Anim. Feed Sci. Technol. 76:103-116.

Skrede, A., L. T. Mydland, Ø. Ahlstrøm, K. I. Reitan, H. R. Gislerød, and M. Øverland.2011. Evaluation of microalgae as sources of digestible nutrients for monogastric animals. J. Anim. Feed Sci. 20:131-142.

Stein, H. H. 2012. Feeding distillers dried grains with solubles (DDGS) and other ethanol co-products to swine. Pages 297 – 315 in Distiller's Grains: Production, Properties and Utilization, K. Liu and K. A. Rosentrater, eds. Urbana, IL: AOCS Publishing.

Stein, H. H., L. L. Berger, J. K. Drackley, G. C. Fahey, Jr., D. C. Hernot, and C. M. Parsons. 2008. Nutritional properties and feeding values of soybeans and their coproducts. Page 620-661 in Soybeans, Chemistry, Production, Processing. L. A. Johnson, P. J. White, and R. Galloway, eds. Urbana, IL: AOCS Publishing.

Stein, H. H., and G. C. Shurson. 2009. Board invited review: The use and application of distillers dried grains with solubles (DDGS) in swine diets. J. Anim. Sci. 87:1292-1303.

Stein, H. H., S. P. Connot, and C. Pedersen. 2009. Energy and nutrient digestibility in four sources of distillers dried grains with solubles produced from corn grown within a narrow geographical area and fed to growing pigs. Asian-Austral.J. Anim. Sci. 22:1016-1025.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by products in feedlot diets. J. Anim. Sci. 77:1v-12v.

Weber, T. E., S. L. Trabue, C. J. Ziemer, and B. J. Kerr. 2010. Evaluation of elevated dietary corn fiber from corn germ meal in growing female pigs. J. Anim. Sci. 88:192-201.

Widmer, M. R., L. M. McGinnis, and H. H. Stein. 2007. Energy, amino acid, and phosphorus digestibility of high protein distillers dried grain and corn germ fed to growing pigs. J. Anim. Sci. 85:2994-3003.

Woodworth, J.C., M.D. Tokach, R.D. Goodband, J.L. Nelssen, P.R. O'Quinn, D.A. Knabe, and N.W. Said. 2001. Apparent ileal digestibility of AAs and the digestible and metabolizable energy of dry extruded-expelled soybean meal and its effect on growth performance of pigs. J. Anim. Sci. 79:1280–1287.

Yan, L., J. P. Wang, and I. H. Kim. 2012. Effects of different fermented soy protein and apparent ileal digestible lysine levels on weaning pigs fed fermented soy protein-amended diets. Anim. Sci. J. 83:403-410.

Yang, Y. X., Y. G. Kim, J. D. Lohakare, J. H. Yun, J. K. Lee, M. S. Kwon, J. I. Park, J. Y. Choi, and B. J. Chae. 2007. Comparative efficacy of different soy protein sources on growth performance, nutrient digestibility and intestinal morphology in weaned pigs. Asian-Aust. J. Anim. Sci. 20:775–783.