Protein Sources for Swine Diets

The main plant protein sources for swine are soybean meal, canola meal, sunflower meal, cottonseed meal, and field peas. Animal protein sources such as spray-dried blood products, meat and bone meal, and fish meal also can be used in swine diets. The most common protein sources used in swine diets are discussed in this fact sheet.

Selection of protein sources

The decision of selecting a protein source for swine diets must consider many factors, including amino acid profile and digestibility, energy content, presence of anti-nutritional factors, variability in nutrient concentration, ability to consistently source a high-quality ingredient, cost, and production goals. Also, lysine content and digestibility often dictate the value of a protein source because it is the most limiting amino acid in most swine diets. **Table 1** presents the typical use of protein sources in swine diets considering some limiting factors.

Plant protein sources

Plant protein sources provide most of the protein in swine diets. Soybean meal is the leading protein source for swine due to its superior quality and amino acid profile. Soybean meal is generally the base to which alternative plant protein sources are compared.

Soybean products

Soybeans are the most widely used protein in the world and is the primary protein source in most swine diets. Soybean products used in swine diets include soybean meal, full-fat soybeans, fermented soybean meal, enzyme-treated soybean meal, soy protein concentrate, and soy protein isolate.

Soybeans contain anti-nutritional factors that reduce nutrient utilization, most notably trypsin inhibitors. The trypsin inhibitors have to be inactivated by heating or toasting soybeans prior to use in swine diets. Raw soybeans are not recommended for use as such in swine diets.

Pigs have a transitory hypersensitivity reaction to soybean meal induced by allergenic proteins, namely glycinin and β-conglycinin, and indigestible carbohydrates of soybeans. Pigs experience a period of poor nutrient absorption and low growth performance following the first exposure to a diet with high amounts of soybean meal (Li et al., 1990). The effects are transitory and pigs develop tolerance after 7 to 10 days (Engle, 1994). To alleviate the effects during this period, pigs are gradually acclimated to diets with increasing amounts of soybean meal after weaning. Furthermore, soybean meal can be further processed to remove the allergenic compounds and improve the utilization of soy proteins by weanling pigs (Jones et al., 2010).

♦ Soybean meal

Soybean meal is the standard protein source in swine diets and is used as the reference ingredient for protein quality. The amino acid profile, balance, and digestibility in soybean meal is better than any other plant protein source used in swine diets.

Soybean meal is produced from hulled or dehulled soybeans. Dehulled soybean meal is often referred to as high-protein soybean meal and contains approximately 48% crude protein and 3% lysine content, whereas hulled soybean meal contains approximately 44% crude protein and 2.8% lysine content and is referred to as low-protein soybean meal (NRC, 2012). Standardized ileal digestibility of lysine and most amino acids is above 85 to 90% (Cervantes-Pahm and Stein, 2010).

Processing methods to extract oil from soybeans include expelling and solvent extraction. In the expelling method, oil is mechanically extracted from soybeans after an extrusion process is used to inactive trypsin inhibitors. In the solvent extraction method, oil is extracted using a solvent and then a toasting process is used to inactive trypsin inhibitors. The expelled soybean meal contains higher oil content than solvent-extracted soybean meal because mechanical extraction is less efficient in de-oiling soybeans. The oil content in dehulled, solvent-extracted soybean meal is around 1.5% (NRC, 2012).

♦ Full-fat soybeans

Full-fat soybeans are produced by avoiding the oil extraction process after extrusion of soybeans. Properly processed full-fat soybeans are a good source of both protein and energy. The critical factor during extrusion is the prevention of over- or under-processing, since either reduce the nutritional value of full-fat soybeans.

Full-fat soybeans have an oil content of approximately 15% (NRC, 2012), which is a means of providing oil to the diet. However, full-fat soybeans contain less crude protein (35 to 40%) and lysine (2%) than soybean meal (NRC, 2012).

♦ Fermented or enzyme-treated soybean meal

Further-processed soybean meal by microbial fermentation or enzymatic treatment is done to reduce the allergenic proteins and indigestible carbohydrates of soybeans (Stein et al., 2016). Microbial fermentation is usually accomplished by the inclusion of microbes to soybean meal, such as *Aspergillus oryzae*, *Bifidobacterium lactis*, *Lactobacillus subtilis*, among others. Enzymatic treatment is commonly performed by inclusion of proprietary enzymes and yeast to soybean meal (Stein et al., 2016).

Fermented or enzyme-treated soybean meal have greater concentration of crude protein than soybean meal, approximately 50 to 55% (Cervantes-Pahm and Stein, 2010; Jones et al., 2010). However, the standardized ileal digestibility of most amino acids and particularly lysine is lower in fermented or enzyme-treated soybean meal compared to conventional soybean meal (Cervantes-Pahm and Stein, 2010). The reduction in digestibility of amino acids is due to heat during the drying process to produce fermented or enzyme-treated soybean meal.

♦ Soy protein concentrate and isolate

Soy protein concentrate and isolate are high protein products derived from soybeans.

Soy protein concentrate is produced from dehulled, de-oiled soybeans (or soy flakes). The concentration of protein is increased by removing most of the soluble non-protein constituents. Soy protein concentrate contains at least 65% crude protein (NRC, 2012).

Soy protein isolate is also produced from dehulled, de-oiled soybeans (or soy flakes). The process starts by removing most of the soluble non-protein constituents and then the isolation of protein is produced by precipitating the protein in solution. Soy protein isolate is the most concentrated soy protein source and contains at least 85% crude protein (NRC, 2012).

During processing of soy protein concentrate and isolate, the allergenic proteins and indigestible carbohydrates of soybeans are mostly removed (Stein et al., 2016). However, the antinutritional factor trypsin inhibitor might be present in greater quantities compared to soybean meal because processing does not necessarily involve heat-treatment (Cervantes-Pahm and Stein, 2010).

Canola meal

Canola meal is a by-product of oil extraction from canola seeds. Varieties were developed with reduced concentrations of the anti-nutritional factor glucosinolates and referred to as canola in Canada and United States, and double-low rapeseed or 00-rapeseed in Europe. Glucosinolates are goitrogenic compounds that affect the thyroid function and iodine metabolism, impairing feed intake and growth performance of pigs fed diets with high concentrations (Parr et al., 2015). The concentration of glucosinolates in modern varieties is generally less than 30 µmol/g and it varies in canola meal depending on the extent of degradation during toasting (Mejicanos et al., 2016).

Canola meal contains between 35 to 40% crude protein and 2% lysine content (NRC, 2012). Compared to soybean meal, canola meal contains lower crude protein and lysine content but greater concentration of methionine and cysteine. Standardized ileal digestibility of lysine and most amino acids is lower than soybean meal, approximately 70 to 75% (Cervantes-Pahm and Stein, 2010).

Recently, new varieties of high-protein canola meal were developed that contain approximately 45% crude protein (Liu et al., 2014). Although the crude protein value is closer to that of soybean meal, the amino acid digestibility in high-protein canola meal is similar to canola meal and, therefore, less than soybean meal.

The fiber content of canola meal is between 20 to 25% NDF and 3 times greater than soybean meal due to the use of hulled canola seeds (NRC, 2012). The high fiber content reduces the energy value of canola meal.

Sunflower meal

Sunflower meal is a by-product of oil extraction from sunflower seeds. Sunflower meal is free of most anti-nutritional factors.

Sunflower meal contains approximately 30% crude protein and 1% lysine content (NRC, 2012). Similar to canola meal, sunflower meal contains lower crude protein and lysine content but greater concentration of methionine and cysteine than soybean meal. Standardized ileal digestibility of lysine and most amino acids is lower than soybean meal, approximately 75 to 80% (Cervantes-Pahm and Stein, 2010).

The fiber content of sunflower meal is very high, approximately 30% NDF in dehulled sunflower meal, which is around 4 times greater than soybean meal (NRC, 2012). The inclusion of sunflower meal in swine diets is mostly limited by its high fiber content (González-Vega and Stein, 2012).

Cottonseed meal

Cottonseed meal is a by-product of oil extraction from cotton seeds. The limitation to the use of cottonseed meal in swine diets is the anti-nutritional factor gossypol found in the pigment glands of cotton seeds. The free form of gossypol is toxic and not allowed over 100 ppm in complete diets for pigs (Gadelha et al., 2014). Heat processing of cotton seeds is used to inactivate gossypol, but heating allows free gossypol to bind to lysine and reduces lysine digestibility (González-Vega and Stein, 2012). New varieties of cotton seeds commonly referred to as glandless cottonseed do not contain gossypol, but unfortunately are not common (Stein et al., 2016).

Cottonseed meal contains around 40% crude protein and 1.5% lysine content (NRC, 2012). Compared to soybean meal, cottonseed meal contains lower crude protein and lower concentration of lysine and most essential amino acids. Standardized ileal digestibility of lysine and most amino acids is lower in cottonseed meal than in any other oilseed meal, approximately 60% (Cervantes-Pahm and Stein, 2010).

The fiber content of cottonseed meal is between 20 to 25% NDF, which is 3 times greater than soybean meal (NRC, 2012).

Field peas

Field peas are predominantly produced in Canada and temperate areas where oilseeds are not grown. Field peas are pulses that can fix most of their own nitrogen and do not require substantial use of nitrogenous fertilizer for cultivation, which considerably reduce the environmental concerns (White et al., 2015). Field peas contain low concentrations of the anti-nutritional factors trypsin and chymotrypsin inhibitors, which are usually inactivated by heat processing.

Field peas contain around 22% crude protein and relatively high lysine content, around 1.5% (NRC, 2012). Compared to soybean meal, field peas have considerably lower crude protein, lysine, methionine, cysteine, and tryptophan. Standardized ileal digestibility of lysine and most amino acids is similar to that of soybean meal, around 80% (Stein et al., 2016).

Field peas have a relatively high energy value compared to other oilseed meals. This is a result of relatively low fiber (13% NDF) and high starch (43%) content in field peas (NRC, 2012), which is similar to the composition of some cereal grains.

Animal protein sources

Animal protein sources have been commonly used to minimize soybean meal inclusion in initial nursery diets and encourage feed intake in weanling pigs. Animal protein sources are typically palatable and contain highly digestible amino acids. However, animal protein sources are more expensive and variability in composition is often greater than plant protein sources.

Biosecurity concerns arise from the potential disease transmission via animal-sourced ingredients, particularly porcine-based. Animal protein sources typically undergo a thermal processing that eliminates most pathogens, but post-processing recontamination can be a concern. In addition, some pork marketing programs may limit the use of animal protein sources in swine diets.

Spray-dried blood products

Spray-dried blood products are by-products obtained from swine and bovine harvesting plants. The whole blood is collected in chilling tanks and prevented from coagulating by adding an anticoagulant. Spray-dried blood cells and spray-dried plasma are produced by separating the blood fractions, whereas spray-dried blood meal contains both blood cells and plasma (Almeida et al., 2013).

Spray-dried blood products contain high concentration of crude protein (75 to 90%) and lysine (7 to 8%) (NRC, 2012). Standardized ileal digestibility of lysine and most amino acids is high, above 95 to 95% (Almeida et al., 2013). However, lysine availability is reduced with use of excessive heating in spray-dried blood products.

The use of spray-dried blood products requires attention to an favorable balance of branched-chain amino acids due to the high concentration of leucine but low concentration of isoleucine and valine, particularly in spray-dried blood cells or blood meal (Kerr et al., 2004; Goodband et al., 2014). Also, the concentration of methionine is low in all spray-dried blood products. The inclusion of other protein sources or supplementation of diets with feed-grade amino acids is important to adjust the amino acid profile in diets with spray-dried blood products (Remus et al., 2013).

Spray-dried blood products may vary substantially in composition and quality according to source and processing methods. The application of heat is critical to eliminate pathogens (Narayanappa et al., 2015), but post-processing recontamination can be a concern. In order to minimize the risk of disease transmission via feed ingredients, it is advisable to only use non-porcine-derived blood products.

Meat and bone meal

Meat and bone meal is a by-product from various tissues obtained from harvesting plants. Meat and bone meal contains high concentrations of crude protein (50 to 55%), lysine (2.5%), and most amino acids except for tryptophan (NRC, 2012). Standardized ileal digestibility of lysine and most amino acids is low, approximately 65 to 80% (Kong et al., 2014). Moreover, lysine availability is further reduced with use of excessive heating during processing of meat and blood meal.

Meat and bone meal is an excellent source of calcium and phosphorus, providing the minerals in high concentration and with a high phosphorus bioavailability (Traylor et al., 2005).

Meat and bone meal quality and composition may vary substantially according to the raw materials characteristics. The thermal processing of meat and bone meal is critical to eliminate pathogens, but post-processing recontamination can be a concern. In order to minimize the risk of disease transmission via feed ingredients, it is advisable to only use non-porcine-derived meat and bone meal.

Poultry meal

Poultry meal is a by-product from viscera and various tissues obtained from poultry harvest. Poultry meal contains high concentration of crude protein (60 to 65%), lysine (4%), and most amino acids except for tryptophan (NRC, 2012). The digestibility of amino acids can be affected by the ash content of poultry meal. The ash content is directly related to the level of bone included in poultry meal and is a measure associated with low digestibility and inferior quality (Keegan et al., 2004). Moreover, lysine availability is further reduced with use of excessive heating during processing of poultry meal.

Poultry meal quality and composition may vary substantially according to the raw materials characteristics. The thermal processing of poultry meal is critical to eliminate pathogens, but post-processing recontamination can be a concern.

Fish meal

Fish meal is a product obtained by processing whole fish or fish waste. Fish meal typically contains high concentration of crude protein (60 to 65%) and lysine (4.5%), favorable amino acid profile, and omega-3 fatty acids (NRC, 2012). Standardized ileal digestibility of lysine and most amino acids is high, approximately 85% (Cervantes-Pahm and Stein, 2010).

The inclusion of fish meal in swine diets enhances palatability and usually increases feed intake. However, fish meal quality can vary considerably depending on the species of fish, raw fish freshness, and processing method (Kim and Easter, 2001; Jones et al., 2018). Fish solubles, also known as stickwater concentrate, is a by-product rich in B vitamins and minerals derived from fish meal processing. The amount of fish solubles is variable in fish meal, generally found at 8 to 15%, but it is not associated with fish meal quality (Jones et al., 2018).

Currently, there is no single laboratory test that provides a general estimate of fish meal quality. Analysis of mineral content and fat can be used as an indicative of fish meal feeding value. Fish meal with high mineral content (> 20%) and lower fat level (< 7.5%) is generally from fish offal and contains lower feeding value compared to fish meal from whole fish. Freshness of raw fish can be estimated by analysis of total volatile nitrogen. Values below 0.15% total volatile nitrogen generally indicate good fish meal freshness. Bacterial analysis is important to assess quality of fish meal, as *Salmonella* can be transmitted via fish meal (Morris et al., 1970).

Porcine intestinal mucosa products

Porcine intestinal mucosa products are by-products of the pharmaceutical industry obtained from processing of porcine intestinal mucosa to extract the anticoagulant heparin. The mucosa linings are enzymatically hydrolyzed after extraction of heparin and co-dried with plant proteins to produce porcine intestinal mucosa products. Commercially available products are generally referred to as enzymatically-hydrolyzed intestinal mucosa, dried porcine solubles, or peptones.

Porcine intestinal mucosa products provide small peptides that are easily digestible by pigs. The concentration of crude protein is high (50 to 60%) and amino acid profile is favorable (Myers et al., 2014). Standardized ileal digestibility of lysine and most amino acids is high, above 80 to 85% (Sulabo et al., 2013).

Variation in composition of porcine intestinal mucosa products is due to different plant proteins used as carriers during drying and processing of intestinal mucosa (Jones et al., 2010; Myers et al., 2014). The thermal processing of porcine intestinal mucosa products is critical to eliminate pathogens, but post-processing recontamination can be a concern.

Spray-dried egg

Spray-dried egg is a by-product from the egg industry produced only from eggs without shell that do not meet the quality standards for human consumption. Spray-dried egg contains high concentration of crude protein (50%), lysine (3.5%), and favorable amino acid profile (NRC, 2012). Spray-dried egg is also a good source of energy.

Spray-dried egg provides bioactive compounds, such as antimicrobial proteins (lysozyme) and immunoglobulins (IgY). The composition of spray-dried egg is thought to provide benefits to improve health (Song et al., 2012). Moreover, hens can be immunized against pathogens, such as enterotoxigenic *Escherichia coli*, and the hyperimmunized eggs serve as a pathogen-specific antibody source (Da Rosa et al., 2014).

Whey products

Whey is derived from milk curdling during production of milk products like cheese and yoghurt (Grinstead et al., 2000). The whey is separated from the curd and processed into whey products, including dried whey, whey protein concentrate, and whey permeate. Whey products are sources of both protein and lactose.

Dried whey is produced by removing most of the water from liquid whey. The drying process can be accomplished by spray drying or roller drying. Spray-drying is the preferred method to prevent over-heating of whey because of the fast evaporation at lower temperatures compared to roller-drying method (Grinstead et al., 2000). Dried whey contains 11 to 12% crude protein and high lactose concentration, approximately 72% (NRC, 2012).

Whey protein concentrate is produced by having an additional process of ultrafiltration of liquid whey before the drying process (Grinstead et al., 2000). The ultrafiltration process concentrates the whey protein and removes most of the lactose. Whey protein concentrate contains 75 to 80% crude protein and low lactose concentration, generally around 5% (NRC, 2012). Whey protein concentrate is an edible-grade product in high demand by the food industry, limiting its availability for use in swine diets.

Whey permeate is a by-product from the ultrafiltration process of liquid whey to produce whey protein concentrate. Whey permeate contains most of the lactose that is removed from the ultrafiltration process. Whey permeate contains low crude protein (3.5%) and high lactose concentration, approximately 80% (NRC, 2012).

Yeast protein source

Dried fermentation biomass

Dried fermentation biomass consists of residual material from the feed-grade amino acid production. Feed-grade amino acids are derived from amino acid-producing bacterium in a process that requires a carbon source (sugars, typically from corn) and a nitrogen source (yeast extract) for bacterial fermentation. The fermentation biomass left after extraction of crystalline amino acids is used to produce dried fermentation biomass.

Dried fermentation biomass contains high concentration of crude protein (around 80%), lysine, and essential amino acids (Sulabo et al., 2013; Almeida et al., 2014). Standardized ileal digestibility of lysine and most amino acids is high, above 90% (Sulabo et al., 2013; Almeida et al., 2014).

The amino acid-producing bacteria within the dried fermentation biomass are not harmful to pigs, but a structural component of Gram-negative bacteria (lipopolysaccharide) may have endotoxin activity (Wallace et al., 2016), which affects feed intake.

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Table 1. Inclusion rates and limitations of common protein sources in swine diets

Ingredient	Swine diet[1] Nursery < 25 lb	Nursery > 25 lb	Grow-finish	Gestation	Lactation	Limitation
Alfalfa meal	**	5	15	25	**	High fiber
Animal plasma, spray-dried	*	*	**	**	**	Amino acid balance, cost
Blood meal or cells, spray-dried	3	3	5	5	5	Amino acid balance
Canola meal	**	5	20	15	15	Anti-nutritional factor (glucosinolates)
Corn DDGS	20	20	40	40	10	Amino acid balance
Corn germ meal	10	20	20	30	15	Protein quality, high fiber
Corn gluten meal	5	10	20	30	10	Protein quality
Cottonseed meal	**	10	10	15	**	Anti-nutritional factor (gossypol), high fiber
Egg protein, spray-dried	10	*	**	**	**	Cost
Field peas	15	30	40	15	25	Anti-nutritional factor (trypsin inhibitor)
Fish meal	15	20	**	**	**	Variability
Meat and bone meal	5	10	*	*	*	Variability, high minerals
Meat meal	5	10	*	*	*	Variability, high minerals
Skim milk, dried	*	*	**	**	**	Cost
Poultry meal	5	5	*	*	*	Variability, high minerals
Soy protein concentrate	20	*	**	**	**	Palatability
Soy protein isolate	*	*	**	**	**	Cost
Soybean meal	25	*	*	*	*	None
Soybean, full-fat	25	*	*	*	*	Anti-nutritional factor (trypsin inhibitor)
Sunflower meal	**	5	*	*	*	High fiber
Wheat gluten	10	*	*	*	*	Low lysine
Whey, dried	40	30	**	**	**	High lactose
Whey permeate	30	25	**	**	**	High lactose
Whey protein concentrate	*	*	**	**	**	Availability, cost

Adapted from National Swine Nutrition Guide (2010).
[1]Suggested maximum inclusion percentage rates for protein sources.
*No limitation for inclusion in the diet.
**Inclusion in the diet is not practical or economical.