Development and Nutritional Value of Advanced Soybean Products Used in Diets for Young Pigs

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Summary

Soybean meal is an excellent source of protein for pigs because of its excellent amino acid profile and its high amino acid digestibility. However, the presence of anti-nutritional factors such as trypsin inhibitors, lectins, oligosaccharides, and antigenic proteins reduces the inclusion level in weanling diets. The oligosaccharides can be reduced or eliminated by processing the soybean meal via aqueous ethanol extraction, fermentation, or enzymatic treatment. Reducing the concentration of oligosaccharides increases the concentration of other nutrients such as crude protein. Soy protein concentrate and soy protein isolate have low levels of stachyose and raffinose and antigenic proteins, and greater digestibility of amino acids and energy than soybean meal. Enzyme-treated soybean meal also has low concentration of oligosaccharides, and fermented soybean meal contains no stachyose or raffinose. However, fermented soybean meal sometimes has a reduced digestibility of lysine because of Mailard reactions caused by excess heating during drying after fermentation, but this is usually not observed in enzyme-treated soybean meal where the amino acid digestibility is similar to soybean meal.

Introduction

Soybeans is one of the most important crops in the U.S. and the co-product soybean meal (**SBM**) is the primary source of protein in swine diets because of its favorable concentration and balance of digestible amino acids (**AA**). Domestic livestock and poultry consumed 28 million metric tons of SBM in 2010, using nearly 80% of all the soybean meal processed in the U.S. However, raw soybeans contain anti-nutritional factors: trypsin inhibitors, lectins, phytic acid, oligosaccharides (raffinose, stachyose, and verbascose), and antigenic protein (glycinin and β-conglycinin; Baker, 2000; NRC, 2012; He et al., 2015). To reduce the concentration of some of the anti-nutritional factors such as trypsin inhibitors, soybean products need to be heated before being fed to swine because trypsin inhibitors are heat-labile.

Soybeans contain approximately 37% crude protein and 20% fat (Table 1). However, after crushing, most of the fat is removed via solvent extraction, and the resulting SBM contains less than 2% fat. The concentration of total carbohydrates in intact soybeans is 35 to 40% with approximately 15% being non-structural carbohydrates, such as sucrose, uronic acid, oligosaccharides, and free sugars. The concentration of oligosaccharides (raffinose, stachyose, and verbascose) in soybeans is between 4 and 7% (NRC, 2012). However, in SBM the concentration of oligosaccharides may be between 7 and 11%, where the concentration of stachyose is between 5.1 and 7.3% and the concentration of raffinose is between 1.1 and 3.8% (Cervantes-Pahm and Stein, 2010; NRC, 2012).

The main oligosaccharides in soybeans are raffinose, stachyose, and verbascose, and they are commonly called α-galactosides because of the presence of galac-

Table 1. Nutritional composition of U.S. soybeans and U.S. soybean meal (NRC, 2012).

	Full-fat soybeans	48% U.S. SBM, dehulled
Dry matter, %	92.36	89.98
Crude protein, %	37.56	47.73
Ash, %	4.89	6.27
Ether extract, %	20.18	1.52
Carbohydrates, %		
Sucrose	6.42	4.30
Raffinose	0.77	3.78
Stachyose	3.89	7.33
Verbascose	0.03	0.00
Starch	1.89	1.89
NDF	10.00	8.21

tose in the structure of these three oligosaccharides. Raffinose consists of one unit of glucose, one unit of fructose, and one unit of galactose. Stachyose and verbascose have a structure that is similar to raffinose with the exception that they contain two or three units of galactose, respectively. The glucose and fructose units in the oligosaccharides are connected by an α-(1-2) glycosidic linkage, whereas an α-(1-6) linkage connects glucose to galactose and also connects the galactose units in stachyose and verbascose. Therefore, the glycosidic linkages in the α-galactosides may be hydrolyzed by the enzyme α-galactosidase. However, pigs do not secrete the digestive enzymes necessary to cleave α-1,6 linkages and raffinose, stachyose, and verbascose are, therefore, considered indigestible by pigs, and are fermented in the digestive tract (Canibe and Bach Knudsen, 1997). However, it has been demonstrated that the ileal digestibility of α-galactosides is between 50 and 80% (Bengala-Freire et al., 1991; Canibe and Bach Knudsen, 1997; Smiricky et al., 2002), which indicates that there is considerable fermentation taking place in the small intestine of pigs. This fermentation allows pigs above approximately 20 kg to utilize the energy from the oligosaccharides in the form of short chain fatty acids. However, younger pigs fed large quantities of SBM do not handle the fermentation of these oligosaccharides very efficiently, and negative side effects such as diarrhea, gastrointestinal discomfort, and a reduction of weight gain are observed (Liying et al., 2003). Inclusion of SBM in diets fed to weanling pigs is, therefore, usually restricted to less than 20%. The total tract digestibility is considered to be 100% because any α-galactosides that are not fermented in the small intestine are rapidly fermented in the large intestine.

Removal of the Oligosaccharides

Removing the oligosaccharides from conventional SBM may be achieved by removing the non-protein constituents from dehulled and deffated soybeans, by fermentation or by enzyme treatment. Therefore, different products can be obtained: soy protein concentrate (**SPC**), soy protein isolate (**SPI**), fermented soybean meal (**FSBM**), or enzyme-treated soybean meal (**ESBM**).

Soy Protein Concentrate

Soy protein concentrate by definition contains a minimum of 65% crude protein (**CP**) on a dry matter (**DM**) basis (Endres, 2001), and it is produced by acid leaching, extraction with aqueous alcohol, or by denaturing the protein with moist heat before extraction with water (Endres, 2001). Thus, SPC contains fewer trypsin inhibitors, sucrose, raffinose, and stachyose than SBM (Oliveira and Stein, 2016), and the concentration of CP and AA are greater than in SBM (Table 2). The AA digestibility in SPC is similar to SBM, except for some AA where the standardized ileal digestibility (**SID**) is greater in SPC than in SBM (Oliveira and Stein, 2016; Pedersen et al., 2016). However, SPC contains more DE and ME than SBM (Oliveira and Stein, 2016).

Reduction in particle size of SBM improves the digestibility of most indispensable AA (Fastinger and Mahan, 2003) and the values of DE and ME (Rojas and Stein, 2015). Therefore, when SPC is ground to 70 or 180 µm the SID of arginine, isoleucine, phenylalanine, and tryptophan is greater than in SBM. However, there are no differences among conventional SBM and SPC ground to 70, 180, or 700 µm in DE and ME (Casas et al., 2017).

Addition of SPC to weanling pig diets at the expense of animal proteins does not affect the growth performance during the initial 4 weeks post-weaning (Guzmán et al., 2016; Casas and Stein, 2017), but SPC reduces the incidence of post-weaning diarrhea (Guzmán et al., 2016). Therefore, SPC may be used in diets fed to weanling pigs as a replacement for animal proteins.

Table 2. Nutrient composition of soybean meal, soy protein concentrate, and soy protein isolate (NRC, 2012).

	Soybean Meal	Soy Protein Concentrate	Soy Protein Isolate	Fermented SBM	Enzyme-treated SBM
Dry matter, %	89.9	92.6	93.7	92.7	92.9
Crude protein, %	47.7	65.2	84.8	55.6	54.1
Ether extract, %	1.5	1.1	2.8	1.8	2.3
Ash, %	6.3	6.11	4.2	7.1	7.0
Carbohydrates, %					
Sucrose	4.30	0.67	0.13	-	-
Raffinose	3.78	0.46	-	-	-
Stachyose	7.33	0.91	-	-	-
Verbascose	0.00	-	-	-	-
Amino Acids, %					
Arginine	3.45	4.75	6.14	3.95	3.70
Histidine	1.28	1.70	2.19	1.41	1.37
Isoleucine	2.14	2.99	3.83	2.48	2.55
Leucine	3.62	5.16	6.76	4.09	4.25
Lysine	2.96	4.09	5.19	3.20	3.14
Methionine	0.66	0.87	1.11	0.71	0.75
Phenylalanine	2.40	3.38	4.40	2.78	2.87
Threonine	1.86	2.52	3.09	2.13	2.09
Tryptophan	0.66	0.81	1.13	0.72	0.69
Valine	2.23	3.14	4.02	2.57	2.67

Soy Protein Isolate

Soy protein isolate contains at least 80% CP (Middelbos and Fahey, 2008). It is produced by solubilizing the protein at neutral and slightly alkaline pH, and the extract is then precipitated by acidification to obtain the protein isolate (Berk, 1992). Therefore, most of the non-protein constituents from soybeans are removed, and SPC therefore contains very few trypsin inhibitors, limited fiber, and practically none of the oligosaccharides (Table 2). The allergenic proteins glycinin and β-conglycinin are deactivated in soy protein isolate, and also in SPC because they are produced by extraction at temperatures greater than 50°C (Sissons et al., 1982). The AA digestibility of SPI is similar to that in casein (Cervantes-Pahm and Stein, 2010) and similar to SBM, but for some AA, SPI has greater SID values than SBM (Pedersen et al., 2016). Soy protein isolate is well tolerated by weanling pigs (Li et al., 1991) but its high cost of production makes it uncommon in commercial pig feed production.

Fermented Soybean Meal

Fermented soybean meal is produced by inoculating conventional soybean meal with the bacterium *Aspergillus oryzae* or other microbes (Hong et al., 2004). Raw soybeans are soaked in distilled water for 3 hours and placed in an autoclave at 100–120°C for 20 minutes. After that, autoclaved soybeans are cooled to room temperature for 3 hours. The soybeans are then inoculated with *A. oryzae* and placed in an incubator for 48 hours at 30°C with 90% moisture. After fermentation, soybeans are dried at 50–60°C and ground in a hammer mill (Hong et al., 2004).

Fermented soybean meal contains more DM, CP, and ash than conventional SBM (Table 2). The absence of sucrose, stachyose, and raffinose in FSBM is attributed to the production of α-galactosidase by *Aspergillus oryzae* during the fermentation process (Cervantes-Pahm and Stein, 2010). The disappearance of these saccharides is the main reason for the analyzed increase in the concentration of other nutrients in FSBM as compared with SBM.

Yoon (2012) analyzed 4 different samples of FBSM and observed that the concentration of CP is between 53 and 58%, which is greater than in conventional SBM. However, the SID of lysine is lower in FSBM than in SBM (Cervantes-Pahm and Stein, 2010) and lower lysine-to-CP ratio compared with SBM, SPC, SPI, and ESBM (Pedersen et al., 2016). This is likely a result of the heat that is used during drying of FSBM, which may result in heat damage. Heat damage may result in Maillard reactions that can destroy some of the lysine in the FSBM (Stein et al., 2009), and Maillard reactions can also result in reduced SID of lysine (Stein et al., 2009).

Peptide size distribution does not differ between SBM and FSBM and there is no evidence for hydrolysis of the peptides in FSBM (Cervantes-Pahm and Stein, 2010). The concentration of glycinin and β-conglycinin in FSBM is similar to SBM, which is in contrast with SPI that has low concentration of the allergenic proteins (Cervantes-Pahm and Stein, 2010). Antigenic proteins glycin and β-conglycinin reduce ADG and G:F in young pigs (Zhao et al., 1998) and may reduce villus height in the small intestine and decrease nitrogen digestibility in pigs (Li et al., 1991).

Enzyme-treated Soybean Meal

Enzyme-treated SBM is produced by treating dehulled solvent-extracted SBM for several hours with a proprietary blend of enzymes (Goebel and Stein, 2011). Enzyme treatment removes sucrose and reduces the concentrations of oligosaccharides and allergenic proteins (Cervantes-Pahm and Stein, 2010). Therefore, the concentration of CP and other nutrients is greater in ESBM than in SBM (Table 2). In addition, there are no differences in SID of AA between SBM and ESBM (Cervantes-Pahm and Stein, 2010; Pedersen et al., 2016). Several studies have demonstrated that ESBM is well accepted by young pigs, and ESBM may, therefore, replace animal proteins in starter diets for pigs.

Conclusion

The reduction of oligosaccharides and antigenic proteins in SPC, SPI, FSBM and ESBM increases the nutritional value to young pigs and the AA digestibility is usually similar to that in SBM or greater. As a result, these special soybean products may be used in diets fed to weanling pigs as a replacement for fishmeal or others animal proteins.

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