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Soy Protein Concentrate –a manifold Product group

Classification, processing, nutritional value and feed application

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Characterized by balanced amino acids profile, soy protein is by far the most important plant protein source used in animal feed. It is well known that raw soybeans contain high amount of soy anti-nutritional factors and need to be properly processed before their applications in animal feed. The manufacturing process for soybean meal can be considered the same across the globe and quality differences are only determined by protein content and sometimes insufficient inactivation of trypsin inhibitor activity. When it comes to highly processed soy protein (e.g. fermented soy protein and soy protein concentrates (SPC)), the picture might be very different. As different production processes are used, commercially available highly processed soy proteins differ not only in protein, but also in carbohydrates content and the level and activity of soy heat stable anti-nutritional factors (ANFs).

The ANF in soybeans can be divided into heat sensitive and heat stable components. The most important heat labile anti-nutritional factor for animal performance is trypsin inhibitors activities (TIA). TIA can reduce the digestibility of protein and other nutrients. TIA can be reduced by heat treatment. Most of the commercially available full fat soybean meal and defatted soybean meal (SBM) are processed by heat treatment to reduce TIA. Therefore TIA is commonly recognized and used as quality assessment criteria for SBM.

The heat stable soy ANFs, however, are not very well recognized. The most important heat stable ANFs are antigens and oligosaccharides. Soy antigens are storage globulins, glycinin and β-conglycinin, these proteins may escape digestion and are immunogenic in young calves, piglets and in fish. They have been suspected to interfere with intestinal function via immunological mechanisms (Tukur et al., 1996). Piglets and young calves do not have the enzyme to digest soy oligosaccharides, the fermentation of soy oligosaccharides by intestinal bacteria can cause intestinal disorder and diarrhea problems. These heat stable soy anti-nutritional factors can not be removed by heat treatment, but can be eliminated by ethanol/water extraction or enzyme treatment.

This paper reviews different soy protein products based on production processes and their nutritional values and applications in animal feed.

Classification of soy products

There are several commercial soy protein products available in the market, thus different terms are used to describe these soy protein products. Different production processes for different soy products result in different crude protein (CP) levels of the final products. Soy protein products in general can be simply classified based on their crude protein content (Table 1).
For highly processed soy products, however, the simple crude protein content classification may fall short of a proper assessment of their quality, since their content of ANFs must be considered.

Table 1 classifies commercially available soy protein products that are produced by different processes.

***Table 1**. Classification of soy protein products based on crude protein (CP) content*

Classification		**Typical CP content** % (as is)	**Term of soy products**	**Production process**
Basically Processed Soy Products (< 50% CP)		36 %	Full fat soybean meal	Heat treatment
		44 %	De-fatted soybean meal Or soybean meal	De-hulled, defatted soy flakes, heat treatment, add back soy hulls
		48 %	Hi-pro soybean meal	De-hulled, defatted soy flakes, heat treatment,
Highly Processed Soy Products (> 50% CP)	Fermented Products (50 < 60 % CP)	52-56 %	Fermented soy protein	Fermentation of hi-pro SBM
	SPC (> 60% CP)	60 %	Non-Classical SPC	Produced by ethanol/water extraction of hi-pro SBM
		65 %	Classical SPC	Produced by ethanol/water extraction of white flakes

Production process

Full fat soybean meal: The full-fat soybean meal products are produced by heat treatment to reduce the trypsin inhibitor activity. The heat processing methods used to produce full-fat soybean include mainly toasting, micronizing, cooking and extrusion. Due to different heat processing conditions, variations in anti-nutritional factors level, such as trypsin inhibitor activities of the resulting products may exist. The heat sensitive soy anti-nutritional factors may not be sufficiently removed and heat stable ANFs are not removed at all from full-fat soybean meal.

Defatted soybean meal 44% CP: Defatted soybean meal is a by-product from soy oil processing. The raw soybeans are first cleaned, de-hulled and cracked, and then solvent extracted to remove soy oil. The defatted soy flakes are then heat treated to recover the extraction solvent and to reduce the heat labile anti-nutritional factors. For 44% CP soybean meal, the soy hulls are added back to soybean meal.

Hi-pro soybean meal 48% CP: The same process is used as above, but without adding back soy hulls. Thus the product has high crude protein and low fiber content compared to 44% CP soybean meal. For both 44% and 48% CP SBM products, large variations may exist in TIA levels and heat stable ANFs are not removed.

Fermented/enzyme treated soy protein: This type of soy protein is produced by fermentation/enzymes treatment of defatted soy flakes or hi-pro soybean meal. In case a fermentation process is applied for manufacturing, microorganisms with known features are added stepwise to denature the soy antigens and to degrade the oligosaccharides in the product by the microorganism`s own enzyme activity. When microorganisms are used in a fermentation process, the increase in protein level in the final product is rather low (50 –56%) and the degradation of ANF`s may be inconsistent. The soluble non-starch polysaccharides are not removed from this production process.

Non-classical SPC: This soy protein concentrate is produced differently from classical soy protein concentrate. It is produced by ethanol/water extraction of hi-pro soybean meal. In contrast to the classical soy protein concentrate, soluble carbohydrates are not removed before heat treatment, this may increase the occurrence of Maillard reaction during heating process.

Classical SPC: The classical soy protein concentrate is produced starting from soybeans, using low temperature to separate soy oil and yields high quality soy white flakes. To produce white flakes, excess hexane is drained by low heat vacuum drying, with minimum protein denaturation. The white flakes are subjected to an ethanol/water extraction process to remove the soluble carbohydrates. During ethanol/water extraction, the heat stable anti-nutritional factors, e.g antigens are de-natured and indigestible soy carbohydrates including oligosaccharides and soluble non-starch polysaccharides (NSP) are removed. After ethanol/water extraction, the product is steam heated in order to remove heat labile anti-nutritional factors. In this way, both heat stable and heat labile anti-nutritional factors are removed during SPC processing.
Because the heat treatment is applied after the removal of soluble carbohydrates, this processing method has the advantage of reducing the likelihood of Maillard reactions during the heat treatment and improves the availability of amino acids. The production processes of different soy products are illustrated in Figure 1.

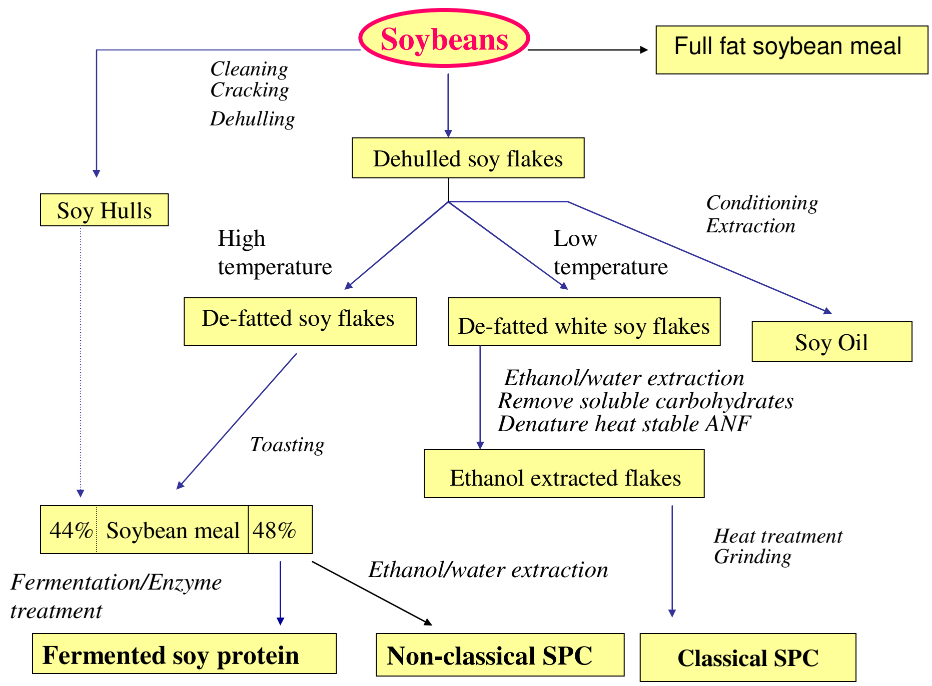

***Figure 1**. Production process of commercially used soy protein products.*

Hancock et al. (1990) determined the effect of ethanol extraction of soybean flakes on performance of piglets, function and morphology of pig intestine (Table 2). Three different processing methods were tested: method 1: without ethanol extraction; method 2: ethanol extraction after heat treatment (non-classical SPC) and method 3: ethanol extraction before heat treatment (classical SPC). It was observed that ethanol extraction before heat treatment improved nitrogen digestibility, plasma lysine concentration, growth performance and intestinal health (as indicated by greater villus size, e.g. area, height and perimeter length). The process of ethanol extraction before heat treatment clearly proved beneficial compared to ethanol extraction after heating process, the latter process did not improve growth performance or intestinal health of the piglets when compared to defatted soy flakes.

Table2. *Effect of ethanol extraction of soybean flakes on product composition, average daily weight gain (ADG), average daily feed intake (ADFI) and gain/feed ratio, plasma urea and lysine concentration, digestibility of nitrogen and morphology of the intestine in piglets (Hancock et al., 1990)*

	Without ethanol extraction (defatted soyflakes)	***Ethanol extraction after heat treatment (Non-classical SPC)***	***Ethanol extraction before heat treatment (Classical SPC)***
Analysis of the soy product, %:			
Crude protein	50.9	67.1	67.2
Lysine	3.6	4.5	4.6
Isoleusine	2.1	3.1	3.2
Met+cys	2.0	2.7	2.6
TIA, mg/g	4.4	2.1	3.1
Trial results:			
ADG, g/d	318	319	378
ADFI, g/d	638	645	713
Gain/feed	0.499	0.493	0.533
Plasma urea, mg/dl	39	36.3	32.1
Plasma lysine, %	1.13	1.09	1.16
N digest %	80.9	83.1	84.7
Duodenum villus height, μm	493	474	539

Nutritional value and application of soy protein products

The typical nutritional value of soy protein products are given in Table 3.
Highly processed soy protein products have low level of both heat labile and heat stable soy anti-nutritional factors, this makes the product more suitable for application in young animal's feed. The ANF levels, however, may differ between different products produced at different fermentation conditions or ethanol extraction conditions.

Different production processes result in also difference in indigestible carbohydrates content, especially soluble NSP content. Fermented soy protein contains higher amount of soluble NSP compared to SPC, as these soluble NSPs are not removed during the fermentation process (see Figure 1, Table 3).

It is generally accepted that increasing dietary NSP levels can have negative effect on the digestibility and rate of absorption of nutrients. The fermentation of NSP in the intestine may cause flatulence and diarrhoea. Pluske et al. (1996) showed that an elevated level of dietary soluble NSP was associated with the increased pathogenesis of swine dysentery in weaner pigs. Thus reducing the quantity of fermentable substrate entering the large intestine reduced the incidence of swine dysentery. The authors suggested that the presence of soluble NSP in weaner diets was detrimental for piglet growth and caused proliferation of E. coli in the small intestine, a level of soluble NSP less than 1% in the diet would be associated with less disease.

***Table 3**. Typical composition, measured standard ileal digestibility of CP and AA in weaning piglets and approximate level of anti-nutritional factors in soy products (based on NRC, 1998 or producer's data sheet)*

	Full fat SBM	*SBM 44%CP*	*Hi-pro SBM*	*Fermented soy*	*Non-Classical SPC*	*Classical SPC*
Composition, %, as is						
CP	36	44	48	52-56	60	65-67
Fat	18	1-3	1-3	1-2.5	2	0.5-1
Moisture	10	10-11	10-11	8-9	10	5-7
Crude fiber	5.5	7	3-3.5	3-4.5	<5	3-4
NFE[1]	30.5	30-35	30-35	24-28	18	16-18
Ash	4.5	6.3	5.8	6.2-6.8	<5	5.6-7
K	1.7	1.96	2.14	2.3	1.35-1.65	2.2
AA, % CP						
Lys	6.31	6.46	6.43	6.1-6.2	5.67-7*	6.5
Thr	4.01	3.95	3.94	3.93-4.0	3.67-4.5*	4.2
M+C	3.07	2.99	3.00	2.86-3.02	2.67-3.34*	2.91
SID, %[2]						
CP	73	-	80	86	-	86
Lys	78	-	85	89	-	90
Thr	70	-	78	81	-	83
M+C	67	-	80	83	-	82
Trp	72	-	82	84	-	84
ANF						
TIA, mg/g	1-8	1-8	1-8	1	NR**	<3
Glycinin, ppm	>66000	˜66000	˜66000	<100	NR	<20
β-conglycinin,ppm	>16000	16000	16000	1-2	NR	<5
Oligosaccharides,%	10-14	10-15	10-15	< 3	< 3	< 3
Soluble NSP, %	10-12	10-14	10-14	10-12	1-3	1-3

[1] NFE: Nitrogen free extract = 100-CP-Fat-Fiber-water-ash, e.g, carbohydrates fraction.
[2] SID: standard ileal digestibility of crude protein and essential amino acids in weaning piglets (Mosenthin et al., 2006).
'–' not determined in this study.
* In a producer's data sheet, a range of amino acids content is given.
** Not reported by producer.

When comparing amino acids content, classical soy protein concentrate has higher lysine content on percentage of crude protein basis than fermented soy protein products. This may be explained by that in fermentation process, bacteria growth will consume essential amino acids and this will result in a low lysine content. Also the low Maillard reaction during the production process of classical SPC may explains the high lysine content when compared to other soy protein products. In order to compare highly processed soy products economically it is recommended to calculate the lysine per unit crude protein concentration and the total digestible lysine supply of different products, since this is the most important nutritional and economic parameter in feed formulation.

Standard ileal digestibility measurement by Hohenheim University (Mosenthin et al., 2006) has confirmed full fat soybean meal and hi-pro soybean meal have lower protein and amino acids digestibility in weaning piglets compared to soy protein concentrate and fermented soy protein. Highly processed soy protein products have improved protein and

AA digestibility in weaning piglets, which is related to low level of soy anti-nutritional factors.

The basically processed soy protein products, including full fat soybean meal, defatted soybean meal and hi-pro soybean meal are commonly used protein sources for poultry, grower and finisher pigs. As these soy products are produced by heat treatment, therefore, these soy protein products contain high levels of soy heat stable anti-nutritional factors. This limits their applications in young animals' feed, such as in weaning piglets feed, calf milk replacer and aqua-feed.

Characterized by high protein content, improved digestibility, low indigestible carbohydrates content and low level of soy ANF, highly processed soy products, in particular classical soy protein concentrate have proven to be a high quality protein source for the feed of young animals. Table 4 indicates general considerations about possible applications of commercially available soy protein products in animal feed.

***Table 4**. Application of different soy protein products in animal feed*

	Full fat SBM	*SBM 44%CP*	*Hi-pro SBM*	*Fermented soy*	*Non-Classical SPC*	*Classical SPC*
Growing/finisher pigs	++	+++	++			
Poultry	++		+++			
Weaning piglets	-	-	L*	++	++	+++
Calf milk replacer	-	-	-	++		+++
Poultry pre-starter	L	-	L	+++	++	+++
Aqua-feed	L	-	L	+++	+++	+++

* Limited inclusion levels

Summary

There are many commercially available soy protein products available in the market, these products are produced differently and therefore have different nutritional values. These soy products can be classified based on their crude protein content, as this is related to production processes. Full fat soybean meal contains 36% crude protein, while defatted soybean meal and hi-pro soybean meal contains typically 44 and 48% CP, respectively. These basically processed products contain high amounts of heat stable soy ANFs and have limited application in young animal's feed.

Highly processed soy protein products have low soy ANF, however, the ANF content and indigestible soy carbohydrates content are related to the processing methods and treatment conditions. Classical soy protein concentrate has advantages of low indigestible carbohydrates content, high protein and lysine content compared to fermented soy protein products.

For soy protein concentrate produced by ethanol/water extraction, the product produced by classical process, that is, ethanol extraction of low temperature produced soy white flakes, has improved product quality compared to non-classical SPC produced by ethanol/water extraction of soybean meal.

In conclusion, when evaluating soy protein products quality for young animals, the following parameters, including crude protein content, essential AA content as percentage of crude protein, AA digestibility in different age of animals, indigestible carbohydrates content, soy anti-nutritional factors content including TIA, antigens, oligosaccharides and soluble non-starch polysaccharides should be considered.

(References are available upon request).