DESCRIPTION OF VARIOUS SOY PRODUCTS

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Introduction

The soybean or soya bean (*Glycine max* L. Merr.) is the species of legume of the Fabaceae family. Soybean is one of the world most important crops on the planet in terms of economic value and its importance in animal and human nutrition. The World produces over 380 million metric tonnes of soybean seeds (soybeans) are produced per year. The Unites States of America (USA) is a leading global producer of soybeans with over 4.1 billion bushels (1 bushel = 27.2155 kg) of soybeans produced per year (over 150 million metric tonnes) of which about half is exported.

Soybeans comprise approximately 8% seed coat or hull, 90% cotyledons and 2% hypocotyl axis or germ. Soybeans are composed of approximately 9% moisture, 36% protein, 20% fat, 30% carbohydrate and 5% ash. Soybeans also contains a variety of natural compounds, such oligosaccharides (raffinose, stachyose), hemagglutinins (also known as lectins), trypsin inhibitors (also known as anti-trypsic factors), phytic acid, soyasaponins, isoflavones, tannins., cellulose, hemicellulose, etc. Some of these components are considered anti-nutritional factors. Glycinin and β-conglycinin (putative allergenic proteins).

Soybeans are processed into a wide variety of final products that are finding wide use in animal feeds, as well as in human foods and the manufacturing of many industrial products (lubricants, paint, polymers, etc.). This short document provides a brief description of various soy products and their production and use in feeds for terrestrial livestock and aquaculture species.

Full-Fat Soy

Raw soybeans contain a high level of some heat-labile anti-nutritional factors that prevent their direct use in animal feeds. The anti-nutritional factors affects the ability of animal to digest proteins. Heat treatment allows significant reduction of the level or the activity of anti-nutritional factors, such as trypsin inhibitors (anti-trypsic factors) and hemagglutinins (lectins), and allows efficient digestion and utilization of nutrients contained in soybeans.

Full fat soy is produced from the processing of raw soybeans (without prior fat extraction) using a variety of thermal processing techniques, such as, extrusion (wet or dry), roasting/toasting, boiling/autoclaving, micronizing, and jet-sploding.

Full-fat soy contains between 35-40% crude protein and 16-22% fat. It is thus an energy-dense feed ingredients that is also an effective source of amino acids and essential fatty acids.

Soybean Meal

The main use of soybeans is in the production of soybean meal (SBM) and soybean oil. Globally, over 240 million metric tonnes of soybean meal is produced each year. SBM is the most important protein ingredients used in animal feeds. SBM plays a critical role in the supply of amino acids to terrestrial livestock and many aquaculture species.

SBM is a co-product of oil extraction from soybeans. Following grading and cleaning, soybeans are dried and cracked with large rollers. Air flow is then used to separate the hulls from the kernels and the kernels are flattened by rollers in order to increase surface area and disrupt the cell structure. Solvent is run over the flakes to extract the

oil. Alternatively, a mechanical process (extruding-expelling) may be used. The resulting "white flakes" are then processed through a series of steps which include solvent removal, toasting, drying, cooling, and sizing. Heat treatment is an important aspect of processing that must be done in order to deactivate (or lessen the content) of heat-labile anti-nutritional factors, such as trypsin inhibitors and hemagglutinins (lectins),

SBM is widely used in animal feeds due to its high protein content, balanced amino acid profile, high availability, and relatively low cost. The most common forms of SBM is dehulled, solvent extracted (47-48% CP, as-is basis). Non-dehulled SBM is also very common and has approximately 44% CP on an as-is basis.

Dehulled SBM normally contains a maximum of 3.5% crude fiber, while non-dehulled SBM may contain 6 to 7% crude fiber. Solvent extracted SBM contains about 1.5% oil in the resulting SBM, whereas mechanical extraction (expelling) results in SBM containing more than 5% residual oil. Among plant protein sources, SBM is considered high in lysine, but low in the sulfur amino acids, methionine and cysteine.

Soy Protein Concentrate

Soy protein concentrate (SPC) is produced through the removal of the soluble carbohydrate fraction of defatted soy flakes or soybean meal. Three processes can be used to accomplish carbohydrate removal: (1) acid leaching; (2) aqueous ethanol extraction; and (3) moist heat-water leaching. In these treatments, a portion of the carbohydrates become soluble so that their separation from the insolubilized proteins can be accomplished by centrifugation. Solids containing mainly proteins and insoluble carbohydrates are then dispersed in water, neutralized to a pH of 7, and spray dried to produce SPC. SPCs are offered in powder or granular forms as well as re-fatted or lecithinated forms. SPC typically contains 60 to 70% protein on an as-is basis.

Fermented Soybean Meal

Fermented soybean meal (FSBM) is produced from SBM which is inoculated with fungi, bacteria, yeast or a combination of these microorganisms. The predominant microorganisms used to produce FSBM are fungal and bacterial species belonging to the genera *Aspergillus* and *Lactobacillus*, respectively. The fermentation may either be solid-state fermentation (SSF) or submerged fermentation.

SSF is a process in which microorganisms are grown on solid substrate without the presence of free liquid. Comparatively, submerged fermentation has demonstrated lower commercial viability due to the use of large amounts of water containing dissolved nutrients. In SSF, SBM is usually incubated at a moisture content of 45 to 50%. The wet substrate is inoculated with microorganisms and the fermentation process starts immediately. Different microorganisms secrete different enzymes and in varying quantities. The outcome of SSF is a product with improved nutritive value and reduced levels of antinutritional factors. Notably, FSBM has crude protein and amino acid contents about 5-10% higher than SBM. The sugars, mostly sucrose, raffinose and stachyose, are largely transformed into CO_2 and water. Moreover, fermentation results in hydrolysis and inactivation of the allergenic proteins glycinin and β-conglycinin and can potentially decrease the trypsin inhibitor, phytic acid, and saponin contents of SBM. The improvements in the nutritional value and the reductions in antinutritional factors relative to SBM are dependent on the fermentation conditions and the microorganism(s) used.

Solid-state fermentation (SSF) of SBM has been used as a method to reduce the anti-nutritional factors and undesirable components in SBM and increase its nutritive value. SSF is defined as any fermentation process that occurs in the absence of free water on an organic substrate. SBM is usually incubated at a moisture content of 45 to 50% and microbial fermentation is subsequently achieved by inoculating the SBM with fungi, bacteria, yeast or a combination of these microorganisms. Several species of bacteria, fungi, and yeast are used to produce fermented SBM (FSBM). These include *Bacillus subtilis*, *Lactobacillus plantarum*, *Lactobacillus acidophilus*, *Aspergillus oryzae* (or *niger*), *Rhizopus oryzae* (or *oligosporous*), *Saccharomyces cerevisiae*, and *Enterococcus faecium* (or *faecalis*). Fungal and bacterial species are commonly used together or in sequence to synergistically improve the nutritional value of SBM and reduce the content of anti-nutritional factors.

Fungi-based Fermentation

Aspergillus spp., specifically *A. oryzae* or *A. niger*, are frequently used to ferment SBM. Fungi produce filamentous hyphae which grow into the SBM and release enzymes. Moreover, if fungi and bacteria are used together, the hyphae produce paths which enable the bacteria (and enzymes) to penetrate the substrate. The beneficial effects of fungi-based fermentation have been well-documented. Fermentation of SBM with *Aspergillus* spp. of fungi resulted in significant, or complete, reduction of TIs which was associated with the production of proteases (Hong et al., 2004; Liu et al., 2007; Feng et al., 2007). Similarly, production of phytase resulted in a decrease in the content of phytic acid from 14 to 6 g/kg when SBM was inoculated with *A. oryzae*, thereby increasing the availability of phosphorous for the animal. Fermentation with *Aspergillus* spp. of fungi also successfully reduces the oligosaccharide content of SBM, namely stachyose and raffinose. This is attributed to the production of α-galactosidases. Following fermentation, the stachyose and raffinose are reduced to water and CO_2 or transformed into lactic acid and/or ethanol. Water, CO_2 and ethanol are eliminated at drying, whereas lactic acid cannot be eliminated, but may be beneficial for the animal. Initially, fermentation of SBM with fungi is slower than with bacteria or yeast, but after 12 to 24 hours, the production of enzymes by fungi surpasses that of bacteria. Futhermore, fungi produce a wider array of enzymes relative to bacteria.

Bacteria-based Fermentation

Species belonging to the genus *Bacillus* are the most commonly used bacteria to ferment soy flakes or SBM due to their high capacity to produce proteases and a wide range of enzymes. Comparatively, *Lactobacilli* spp. produce carbohydrases and synthesize lactic acid. Other genera used to ferment SBM include *Bifidobacterium*, *Enterococcus* and *Streptococcus*. Fermentation with bacteria that produce lactic acid like *L. plantarum* has been associated with protein hydrolysis and an increased free amino acid content (leucine, isoleucine, aspartic acid, and proline) of FSBM compared to SBM. Similarly, when SBM is fermented with *B.subtilis*, the concentration of small-size proteins increases along with the content of several amino acids including arginine, serine, threonine, aspartic acid, alanine and glycine. Like fungal fermentation, bacterial fermentation with *Lactobacillus* also significantly decreases the TI content of SBM. The effect of fermentation on the content of glycinin and β-conglycinin is dependent on the species and/or strain of bacteria. For example, some strains of *Bacillus* were particularly efficient at reducing the reactivity of glycinin and β-conglycinin (in less than 12 hours), whereas the fungal *Aspergillus* spp.

required more than 48 hours to attain similar results. Strains of *Bifidobacterium* and *Lactobacillus* gave intermediate results. Fermentation of SBM with *B. subtilis* and *A.oryzae* led to the complete disappearance of sucrose, stachyose and raffinose. In contrast, almost complete hydrolysis of sucrose, but limited elimination of oligosaccharides was described in SBM fermented with *L. plantarum*. The capacity of bacteria to produce phytases is species-dependent. The phytase activity of 12 species of *Lactobacillus* ranged from 8 to 421 U/mL. Finally, fermentation of SBM with bacteria can reduce the initial content of soyasaponins by 30 to 40%, depending on the fermentation conditions.

Soy Protein Isolate

Soy protein isolate is a highly purified soy product (> 90% crude protein) made by removing most of the non-protein components, residual fats, fiber, and carbohydrates from defatted meal. More specifically, soy protein isolates are prepared from defatted SBM using aqueous or mild alkali extraction (pH 9 to 11) with sodium hydroxide. The insoluble residue, mostly carbohydrate, is subsequently removed by centrifugation followed by precipitation of soy protein at its isoelectric point (pH of about 4.2 to 4.5) by acidifying with hydrochloric acid. The precipitated protein is separated by centrifugation, washed, neutralized to a pH of about 6.8 with sodium or calcium hydroxide, and then spray-dried.

Soy Lecithin

Soy lecithin is derived as a co-product of soybean oil extraction. Soybean lecithin is obtained by degumming of crude soybean oil using water, organic acids or enzymes. Water degumming results in the removal of 80-95% of the phosphatides (i.e. lecithin). Addition of 2% water to the crude oil at a temperature of 70 to 80 °C in a stirred, agitated tank is usually sufficient to hydrate the gums to the point that they form gels and precipitate from the degummed oil. The crude gums are recovered using centrifugation. Subsequently, the gums, consisting of water and phosphatides, are further processed by drying under a vacuum and heating with steam. The acid degumming process is a variant of water degumming that uses a combination of acid (usually citric acid) and water. Nonhydratable gums can be conditioned into hydratable forms with a degumming acid. Enzymatic degumming utilizes an enzyme, phospholipase, which converts phospholipids into lysophospholipids that can be removed by centrifugation. Following pretreatment with a combination of sodium hydroxide and citric acid, crude oil is mixed with water and enzymes. The emulsion allows the enzyme to react with the phospholipids transforming them into water-soluble lysophospholipids. Centrifugation is used to separate the gums and phospholipids from the oil. Crude soybean lecithin typically contains 18% phosphatidylcholine, 14% phosphatidylethanolamine, 9% phosphatidylinositol, 5% phosphatidic acid, 2% minor phospholipids, 11% glycolipids, 5% complex sugars, and 36% neutral oil. De-oiling can be achieved with acetone and separates the neutral oil and phospholipids. The fatty acid profile of lecithin consists of approximately 16% palmitic acid, 6% stearic acid, 13% oleic acid, 57% linoleic acid, and 2% linolenic acid.

Soybean Oil

Crude soybean oil is extracted from soybean flakes using hexanes. The solvent is removed to produce the initial crude oil. Crude degummed oil is defined as pure soybean oil produced from crude soybean oil from which most of the natural gums (phospholipids) have been removed by hydration and separated by centrifugation. Soybean oil can then be refined in a process

in which the free fatty acids, phosphatides, and pro-oxidants are removed by washing with an alkaline solution. The fatty acid profile of soybean oil is: 51 to 53% linoleic acid, 21 to 24% oleic acid, 9 to 11% palmitic acid, 6 to 8% linolenic acid, 4% stearic acid, and 1% eicosenoic acid. Soybean oil is highly unsaturated, thus, to make certain products (e.g. margarine, shortening) hydrogen is added to double bonds in the triglycerides to increase their melting points. The oxidative stability is also improved in the hydrogenation process.

Table 1. Comparison of the nutritional composition of various soy products including soybean meal, full-fat soy, soy protein concentrate, fermented soybean meal and soy protein isolate

Nutritional Parameter (% as-is)	Soybean Meal[1]	Full-fat Soy[2]	Soy Protein Concentrate[2]	Fermented SBM[2]	Soy Protein Isolate[2]
Dry Matter	88.5	88.6	92.5	92.0	95.5
Crude Protein	47.6	39.5	65.3	56.0	88.0
Crude Lipid	1.7	22.1	0.8	0.8	0.4
Gross Energy (kcal/kg)	4144	5153	4575	4383	5135
Ash	6.7	5.7	6.3	6.9	3.8
Essential Amino Acids (% as-is)					
Arginine	3.44	2.69	4.98	4.60	6.70
Histidine	1.38	0.95	1.81	1.56	2.30
Isoleucine	2.25	1.70	3.20	2.70	4.30
Leucine	3.68	2.80	5.17	4.50	7.20
Lysine	3.09	2.37	4.23	3.25	5.50
Methionine	0.66	0.51	0.92	0.76	1.20
Phenylalanine	2.43	1.90	3.40	2.93	4.60
Threonine	1.79	1.46	2.73	2.16	3.00
Tryptophan	0.71	0.47	0.82	0.74	1.20
Valine	2.34	1.78	3.40	2.79	4.40

[1]Galkanda-Arachchige et al. (2021)
[2]International Aquaculture Feed Formulation Database (IAFFD)

Table 2. Comparison of the fatty acid profiles of soy lecithin and soybean oil

Nutritional Parameter (%)	Soy Lecithin[1,2]	Soybean Oil[2,3]
Palmitic acid (16:0)	15.8	9.4
Stearic acid (18:0)	6.3	4.0
Oleic acid (18:1 n-9)	13.0	22.0
Linoleic acid (18:2 n-6)	57.3	51.0
Linolenic acid (18:3 n-3)	1.8	6.8

[1]Thornton et al. (1944)
[2]International Aquaculture Feed Formulation Database
[3]List (2016)

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Dr. Dominique P. Bureau has had a passion for the life sciences and agriculture and dreams of becoming a scientist from a very young age. His first hands-on exposure to aquaculture was over 30 years ago during extended sojourns to Northeastern Thailand.

He obtained a Bachelor's degree in Bio-Agronomy in 1991 and a Master's degree in Animal Science in 1992 from Laval University (Quebec City, Quebec, Canada). He then obtained a PhD in Nutritional Sciences from the University of Guelph (Guelph, Ontario) in 1997. He joined the faculty of the Dept. of Animal Biosciences in 2000 and holds the rank of professor since 2009.

Dr. Bureau manages the Fish Nutrition Research Laboratory at the University of Guelph where he leads a dynamic research program focusing on nutrients) metabolism and utilization, feed formulation, feedstuff evaluation, management of environmental impacts of fish culture operations, integration and valorization of published scientific information and development of mathematical models of digestion, growth, and nutrient utilization for aquaculture species. He was a member of the US NRC Committee on Nutrient Requirements of Fish and Shrimp (2009-2011) and now leads the International Aquaculture Feed Formulation Database (IAFFD, www.iaffd.com) project.

Dr. Bureau is the co-founder of Wittaya Aqua International (wittaya-aqua.ca), a thriving young company developing a suite of cutting-edge online tools for aquaculture operations, feed manufacturers and ingredient suppliers. Dr. Bureau and his team at the University of Guelph and Wittaya Aqua are working very closely with numerous feed manufacturers, feed ingredient suppliers, aquaculture producers, research groups and organizations from around the world.

Dr. Jamie M. Hooft, BSc., MSc., PhD. Aquaculture Consultant at Wittaya Aqua

Dr. Jamie Hooft graduated with a PhD in Fish Nutrition and Toxicology from the University of Guelph in 2016. Prior to defending her PhD, Dr. Hooft completed her MSc in 2010 in Fish Nutrition and Toxicology also at the University of Guelph. Her thesis work was focused on the effect of the *Fusarium* mycotoxin, deoxynivalenol (DON), on rainbow trout and Nile tilapia. This work was instrumental in determining that rainbow trout are highly sensitive to DON and that

considerable species differences exist among finfish in terms of their response to DON (i.e. rainbow trout vs. tilapia). Moreover, this work represented a considerable effort toward the use of plant proteins in aquaculture feeds. Since defending her PhD, Jamie has been working steadily in the aquaculture industry in various roles, both in a technical capacity and as a research scientist. She is currently a consultant on the Science Team at Wittaya Aqua.

Soy In Aquaculture Program

This technical paper was created through the USSEC Soy In Aquaculture (SIA) program and the USSEC Southeast Asian Regional Program. USSEC works with target audiences in Southeast Asia and globally to show the utility and benefits of using United States soybean products in aquaculture diets.

The SIA program replaces the Managed Aquaculture Marketing and Research Program (the AquaSoy Initiative, funded and supported by the United Soybean Board and American Soybean Association) which was designed to remove the barrier to soybean meal use in diets fed to aquaculture species.

The objective of the SIA is to optimize soy product use in aquaculture diets and to create a preference for U.S. soy products in particular, including but not limited to U.S. soybean meal, soybean oil, soybean lecithin, and "advanced soy proteins" such as fermented soy and soybean protein concentrate.

This paper follows the tradition of USSEC to provide useful technical materials to target audiences in the aquaculture industry.

For more information on soybean use in aquaculture and to view additional technical papers, please visit the Soy-In-Aquaculture website at www.soyaqua.org.

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