SOYBEAN

Feed Industry Guide

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Dr. Newkirk is a director at the Canadian International Grains Institute, an organization that promotes the use of Canadian field crops by providing technical support and conducting applied research that demonstrates the attributes of the products to users. Dr. Newkirk received his PhD from the University of Saskatchewan for his work on the optimization of oilseed processing to increase nutritional value for animals. He holds several patents related to oilseed processing and has published feed industry guides for canola and flax, which have become standard reference for users around the world.

Soy 20/20 initiated the development of this guide and provided funding and direction to its production. Soy 20/20 is a unique partnership between farmers, industry, government and academia to stimulate and seize new domestic opportunities for Canadian soybeans. Soy 20/20 assists researchers, industry, growers and policy makers in focusing on key opportunities and working together to realize them. For more information, please visit www.soy2020.ca

Grain Farmers of Ontario (GFO) provided funding towards this guide. GFO represents Ontario's 28,000 growers of corn, soybeans and wheat, whose crops cover five million acres of farm land across the province, and are a major economic driver for Canada. Ontario-grown corn, soybean and wheat crops generate over $2.5 billion in farm gate receipts, resulting in over $9 billion in economic output, and are responsible for over 40,000 jobs in the province. For more information, please visit www.gfo.ca.

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An electronic version of this guide can be downloaded at: http://www.cigi.ca/feed.htm

soy20/20 building the business of soy

Canadian International Grains Institute
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GRAIN FARMERS OF ONTARIO

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Introduction

Soybean products are the most commonly used vegetable protein source worldwide. Soybeans are an important crop in Canada often favoured by farmers due to their low nitrogen fertilizer requirements and high economic returns. Processed soybeans are a high-quality source of protein for livestock species of all types and the oil is a high-quality vegetable oil. The objective of this publication is to provide a reference guide for users of soybean products that includes current information on the processing and applications of soybeans in a wide range of diets.

Table Of Contents

Soybean Background and Market

When one thinks of the Canadian agricultural landscape, fields of golden wheat are likely to come to mind. However, the production of soybeans has increased significantly in Canada over the past 30 years, with 1.4 million hectares of soybeans grown in 2009. Once only a crop suitable for the warmer southern Ontario climate, new soybean varieties better suited to Canada's shorter growing season have resulted in an eight-fold increase in production since the 1970s. Soybeans now account for the largest land usage amongst field crops in Ontario and growth has been particularly prominent in Western Canada.

The soybean is a legume which is native to East Asia and is classed as an oilseed. Soybeans have become a popular global choice for food consumption, animal rations and edible oils because they are high-protein, high-oil beans. The average oil, feed and meal soybean is 16 to 19 g/100 seeds and contains 18 to 21 per cent oil and 36 to 40 per cent protein.

Traditional uses of soybeans for human food consumption include soy milk, tofu, soy sauce, oil, margarine, shortening, edamame and imitation meat products (i.e. artificial bacon bits). Soybean meal and roasted soybeans are used as animal feed. With investment in research and technology, soybeans have also grown in popularity for use in industrial applications, including printing ink, biodiesel, waxes, solvents, lubricants, plastics, fibres, textiles and adhesives, amongst others.

In the 2009 calendar year, Canada's soybean crop represented $1.39 billion in farm cash receipts. It is the third most important field crop by farm cash receipts in Canada behind wheat ($5.1 billion), and canola ($5.0 billion). In Ontario, its importance as a field crop is notable, with farm cash receipts ($1.03 billion) exceeding traditional crops of corn ($805 million) and wheat ($267 million).

Canada currently ranks seventh in average total soybean production worldwide behind the U.S., Brazil, Argentina, China, India and Paraguay. However, Canadian soybean breeders have developed specialized high-quality, food-grade beans that demand a premium price in foreign and domestic markets, particularly Asia. Exports of Canadian soybeans increased 14 per cent from the 2007-08 to 2008-09 crop year, with Japan, the U.S., China, Belgium and the Netherlands as leading importers.

For more export information, please see chart at:

www.canadiansoybeans.com/UserFiles/File/exportsbycountry_08.pdf

TRADING RULES

The Canadian Oilseed Processors Association (COPA), a federally incorporated non-profit industry association that represents oilseed processors in Canada, publishes a set of trading rules that provide a guideline for the trade of oilseed meal and oil. These trading rules are suggested standards and are used as a basis for negotiating terms of trade.

Solvent-Extracted High-Protein Soybean Meal

Standard specifications are as follows:

Protein..minimum 47.5 per cent - 49.0 per cent
Fat..minimum 0.5 per cent
Fibre...maximum 3.3 per cent - 3.5 per cent
Moisture...maximum 12.0 per cent

Soybean Oil (Crude)

(1) Not more than 0.5 per cent moisture and volatile matter
(2) A refined and bleached colour not darker than 6.0 red
(3) A neutral oil loss not exceeding 7.5 per cent
(4) Not more than 1.5 percent-unsaponifiable matter (exclusive of moisture and insoluble impurities)
(5) A flash point not lower than 250°F

Seed, Roasted or Expelled Soybean Meal

The Canadian Grain Commission regulates the grading of soybeans. Specifications for grades of seed can be found at www.grainscanada.gc.ca. There are no trading rules or grading standards currently in place for roasted, extruded or expelled soybean products.

SOYBEANS - RECENT ADVANCES

Soybeans are a highly adaptable and multi-purpose crop used worldwide as a source of protein for human and animal consumption as well as for many industrial uses. Seen as a 'green alternative' to non-renewable resources, the many possible uses of soy are full of untapped potential, resulting in considerable global private and public research to develop the sector.

Scientists are deliberately working with the genes in soybeans to modify and select specific properties and traits that will improve yields, increase disease resistance and profitability for farmers, provide health benefits for humans and animals, and bring varieties to market that are specifically suited for industrial uses.

Soybean biotechnology success stories include varieties that are resistant to herbicides like glyphosates (i.e. Roundup®). Known as first-generation traits, these herbicide-resistant varieties have helped to reduce costs and improve production efficiencies for farmers.

Second-generation traits in soybean breeding include the development of varieties that improve the nutritional value of the soybean for human and animal consumption. Methods include decreasing anti-nutritional factors such as trypsin inhibitors or lectins, and the development of high-lysine, high-oleic, or low-phytic acid varieties. Due to increased consumer demand for omega-3 fatty acids in food, several seed companies have been working on soybean varieties that are high in omega-3s.

Third-generation soybean research focuses heavily on green energy and industrial uses. Soybeans can be used in the production of biodiesel, pharmaceuticals, plastics, waxes, solvents, lubricants, hydraulic fluid, fibres, textiles and adhesives, among literally hundreds of other uses.

The future is certainly bright for soybeans, with seemingly endless opportunity for their use in human and animal nutrition and the possibility for exponential growth in industrial uses.

Soybean Processing

Soybeans are typically processed prior to inclusion in animal diets. It is important that the anti-nutritional components in soybeans are denatured prior to feeding them to monogastric animals, such as poultry and swine, so that digestibility and animal performance are not reduced. Soybeans are also processed prior to feeding to ruminant livestock, but here the primary purpose of processing is to increase the proportion of protein that bypasses the rumen rather than the destruction of anti-nutritional compounds. A secondary objective of soybean processing is the extraction of oil for use in food, feed or industrial applications.

HEAT LABILE ANTI-NUTRITIONAL FACTORS

The anti-nutritional components contained in soybeans, like in other plant products, function presumably as a defence mechanism to prevent ingestion. The two most important and best understood are trypsin inhibitors and haemaglutanins (lectins). With proper heat processing, these anti-nutritional factors are denatured, which eliminates their negative effects on animal performance.

Trypsin Inhibitors

Trypsin inhibitors are a unique class of proteins found in raw soybeans that inhibit protease enzymes in the digestive tract. They reduce trypsin activity (a protease enzyme secreted by the pancreas) and, to a lesser extent, chymotrypsin, and, therefore, impair protein digestion by monogastric animals and some young ruminant animals (Leiner, 1994). There are two main classes of trypsin inhibitors found in soybeans: Kunitz and Bowman-Birk. Kunitz soybean trypsin inhibitors bind trypsin enzyme in a 1:1 molar ratio. Bowman-Birk trypsin inhibitors have two binding sites, one which binds trypsin and the other, chymotrypsin.

Feeding raw soybeans to monogastric animals like poultry and swine is not recommended as the presence of trypsin inhibitors and lectins will result in stunted growth, reduced feed efficiency and pancreatic hypertrophy (Leiner, 1994).

Plant breeders have successfully developed lines of soybeans that are devoid of Kunitz inhibitors. This has reduced the amount of processing required to treat this type of soybean (Liener and Tomlinson, 1981). Eliminating the Bowman-Birk inhibitors from soybeans has proven to be more difficult (Livingstone et al., 2007) but progress is being made and commercial varieties devoid of trypsin inhibitors will likely be developed in the future.

Trypsin inhibitors are sensitive to denaturation by heat treatment. The vast majority of soybean products used for livestock feeds are heat-treated in order to eliminate any anti-nutritional effects associated with feeding raw soybeans.

Lectins

Soybeans also contain an anti-nutrient called soybean haemaglutanins or lectins. These compounds are able to bind to glycoprotein receptors found in the wall of the digestive tract and cause damage to its lining, resulting in reduced animal performance (Leiner, 1994). They also bind the glycoproteins that are found on the surface of blood cells and cause them to agglutinate which is the reason they are often called haemaglutanins. This unique property helped scientists initially identify the molecule and is still used to measure its concentration (Leiner, 1994). However, their anti-nutritional affects are primarily associated with the ability to damage the wall of the digestive tract, not their ability to bind to blood cells. Lectins are thought to constitute about 25 per cent of the negative effects associated with feeding raw soybeans to poultry and swine.

Like trypsin inhibitors, lectins are primarily composed of protein and are subject to denaturation by heat treatment, which reduces or eliminates their negative effects on nutrient utilization and animal performance (de Muelenaer, 1964).

Some have suggested commercially practised methods of heat processing soybeans may not always eliminate the negative effects of the lectins as in some circumstances they can be more resistant to heat denaturation than trypsin inhibitors. Concerned that residual lectins may play a role in runting and stunting syndrome in broiler chickens, characterized by malabsorption of nutrients and reductions in skin pigmentation, Casaubon-Hugenin et al. (2004) fed them raw soybeans to determine if they could replicate some of the symptoms of this condition. However, they concluded residual lectins probably do not contribute to this syndrome.

The commercial meal used in the study did have some residual lectins (884µg/g) markedly less than the raw soybeans, which contained 5658µg/g, indicating the heat treatment was effective in this case. In most cases, if soybeans have a residual urease activity of less than 0.2 pH units, then the lectin content should be low enough that the potential negative effects associated with this compound should not be present.

OTHER ANTI-NUTRITIONAL FACTORS

Soybeans contain small amounts of other anti-nutritional factors which include phenolic compounds called tannins, but they are of little concern.

Soybeans also contain phytoestrogens, compounds that can mimic estrogen. These are often characterized as isoflavones but are only found in small concentrations in the mature soybean and are not of practical significance when formulating diets. Soybeans also contain small amounts of saponins, a compound that can impart a bitter taste and possibly impact nutrient absorption, but the concentration is low enough that it is not usually considered to be of any practical significance (Ishaaya et al., 1969).

Oligosaccharides, sugar-based compounds not digested by monogastric species, are also found in soybeans. They are of significant concern as they can cause flatulence in humans as a result of micro-organisms in the large intestine feeding on these undigested compounds and turning them into gases. The primary compounds that cause this effect are raffinose and stachyose. The addition of the enzyme α-galactose to the diet permits the digestion of this product preventing flatulence. These compounds have been studied in animals, particularly poultry, to determine if they have any anti-nutritional properties. Parsons et al. (2000) determined that the metabolizable energy content of the meal could be increased by 7 to 10 per cent if the oligosaccharide content was reduced by alcohol extraction.

Some soybean proteins can be allergenic to portions of the human population, causing some to believe that they may also affect animal performance. The primary concern is that allergenic proteins in soybeans may elicit an allergic reaction in the small intestine and, therefore, affect nutrient utilization and possibly growth rate in some monogastric animals. In most instances, this does not appear to be a significant issue but in some cases, such as in aquaculture or pet foods, reduced allowable inclusion levels will be imposed as a precautionary measure.

Soybeans, like all other plants, contain phytic acid, a bound form of phosphorus that resists digestion by monogastric animals and can interfere with the absorption of other minerals, such as calcium, zinc, iron, and other divalent or trivalent metals. Soybeans contain 1-1.5 per cent phytic acid, which is markedly more than most cereals but about half of the amount found in canola meal. As with other ingredients, it is necessary to formulate diets for monogastric animals based on digestible phosphorus content rather than total phosphorus levels to ensure the animal has sufficient quantities for optimal growth. Phytase, an enzyme which can be added to feeds, has proven to be a cost effective method of increasing phosphorus utilization by hydrolyzing approximately 50 per cent of the phytate in the digestive tract of the animal. Most commercial diets now include this enzyme as an effective means of increasing the phosphorus utilization from all plant-based ingredients, including soybean meal.

PROCESSING OF SOYBEANS TO ELIMINATE ANTI-NUTRITIONAL FACTORS

Numerous methods of eliminating anti-nutritional factors and/or increasing bypass protein content have been developed and tested. They range from methods of treating the whole bean, resulting in a full-fat feed ingredient, to processes that combine oil extraction and heat treatment to produce an oil-free product devoid of anti-nutritional factors. The method used is determined by the requirements of the intended use, the scale of production, and the cost of the process (both capital and operating).

Processing Without Oil Extraction (Full-Fat Soybeans)

Due to capital cost and technical requirements associated with the solvent extraction of oil, many small- to mid-scale processors process whole soybeans without removing the oil. This process involves the elimination of anti-nutritional factors through the application of heat in measured amounts, which denatures the trypsin inhibitors, haemaglutanins (lectins) and possibly allergenic proteins without damaging the quality and digestibility of the protein in the meal. Heat treatment also has the added benefit of reducing the degradation rate of protein in the rumen, therefore increasing bypass protein levels for ruminant animals such as dairy cows which require this type of protein. Methods of heat treating full-fat soybeans include roasting, micronization, fluidized bed drying and microwaving.

Roasting Soybeans

Roasting has proven to be popular with soybean farmers who also raise livestock. Small portable roasting systems are available that can be used to heat process soybeans on-site, eliminating the costs of transport to a processing plant and back to the farm. Roasted soybeans also create a convenient method of increasing fat content in the diet without the need to physically handle a liquid oil product.

Soybeans are typically roasted by exposure to high temperatures for a short time. This is commonly accomplished by passing the soybeans through a flame in a continuous flow system so that the beans are rapidly heated in the process. Another option is to suspend the beans in a stream of hot air (fluidized bed dryer) which offers the advantage of lower air temperatures that reduce the potential for overcooking and the resulting reduction in protein quality. In a study by Faldet and Satter (1991), soybeans were roasted in a direct-fired roaster with air temperature between 430°C and 450°C. They controlled the process so that soybeans exiting the roaster

Image courtesy of Blythe Brae Farms

were 146°C, ensuring sufficient heat was applied but without overcooking the beans and, therefore, not reducing their protein quality. In contrast, Wiriyaumpaiwong et al. (2004) heat-treated whole soybeans in a fluidized bed dryer using an average air temperature of only 164.5°C. The beans needed to be exposed to this air for a minimum of 10 minutes to sufficiently inactivate the anti-nutritional compounds.

Processing temperature must be carefully controlled to ensure the beans are heated sufficiently to eliminate the anti-nutritional factors, but not heated excessively which increases processing cost and reduces protein quality. The recommended operating parameters depend on equipment design and moisture content of the soybeans, but they are typically heated to between 135°C and 150°C. Reddy et al. (1993) demonstrated that optimum quality was achieved when the temperature was between 143°C and 146°C. In all cases, it is important to test the roasted beans to ensure they are properly heat-treated (refer to section Testing Meal Quality on page 16).

Soybean roasting is often practised on-farm but farmers typically have limited access to laboratory facilities so quality control may be more subjective, based on the experience of the operator. They would have a set goal for exit temperature as well as product colour and smell. Roasting offers the benefits of allowing producers the option of using their own soybeans for animal production. Soybeans are also roasted commercially in large facilities, which usually use energy more efficiently and may produce a more consistent product than when using portable on-farm roasting equipment. Commercial roasting facilities achieve this by using a fluidized bed system with counter-current air flow.

Post-roasting conditions also impact the quality of roasted soybeans. When soybeans exit the roasting system, they are still hot and the process of protein denaturation continues until the beans are cooled (steeped). In most cases, it is desirable to ensure sufficient ventilation is available so that the beans cool quickly, preventing protein damage. If the beans are maintained at an elevated temperature post-roasting, the temperature required in the roasting process can be reduced. For ruminant animals, it may be desirable to steep the soybeans for 30 minutes after roasting for optimum digestibility. The shelf life of roasted soybeans is 8 to 10 months and they can be fed either coarsely ground or whole.

Alternative Heat Treatment Methods

In an effort to create more efficient heat treatment processes for soybeans, alternatives have been developed and are used commercially.

Extrusion

Extrusion is the process of applying high pressure and temperature to soybeans in a continuous screw system called a cooking extruder. In this system, heat is created through friction and pressure during the extrusion process.

The extrusion process is of short duration, 30 seconds to 3 minutes residence time, and requires a relatively small amount of equipment. During the extrusion process, moisture is maintained in the seed thereby reducing the amount and duration of heat treatment required. Extrusion also creates shear and pressure, which help disrupt cell walls to increase the availability of nutrients to animals. The digestibility of properly heat-treated soybeans is intrinsically high even without extrusion, but the extrusion process is reported to create a small positive response beyond heat treatment alone. Extrusion does, however, reduce the particle size significantly during the process as a result of the shear encountered in the system. Due to the small particle size and direct contact with heat sources, the material is potentially heat processed in a more uniform manner.

Wiriyaumpaiwong et al. (2004) compared the effects of heat processing soybeans by extrusion with that of air heating whole beans and concluded that the extruded product, although more expensive to produce, was more consistently heat-treated. In contrast, roasted whole beans are more cooked on the outside than the inside due to the time it takes for the heat to be conducted through the seed.

Although this high-intensity process requires a relatively small amount of space, due to the technical nature of the extruder and the high pressures involved, the systems are relatively expensive. The simplest and, therefore, least expensive extruders are called single-screw extruders. These consist of a single rotating screw encased in a specially designed housing that forces the soybeans through a restricted opening which often consists of a tapered plug that can be adjusted to modify the conditions within the system. The screw is designed to specifically generate pressure, heat and shear. The screw is typically composed of a number of elements driven by a single shaft. Changing or rearranging these elements is possible to create the desired processing conditions. A large electric motor turns the screw and creates the movement and pressure. Due to the large amount of friction involved, the screw and the barrel are subject to wear and need to be replaced on a routine basis. Product quality must be monitored closely as the amount of heat generated can be reduced as the components of the system wear. Heating the seed prior to entering the extruder reduces the amount of pressure and friction required to heat-treat the soybeans and, therefore, minimizes the rate of wear, as well as the amount of power required to operate the system.

Extruders can also have two co-rotating screws called twin-screw extruders. These systems are much more complex and costly to produce and, therefore, are not commonly used for heat processing of soybeans for livestock. In some instances, where unique properties are required, the twin screw extruder offers more flexibility and control to generate novel products. Typically, these are restricted to the production of human food products or specialty products for use in some aquaculture or pet food applications.

Micronization

Micronization is the process of heating the soybeans by infrared radiation. The infrared radiation is generally in the range of 1.8 to 3.4 μm and is generated by heated ceramic tiles. The soybeans are passed under the heated plate by a vibrating screen conveyer. The soybeans may be in contact with the infrared radiation for 5 to 15 minutes, depending on the design of the system and the operational parameters used. The radiation causes the beans to quickly heat from the outside in. In some cases, operators will temper the soybeans with water to increase their moisture content in an attempt to increase the efficiency in which the anti-nutritional factors are destroyed. Wiriyaumpaiwong et al. (2004) demonstrated sufficient processing in a commercial micronization unit when the soybeans were heated to 119°C to 121°C without the addition of water.

Micronization has proven to be popular with applications where high-oil content is desirable, but a high degree of quality control is required when feeding young birds or swine.

PROCESSING OF SOYBEANS TO EXTRACT OIL AND DESTROY ANTI-NUTRITIONAL FACTORS

In many cases, it is economically advantageous to also extract oil while processing soybeans to remove anti-nutritional factors. Smaller processors typically use a process called expelling, which is a mechanical type of screw press that essentially squeezes a large portion of the oil out by applying pressure. Another option is to use a solvent, such as hexane, to extract all of the oil from the seed.

SOYBEAN PROCESSING

Solvent Extraction of Oil

Today, the majority of soybeans are processed using solvent extraction, which removes virtually all of the oil from the soybean. The solvent extraction process includes:

- drying
- cleaning
- cracking
- dehulling
- conditioning and flaking
- expansion
- solvent extracting
- meal desolventizing-toasting
- drying and cooling
- grinding

Seed Drying

Post-harvest, soybeans are rapidly dried to ensure optimal moisture content favourable for storage or further processing. This is done either by natural or artificial drying. Artificial drying is more widely used in areas where large quantities of soybeans are harvested quickly and natural drying is not an option due to weather or time constraints. Beans are placed in special equipment called ‘dryers’ and are heated and exposed to forced ventilation. Ideally, soybeans should be dried to approximately 13 per cent moisture to ensure maximum stability during storage.

Cleaning

Following drying, the soybeans are cleaned to remove soil, plant and insect waste, and other contaminants. Cleaner-separator machines, which include a reception hopper, a fan and a set of vibrating sieves, remove the contaminants.

Cracking

By passing the beans through a series of roller mills, they are cracked into 8 to 16 pieces.

De-hulling

Soybean seeds often have the hulls removed prior to solvent extraction to both increase the processing capacity of the plant and the protein content of the meal. Following a process to dry the seeds to approximately 6 per cent moisture, a small amount of moisture is added to the surface of the seeds in a process called tempering. The water absorbed in the surface causes the hull to loosen, making it easier to remove after cracking. The hull, accounting for approximately 8 per cent of the bean by weight, falls away from the seed pieces and is carried away in a stream of air in a process called aspiration. The “meat” of the soybean remains after de-hulling.

Conditioning

Following the cracking process, the soybean meat is heated to approximately 74°C to soften it prior to flaking, preventing the seed from turning into flour when mechanical pressure is applied.

Flaking

To aid oil extraction, the conditioned meat is passed through a set of rotating steel rolls (roller mill), producing a flake that is approximately 0.3 mm thick. The flaking process generates enough pressure that the cells in the seed are ruptured, allowing the solvent to penetrate all parts of the seed and strip out the oil in the process.

Expansion

Prior to solvent extraction, it is critical that the solvent is able to penetrate the flake and drain away the oil. Consequently, some processing plants have incorporated a process called expansion in which the seed is fed into a machine with a rotating screw much like those found in an extruder. A plug at the exit restricts the flow of the seed, generating large amounts of pressure that causes additional cell rupture, increasing oil extraction efficiency. Upon exiting the expander, the product undergoes a rapid change from high pressure within the machine to low pressure upon exit. Steam produced within the seed from the heat generated in the process causes the product to expand and create small spaces within, making it more porous. This increase in porosity increases extraction efficiency and solvent drainage from the solvent-extracted flake.

Solvent Extraction

In the solvent extraction process, the flakes are washed in a counter-current manner with hexane, a petroleum distillate, and the hexane-oil mixture is separated from the flakes. A common style of extractor involves a chain that pulls the meal through the extractor while the solvent is pumped over the meal and drained through the chain below. Due to the highly flammable nature of hexane, the solvent extraction process is conducted in a separate area of the plant to ensure there is no exposure to air or spark. Building solvent extraction plants are very costly as a result, making small commercial systems impractical. Most solvent extraction plants range from 1,000 up to 5,000 tonnes of seed per day.

Desolventizer-Toaster

Once the oil has been removed, the soybean flakes are called “spent flakes” and are sent to a desolventizer-toaster, which is used to remove any undrained hexane. To accomplish this task, the flakes are heated to evaporate the hexane and steam carries away the hexane vapours. This process also toasts the meal, which inactivates the anti-nutritional factors trypsin and lectins as discussed earlier. This toasting process is carefully controlled to effectively remove all traces of the hexane and destroy the anti-nutritional factors while maintaining protein quality. Toasting occurs through the application of both direct and indirect heat sources. The meal is heated on steam-heated trays (indirect) as well through the purging of live steam through the meal (direct). If the meal is overcooked, it can take on a brown colour indicating that Maillard reactions are occurring. These are chemical reactions involving lysine and glucose that create brown-coloured compounds and reduce the digestibility of the lysine and are, therefore, undesirable.

Drying/Cooling

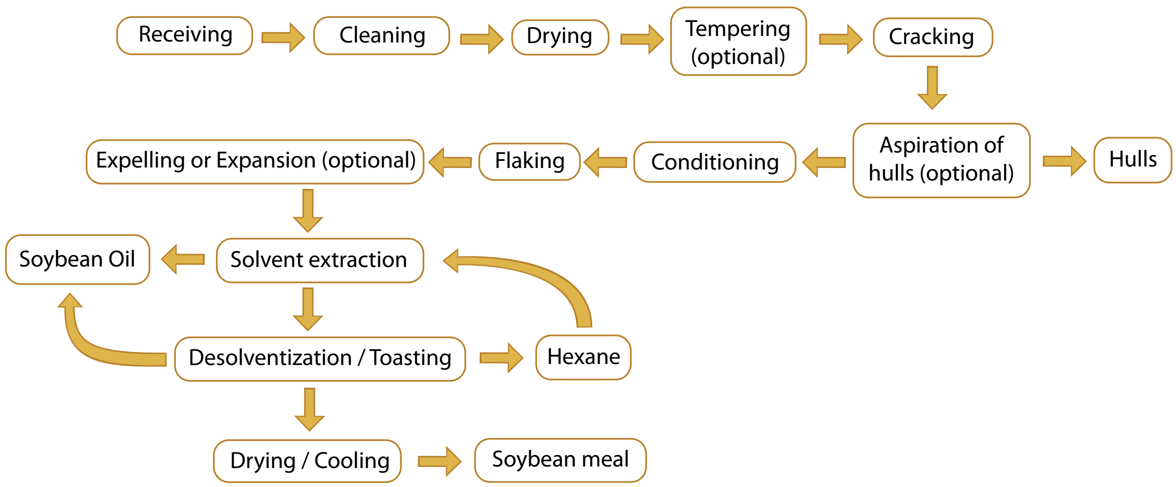
The next step in the process involves drying and cooling the meal to approximately 12 per cent moisture.

Grinding

The final step in soybean processing is grinding, where the meal is screened and ground using a hammer mill. This ensures a uniform particle size.

The final product is a high-protein meal, containing less than 0.5 per cent crude fat and about 48 per cent protein.

Figure 1. Processing Flow.



Alternatives to Solvent Extraction

Solvent extraction is the most common method of processing soybeans as it is the most efficient for extracting oil and destroying anti-nutritional factors. However, due to the complexity of the process and the safety requirements involved with using a flammable solvent, it is not practical or economical on a small scale.

Alternative soybean processing methods exist and are used either on-farm or in small-scale processing facilities that produce specialty products. The primary objective of the process is to remove anti-nutritional factors and produce a consistent, high-quality meal.

Expeller Extraction

Oil can be recovered from soybeans by applying mechanical pressure. This is accomplished by means of a mechanical screw which forces soybeans (typically cracked to facilitate the process) through an orifice. The barrel of the expeller unit has small openings that allow oil to be forced out while retaining the majority of the seed within the barrel. Two common styles of expellers are used for this purpose: standard radial and axial style.

The standard radial expeller press consists of a rotating shaft with a flight machined into it. At the beginning, the groove is relatively deep but as the product is forced down the rotating shaft, the depth of the groove decreases, creating outward pressure. As the pressure builds, oil is "expelled" from the seed which effectively reduces the pressure on the seed. At the exit, a tapered plug prevents the seed from flowing freely out of the press. The plug can be adjusted inward to create more pressure. Standard radial screw presses offer the advantages of being scalable from very small (1 hp) to very large (500 hp). However, they are very sensitive to seed moisture and temperature, so proper cooking and conditioning prior to expelling are essential (Patil and Nawab Ali, 2006).

The axial style press also uses a rotating shaft with a deep groove cut that forces the product along, but unlike the standard press, the depth of the groove does not change over the length of the screw. In this case, all the pressure is generated as the meal is forced out of a small die opening at the end of the barrel. As the pressure builds, the oil squirts back through the seeds and out a series of small holes located in the forward section of the barrel. These presses are used primarily in small manufacturing facilities that produce a high-quality, virgin, oil for food. Due to their design, the soybeans do not require as much cooking and pre-conditioning and the presses are very small and relatively simple to operate. This also makes them relatively easy to disassemble and clean. However, the system is limited in size to only a few tonnes per day of processing capacity. If large capacity is desired then several units must be installed in parallel.

In both cases, it is important that sufficient heat is applied to meet the needs of the livestock that will be consuming the feed. If the product is destined for monogastric rations, trypsin inhibitors and lectins must be denatured. If the meal is used in dairy rations, heat treatment will be desired to achieve the necessary level of rumen degradable protein. Heat is generated during the expelling process but generally it is not enough to achieve these requirements. Pre-treatment often consists of cleaning, cracking and cooking prior to expelling to ensure anti-nutritional factors are denatured or the desired level of ruminant by-pass protein is achieved.

Extrusion/Expeller Processing

As discussed earlier, extrusion cooks the seed, effectively killing the anti-nutritional factors and rupturing cell walls. Extrusion can also be used as an effective pre-treatment prior to expelling (Bargale et al., 1999). Figure 2 shows equipment set-up for typical extrusion/expeller processing. Extrusion heats the seed and disrupts the cell wall, enhancing oil extraction. This method of seed processing has proven to be popular in North America and is the third most common processing method after solvent extraction and roasting. Unfortunately, none of the mechanical methods of extracting oil described above, including extrusion/expeller processing, are able to fully extract all the oil. An extraction level of 91 per cent of the oil is the highest reported level found, according to a report by Bargale et al. (1999). Typically, mechanical extraction results in a meal with greater than 6 per cent residual oil in the meal.

Figure 2. Typical Process to Extrude/Expel Soybeans.

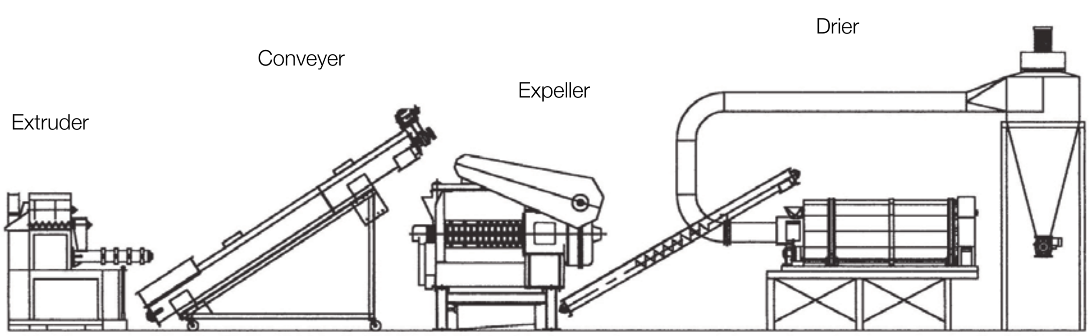


Image courtesy of Insta-pro International

Novel Methods of Oil Extraction

Attempts have been made to develop processes that are more effective in extracting oil than standard mechanical extraction methods. One possibility is to use a special proprietary compressed gas mixture that when under pressure is a liquid and acts as a solvent to extract oil. Upon release of pressure, the gas is collected and recompressed for use in the next sample. This technology is being commercialized by a Canadian company called BioExx™. It does not use hexane but offers a greater degree of oil extraction than can be achieved through the use of mechanical pressure alone.

Gas-supported screw-pressing (GSSP) is another technology that is showing some promise (Nazareth et al., 2009). GSSP consists of applying a high-pressure gas, typically carbon dioxide, into a traditional expeller so that the gas forces additional oil out of the soybean during the extraction process. This process is of particular interest to those interested in potentially making protein concentrates or isolates and need a low oil, high-protein solubility. Since the carbon dioxide can be used to cool the meal as well as extract oil, the meal retains very high protein solubility (Nazareth et al., 2009).

A significant amount of work has been conducted on the potential of water-based oil extraction. This process involves expelling part of the oil from the seed using a standard expeller press, then mixing water into the extracted cake and centrifuging the product. Using this process, oil, water and solids can be separated in several unique fractions. In most cases, a series of enzymes is included in the water that breaks down cell walls and enhances the extraction of oil. This process, called enzyme-assisted aqueous extraction, offers the potential to degrade anti-nutritional compounds such as phytic acid or α-galactosides by adding the appropriate enzymes during the extraction process (de Moura et al., 2008). This method also offers the potential to create unique protein concentrates during the aqueous fractionation of the seed.

In some cases, it is desirable to produce soybean products with elevated levels of protein. Protein concentrates can be produced through a series of water-based extraction processes. Large quantities of protein concentrates and isolates are produced and used in food ingredients; some are also used in feed applications where high-protein levels are required. An alternative to normal protein concentrate production by aqueous fractionation is to use alcohol to extract soluble sugars from soybeans (Coon et al., 1990), resulting in a meal with elevated protein concentration (approximately 57 per cent crude protein). Following alcohol extraction, the meal is dried, the alcohol recovered by distillation, and packaged for distribution. Alcohol extraction not only increases the protein content but also eliminates the anti-nutritional effects associated with oligosaccharides and, therefore, increases energy content of the meal. This method is practised commercially and can result in a cost-effective protein source in some diets, especially aquaculture and pet food applications.

TESTING MEAL QUALITY

It is necessary to test processed soybean products to ensure they have been processed sufficiently to eliminate the anti-nutritional factors present, but not over-processed which reduces protein quality and utilization.

The primary objective of processing is to optimize feed value. Soybean quality can be assessed using animal feeding studies but they are time-consuming, costly, and are subject to errors in diet formulation. In most cases, meal quality is tested by either measuring specific anti-nutrients, such as trypsin inhibitors and lectins, or using assays that predict the effectiveness of the heat treatment, such as urease activity or protein solubility. Vasconcelo et al. (2009), however, suggest that soybean meal should still be tested occasionally by animal feeding trials to ensure the anti-nutritional components have been sufficiently denatured.

Trypsin inhibitors are probably the most important heat labile anti-nutritional factor to be considered when processing soybeans and can be measured using a method described by Kakade et al. (1974). Quantification is accomplished by measuring the residual trypsin enzyme activity after an extract of soybeans containing the inhibitors has been added to a purified source of the enzyme. The degree to which the extract inhibits the activity is calculated and reported as trypsin inhibiting activity. In most cases, this assay is too technically challenging for day-to-day use on-site by soybean processors.

Lectins are typically quantified by a haemaglutinating assay. Soybean extract is placed in a test tube containing red blood cells. Varying dilutions of soybean extract are used and the lowest concentration required to visibly agglutinate the blood cells is determined and used to calculate the concentration of viable lectins in the soybean.

Lectins can also be purified and quantified as described by Moreira and Perrone (1977), but this is a more complex assay and is typically confined to research applications. In most cases, the assumption is made that if the trypsin inhibitors have been successfully denatured, then the lectins are probably denatured as well. Neither assay would be conducted on a routine basis as part of a soybean processing plant's quality control system.

Soybeans contain an enzyme called urease that is easily measured and can be used as an indicator of proper processing. The urease enzyme itself is not an anti-nutrient, but it does denature when heat is applied in a manner similar to trypsin inhibitors and, therefore, can be used to predict residual trypsin inhibitor activity. The urease enzyme causes a reaction where urea is converted into ammonia and carbon dioxide. Since ammonia has a very high pH level, the activity of this enzyme can be determined by monitoring changes in pH. The assay (AACC method 22-90) is relatively simple where 0.2 g of ground soybean meal is added to a test tube and 10 ml of buffered urea solution is added and heated at 30°C for exactly 30 minutes. A blank sample is prepared in the same manner but the buffer used does not contain urea. After 30 minutes the pH of the test sample and the buffer are measured. The pH difference between the blank sample and test sample is recorded. Raw soybeans will produce a pH change of approximately 2.5 pH units, but a properly heat-processed soybean will have a pH change of less than 0.2 units. Simple on-site versions of this assay have been developed and are sold commercially, such as SoyChek™ where a solution is added to soybean meal. After a period of time the sample is examined for evidence of residual urease activity, indicated by the appearance of red spots on the soybean particles.

Urease activity is the standard assay that most producers use as an indicator of sufficient heat processing. However, if the seed is overheated and protein quality damaged, the urease activity assay may not necessarily indicate this. Once the activity is low, there is no way to determine if excess heat has been applied with this assay. When undergoing heat processing, proteins undergo a number of changes. During the denaturation of enzymes such as urease or trypsin inhibitors, the protein structure is altered so that it loses its catalytic activity, but the proteins are still digestible by livestock. If excess heat is applied, additional reactions can occur that either bind lysine to sugars, rendering them indigestible (Maillard reactions), or additional cross linking involving amino acid sulphur groups, also rendering the protein resistant to digestion by livestock. To ensure the protein is still digestible after heat processing, a certain amount of protein solubility is required. If the protein is rendered highly insoluble, it likely has reduced nutritional value for animals.

The most common assay to assess protein solubility is the KOH protein solubility assay. In this assay, soybean meal is mixed with 0.2 per cent KOH solution and the level of protein that is soluble is measured and reported as a fraction of the total protein (Araba and Dale, 1990).

The Protein Dispersibility Index (PDI) is an alternative method that involves mixing soybean meal in a type of blender and measuring the protein present in the supernatant (Batal et al., 2000). The objective of these tests is to ensure the protein has not been overheated so a minimum level of soluble protein or PDI is targeted during processing. Typically, a protein solubility in KOH of 78 to 84 per cent or a PDI of greater than 40 per cent is targeted. However, these are only guidelines and there still remains some debate as to the exact standards that should be used.

A new assay has been developed that uses an immobilized digestive enzyme to predict true amino acid digestibility (Schasteen et al., 2007). This assay, termed IDEA (immobilized digestive enzyme assay), simulates digestion and the remaining (undigested) peptide bonds are measured with a chemical reagent. This assay is showing promise and may become available as a kit for use in quality control for soybean and other protein meal processing.

Soybeans in Poultry Diets

Soybean meal is the most common source of supplemental protein for poultry and is the standard to which all other protein sources are compared. The amino acid content complements that of the main cereals used in poultry diets and is highly digestible by poultry of all types and ages. Soybean meal is deficient in methionine and when used as the sole protein supplement, it is necessary to add synthetic methionine to meet the dietary needs of the birds. However, this amino acid is readily available and is cost-effective in soybean-based diets. In some cases, it may be necessary to add synthetic lysine and threonine to meet the birds' ideal amino acid balance while minimizing protein content of the diet. The amino acid content of soybean products are shown in the nutrient tables provided at the end of this guide. Amino acid digestibility is provided in Table 1.

TABLE 1. Apparent Digestibility (%) of Amino Acids in Soybean Meal Products Fed to Poultry (Adapted from Sauvant et al. 2004).

Amino acids	Solvent-extracted (44% crude protein)	De-hulled solvent-extracted (48% crude protein)	[1]Extruded/ Expeller meal (43% crude protein)	Extruded full-fat	Roasted full-fat
Methionine	91	91	91	86	82
Cysteine	86	86	82	77	76
Met + Cys	88	88	86	81	79
Lysine	91	91	93	88	81
Threonine	89	89	89	85	79
Isoleucine	92	92	92	87	79
Histidine	93	93	92	87	86
Valine	91	91	90	86	77
Leucine	92	92	94	87	80
Arginine	92	92	97	91	85
Phenylalanine	93	93	94	88	80

[1]Opapeju et al., 2006.

Poultry are particularity sensitive to trypsin inhibitors and lectins found in raw soybeans. However, when the meal is heat-treated appropriately, as described in the soybean processing section, bird performance is excellent even when soybean meal is the sole protein supplement used in the diet.

Solvent-extracted soybean meal has relatively high energy content for a protein supplement and fits well into poultry rations. Soybeans contain 0.76 to 0.94 per cent raffinose and 2.96 to 4.14 per cent stachyose (Kennedy et al., 1985) but these carbohydrates are not digested by poultry to any great extent due to a lack of endogenous α-galactosidase. This limits the availability of energy in soybean meal (Parsons et al., 2000). Soybean breeders are working to reduce the level of these oligosaccharides in an attempt to increase the energy content of meal even further. The meal can be extracted with alcohol to both concentrate the protein and increase the energy content of the meal (Coon et al., 1990). Some alcohol-extracted meal is produced commercially, but it is only a small portion of the soybean meal used as it increases costs and standard soybean meal normally meets the needs of the birds.

Commercial enzyme preparations are available that can be used in soybean-based diets to degrade these oligosaccharides through the actions of the enzyme α-galactosidase (Ghazi et al., 2003).

SOLVENT-EXTRACTED SOYBEAN MEAL

The majority of soybeans used in poultry diets are fed as a solvent-extracted meal. As described earlier, oil is extracted leaving a meal with approximately 1.5 per cent fat. The meal is available in two forms, as a 44 per cent crude protein meal and a 48 per cent crude protein meal. The higher protein meal does not contain the hull fraction of the seed. Removing the hull increases both the meal's protein and energy content. The de-hulled 48 per cent soybean meal is the most commonly used soybean product in poultry rations due to its relatively high-nutrient density. The 44 per cent crude protein meal (non-de-hulled) is also used in poultry diets without issue.

Solvent-extracted soybean meal is generally considered to be a highly consistent product in terms of quality due to the large scale of the processors involved. Solvent extraction plants typically process between 2000 and 4000 tonnes of seed per day so that any natural variation caused by genetics or growing conditions is lost due to pooling of seed during processing. In addition, these plants tend to focus on quality assurance; small errors can result in significant business losses.

Due to the high quality of this meal and the low levels of anti-nutrients, there are no limits placed on using this meal in any poultry rations. It can, and often is, used as the sole protein supplement to meet the nutritional needs of the birds.

Given the consistent quality and ease of availability, solvent-extracted soybean meal is an important part of the poultry ration and allows the poultry industry the opportunity to produce a high volume of consistent product. Some would even go so far as to suggest the soybean industry has significantly contributed to the success of the poultry industry and helps it compete effectively with other livestock sectors.

FULL-FAT SOYBEANS

Full-fat soybeans contain significantly more energy than solvent-extracted or expelled soybean meals due to the presence of extra oil. If properly heated, full-fat soybeans can be used in all poultry rations with few, if any, limitations (MacIsaac et al., 2005).

Some users limit the use of full-fat soybeans in poultry diets due to the high unsaturated oil content of the seed as poultry deposit fat they consume with little or no modification. Soybean oil is a high-quality, nutritious oil, but in excess can lead to reduced carcass quality in terms of fat content and stability. Soybean oil consists of about 53 per cent C18:2 (linoleic acid) and about 7.4 per cent C18:3 α-linolenic acid. Although these are desirable fatty acids in the diet and exceed the essential fatty acid requirements of the bird, they produce a softer carcass fat that can oxidize during storage. Stability in storage is particularly important if poultry is further processed into products such as cooked deli meats. The presence of the extra double bonds greatly increase the melting point of the oil (and, therefore, the fat in the carcass) and the affinity towards oxidation. In most cases this does not become an issue, but in some instances, nutritionists have had to put limits on the use of full-fat soybeans to meet the needs of a poultry processor.

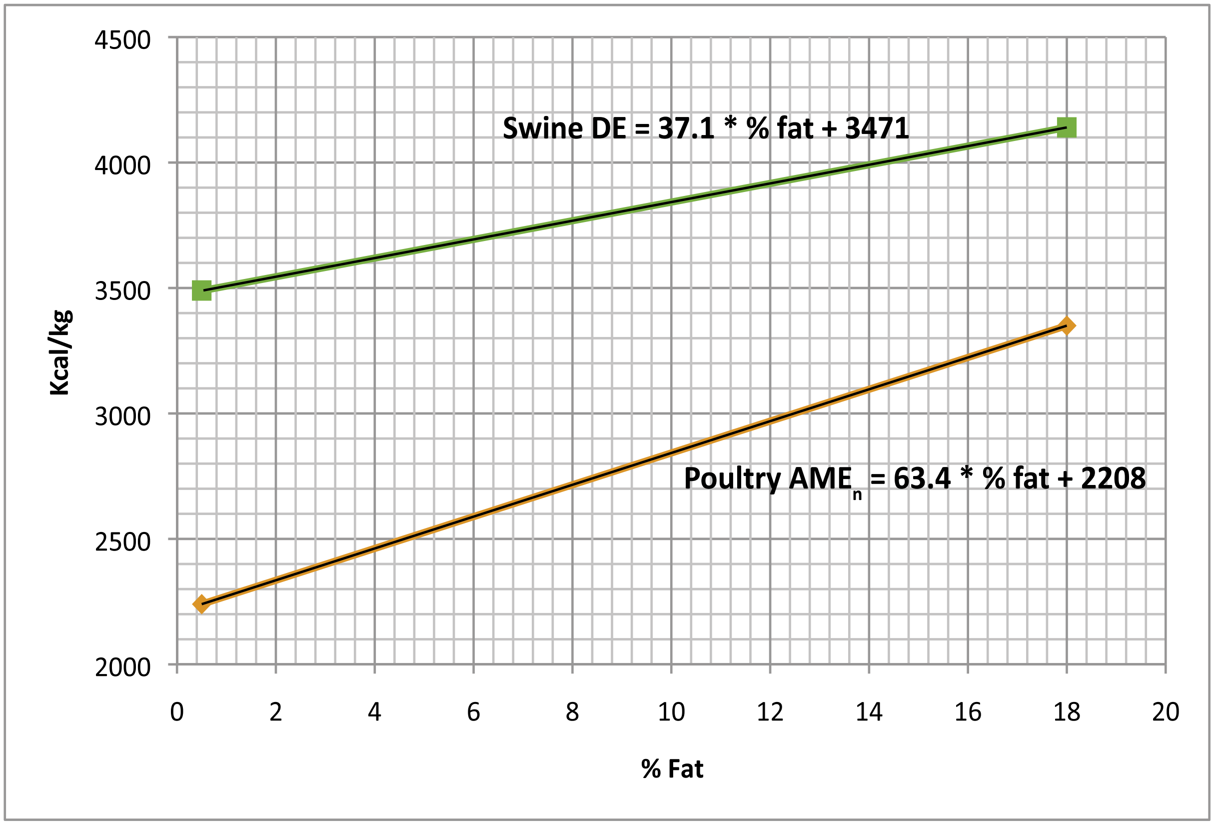
Full-fat soybeans are becoming more popular in soybean-growing regions where there is no local oilseed processing plant. In this case, the cost of shipping the beans to a large solvent extraction plant in another region and shipping the meal back outweighs the economic benefits associated with the extraction of oil for human consumption. Systems for processing full-fat soybeans (roasting or extrusion) are available on a relatively small scale (one to 200 tonnes/day) and can be a practical and economically attractive process in these instances.

EXPELLER MEAL

In regions where the supply of soybeans is too limited to warrant the construction of a large solvent-extraction plant but there is demand for meal for poultry, an alternative to full-fat soybeans is to extract part of the oil using an expeller. As previously described, these systems tend to be much smaller in scale than a solvent-extraction plant, but do offer the potential to extract and, therefore, sell some of the highly valued oil. In addition to the economic benefits of oil sales, expellers produce a meal that in many ways is ideally suited to poultry. However, the expelling process itself does not typically provide enough heat treatment to eliminate the trypsin inhibitors so additional heat must be applied to the meal to make it well-suited to poultry.

If properly heat treated, expeller meal can be used in all species of poultry diets without any limitation on inclusion level in the diet. Expeller meal retains a significant amount of oil (5-8 per cent) and, therefore, has elevated energy content (~2751 kcal/kg AMEn). Fat content varies between processors and, therefore, should be analyzed to determine the energy content of the meal prior to feed formulation. Figure 3 shows an equation which can be used to predict energy content of soybean meals based on fat content. The equation was developed by extrapolating energy values from soybean meal and whole soybeans, which are provided in the tables at the end of this guide.

Figure 3. Effect of Oil Content of Soybean Meals on Poultry Apparent Metabolisable Energy in Poultry (AMEn) and Digestible Energy in Swine (DE).



Combining an extrusion process with expelling has proven to be an effective method of producing a high-quality soybean expeller product for poultry that has been adequately heat treated to eliminate the anti-nutritional factors (Zhang et al., 1993). The extrusion process tends to disrupt cell walls and, therefore, increase digestibility. It is also reported as enhancing oil extraction, likely due to the disruption of cell walls.

CONCLUSION

All properly heat-treated soybean products are well-suited for use in poultry feeds. There are few limits on their use and they are often the sole source of supplemental protein in poultry diets. Soybean meal is the current standard for poultry rations and is the protein by which all other plant-based proteins are measured. Expelled and whole-fat soybean seeds offer the advantage of significantly higher energy content and can be a source of both protein and energy. However, use of high-fat soybeans will likely require the use of additional vitamin E due to the potential for oxidation of the highly unsaturated oil in soybeans.

Soybeans in Swine Diets

Soybean meal is commonly used in swine diets worldwide. Soybean meal products contain high concentrations of protein, an excellent balance of amino acids and high-energy content, making them an excellent source of protein in all types of swine diets. Soybean meal contains elevated levels of lysine and tryptophan, amino acids that are deficient in common energy sources such as corn. Using soybean meal, it is possible to simplify diets and not require other supplemental protein sources. In most cases, soybean meal does not contain sufficient quantities of methionine to counteract the low levels found in corn and other common cereals, but this amino acid is readily available in synthetic form at a cost-effective price. Nutrient composition of solvent-extracted meal, expeller meal and whole roasted soybeans are provided at the end of this guide. Apparent amino acid digestibility in swine is shown in Table 2.

TABLE 2. Apparent Illeal Digestibility (%) of Amino Acids in Soybean Meal Products Fed to Swine (Adapted from Sauvant et al. 2004).

Amino acids	Solvent-extracted (44% crude protein)	De-hulled solvent-extracted (48% crude protein)	[1]Extruded/ Expeller meal (43% crude protein)	Extruded full-fat (34% crude protein)	Roasted full-fat (35% crude protein)
Methionine	88	90	73	83	76
Cysteine	82	84	77	77	73
Met + Cys	85	87	75	80	75
Lysine	87	89	84	86	77
Threonine	82	84	74	81	73
Isoleucine	87	89	83	83	73
Tryptophan	84	87	n/a	74	81
Histidine	88	90	84	87	80
Valine	85	86	80	82	72
Leucine	86	88	83	83	74
Arginine	92	94	88	90	82
Phenylalanine	88	90	84	85	76

[1]Opapeju et al., 2006.

Soybean products are also attractive due to their apparent consistency and reliability of supply. Availability of large quantities of consistent product has made soybean one of the most common feed ingredients in swine rations. Using soybean meal has the added benefit of reducing the required crude protein content of the diet as the amino acid content closely complements that of cereals used in the ration. The lower crude protein requirement not only reduces the cost of producing the feed, but also reduces the nitrogen load in the manure and the metabolic energy consumed in the process of using excess amino acids for energy.

Swine are sensitive to the adverse affects of the heat labile anti-nutritional factors found in unprocessed soybeans (trypsin inhibitors and lectins). If properly heat-processed, however, these factors do not affect animal performance. The oligosaccharides – stachyose and raffinose – do not affect energy utilization in swine and are not considered an anti-nutrient for that species.

In most cases, there are no artificial upper limits placed on soybean meal in swine diets. Soybeans are commonly used as the sole source of supplemental protein in swine diets at most ages. However, in stage-one starter diets immediately following weaning, there is a preference to use milk-based proteins as the digestive tract may not yet be mature enough to handle significant quantities of plant-based proteins.

SOLVENT-EXTRACTED MEAL

Solvent-extracted soybean meal is the most common source of protein used in swine rations. Both the 44 per cent crude protein (hulls not removed) and the 48 per cent crude protein (de-hulled) meals are excellent sources of protein for all types of swine rations. The de-hulled meal is often the preferred source of protein due to its higher energy (plus 5 per cent) and lysine (plus 10 per cent) content, but both work well in a wide range of swine rations.

During the solvent extraction process, soybean meal is toasted at 105°C to 110°C for 15 to 30 minutes which eliminates all anti-nutritional factors, making the meal suitable for swine rations. Solvent-extracted soybean meal is currently the plant protein to which all other plant protein sources are compared and is the single most common source of protein for swine diets worldwide. Shelton et al. (2001) compared solvent-extracted soybean meal with eight other protein sources and demonstrated that solvent-extracted meal is well suited to swine diets, resulting in excellent animal performance and carcass quality.

FULL-FAT SOYBEANS

Full-fat soybeans are popular with farmers who produce both soybeans and hogs. By using the soybeans on-farm, transportation and marketing costs are avoided, but the soybeans must be heat-treated as previously described in order to eliminate their anti-nutritional factors.

Full-fat soybeans contain significantly more energy than solvent-extracted meal due to the presence of additional fat, which makes them very attractive in diets designed to maximize energy intake. One example of this would be the lactating sow. Feeding her full-fat soybeans allows her the opportunity to produce the maximum quantity of the highest fat content milk possible. Full-fat soybeans contain about 15 per cent more energy than de-hulled soybean meal and 27 per cent more energy than the soybean meal, which contains the hulls.

Full-fat soybean meal, if properly processed, can be used as a protein source in all swine feeds except stage-one starter rations as described earlier. The meal introduces significantly more energy into the diet so it is important that rations be formulated accordingly to ensure target carcass grades are met. In any diet it is always important to ensure a constant ratio of energy to essential amino acid content. In most cases, there are no limits placed on the amount of soybean meal that can be used in the diet, but full-fat soybeans can negatively affect carcass quality if fed in too high concentrations in the finisher ration. Soybean oil contains low levels of saturated fat and high levels of polyunsaturated fats as described previously. Since the pig deposits the fat directly without modification, excess soybean oil or whole soybean can cause the deposition of soft fat that may be unappealing to some consumers.

The level of full-fat soybeans that can be incorporated into finisher rations before consumers notice differences will vary according to consumer segments and their expectations. The allowable level of full-fat soybeans also varies, depending on the other ingredients in the ration. For example, corn has relatively high levels of polyunsaturated fat and also contributes to a soft fat so in some cases, full-fat soybeans may need to be limited to as low as 10 per cent of the diet. In other cases, energy sources such as wheat or barley may promote a harder type fat which may allow use of up to 25 per cent full-fat soybeans in a ration.

If carcass quality and softness of fat is a concern, it may be wise to start with a reduced level of full-fat soybeans, perhaps 15 per cent, then increase the level if the carcass quality is still within the expected ranges. Van Lunen et al. (2003) replaced solvent-extracted soybean meal with 0, 10, 20 and 30 per cent full-fat extruded soybeans in wheat and barley-based diets and observed excellent performance in growing hogs, demonstrating that full-fat soybeans can be used as the sole source of protein. They did observe changes in the fatty acid profiles of the meat, however. Inclusion of full-fat soybeans increased the C18:2 from 10.6 per cent to 27.06 per cent and the C18:3 from 0.96 per cent to 3.82 per cent. This increase resulted in a decrease in the n-6:n-3 ratio from 10.4 to 6.7 when full-fat soybeans were the sole source of supplemental protein. This result is desirable from the perspective of producing a healthier product for humans, but inclusion of full-fat soybeans reduced the fat firmness score from 2.1 to 1.2 and this may reduce the appeal of the product for consumers.

The presence of large quantities of polyunsaturated fat and linoleic (C18:2) and linolenic (C18:3) acids also make the feed and the meat products potentially more susceptible to oxidation. The extra double bonds are much more susceptible to oxidation than saturated fat (no double bonds) or monounsaturated fat, reducing the stability of the products during storage. Generally, this issue can be overcome through the addition of anti-oxidants to the feed, such as vitamin E (Morel et al., 2006).

EXPELLER PROCESSED SOYBEANS

As with all other soybean products, it is important to ensure the soybeans have been adequately processed to ensure the heat labile anti-nutritional factors have been eliminated. If properly heat-processed, expeller meal can be used in all swine diets, except possibly stage-one starter rations, as the sole source of protein in the diet.

Expeller meal has higher energy content than solvent-extracted meal due to the presence of additional oil. However, oil content can vary in expeller meal so it is important to ensure the fat content of the product is known and the energy content is adjusted accordingly. Figure 3 in the previous section shows the relationship of meal fat content and the predicted digestible energy (DE) values for swine. Protein content declines as fat content increases so crude protein content should be measured and the amino acid content of the meal determined

Extruded soybean expeller meal

using the following prediction equations from NRC 1998: Lys = -0.081 + 0.0644 x per cent crude protein, Trp =0.058 + 0.0118 x per cent crude protein, Thr = 0.081 + 0.0381 per cent crude protein, Met = 0.017 + 0.0141 x per cent crude protein, Met + Cys = 0.147 + 0.0261 x per cent crude protein.

In many cases, processors combine extrusion with expelling as it is an efficient method of heat processing the soybeans while also disrupting cell walls, increasing both oil extraction efficiency in an expeller and utilization of the meal by the pig. Since the oil content is typically reduced to less than 7 per cent of the meal, the product can be used at high levels in all swine diets without affecting carcass quality or product stability.

CONCLUSION

Properly heat-treated soybeans are an excellent source of protein for all stages of swine production. Soybean meal satisfies all protein-related needs of swine with the exception of methionine which can be supplemented in synthetic form. Extruded and whole-fat soybeans also offer the advantage of increased energy content, but carcass quality must be considered when determining maximum inclusion levels for whole fat soybeans.

Soybeans in Ruminant Diets

Soybean meal is the most widely used protein supplement fed to cattle and other ruminants and is the standard to which all other protein sources are compared. Additionally, whole soybeans and soybean hulls are used extensively in ruminant cattle feed.

As a feedstuff, solvent-extracted soybean meal is very palatable and has a good amino acid balance. Of the common plant protein supplements used in animal feeds, soybean meal has one of the highest levels of essential amino acids (47.6 per cent) as a percentage of crude protein (Schwab et al., 1995).

Heated soybean meal has a high intestinal digestibility (Stern et al., 1994) and the essential amino acid index of the rumen undegradable protein is better than all other undegradable plant protein sources in terms of its similarity to ruminal microbial protein (Chandler, 1989). Relative to other commonly used feed proteins, soy proteins are rich in lysine, but methionine, valine and isoleucine are the first, second and third limiting amino acids, respectively (Schingoethe, 1996). In fact, when soybeans are fed with corn (its first limiting amino acid is lysine), the combination provides a well-balanced protein. Soybeans as a protein supplement are also an economical and convenient way to provide dietary fat. However, soybeans and soybean meal have relatively low protein efficiency because of extensive ruminal degradation and their use is becoming limited in diets of rapidly growing and high-producing ruminant animals. Therefore, improvement in the amount of protein that escapes degradation in the rumen in soybeans and soybean meal is of major importance to both beef and dairy farmers and the soybean industry.

Historically, terms like “escape” and “by-pass” have been used to describe the proportion of feed protein that is not degraded within the rumen, with higher numbers being viewed as better for providing post-ruminal supplies of crude protein. In the 1989 edition of the National Research Council’s (NRC) “Nutrient Requirements for Dairy Cattle” publication, they estimated that only 25 per cent and 34 per cent of protein in soybeans and soybean meal respectively escape rumen fermentation. These values were static and did not reflect what actually occurs in the rumen. Therefore, references to these “by-pass” values should only be used for comparative purposes and not for diet formulation purposes.

This deficiency was rectified in the 2001 edition of the NRC publication, where feed proteins are divided into rumen undegradable protein (RUP) and rumen degradable protein (RDP). The proportion of the feed protein that is either RDP or RUP is dynamic and is a function of feed intake. Therefore, while ruminal bypass values are reported here, reflecting the publications where the information is extracted, they are for comparative purposes only.

Various methods of treating soybeans and soybean meal have been studied over the last three decades to alter the rate and extent of protein degradation in the rumen. Some of the techniques, such as extrusion, roasting, expeller, lignosulfonate and formaldehyde have been successfully used to protect soybeans and soybean meal from ruminal degradation. Treating soybeans and soybean meal by these methods increases their ruminal by-pass protein content up to 70 per cent (Waltz and Stern, 1989). When dairy cattle were fed diets containing heat-treated soybeans or soybean meal, milk production and/or feed efficiency were improved (Schingoethe et al., 1988; Faldet et al., 1991; Nakamura et al., 1992). Casper et al. (1994) substituted extrusion heat-treated soybean meal for solvent-extracted soybean meal in a barley diet fed to fast-growing young dairy heifers. They found increased weight gain and improved feed conversion. Heat-treated soybeans and soybean meal are commercially available and rapid growth has been seen in the use of these products as protein supplements for beef and dairy cattle (Satter et al., 1994).

METHODS OF TREATING SOYBEAN AND SOYBEAN MEAL TO REDUCE PROTEIN DEGRADATION IN THE RUMEN

Various methods of treating proteins have been used to reduce their degradation in the rumen. They can be categorized into chemical and physical treatments. Chemical treatments can be further divided into methods in which the chemicals actually combine with the proteins (e.g. formaldehyde treatment) and those in which the chemicals denature the proteins, e.g. alcohol, sodium hydroxide and propionic acid.

The most successful physical treatment has been heat which facilitates the Maillard or non-enzymatic browning reaction between the sugar aldehyde groups and the free amino acid groups of protein to yield an amino-sugar complex. This complex is more resistant to digestion than normal peptides. Some precautions must be taken when heat-treating feeds, as excessive heat causes sugar and amino acid loss, especially of the essential amino acid lysine where destruction can be more than 5 to 15 times greater than that of other amino acids (Adrian, 1974). In soybeans, excess heating also causes loss of sulphur containing amino acids such as methionine. Heat treatment varies widely in application methods and amount of heat utilized. Extrusion and expeller processing are two protection methods involving heat. Lignosulfonate treatment utilizes wood sugars and heat to elicit the Maillard reaction.

ROASTING

There has been rapid growth in the use of heat-processed soybeans as a protein and energy supplement for beef, dairy cattle, dairy sheep and goats in North America. Roasted soybeans are an excellent source of rumen undegradable protein but there can be variation in quality. Faldet and Satter (1991) examined 13 samples of roasted soybeans and found considerable variation in product quality. Rumen undegradable protein content ranged from 36 to 58 per cent of crude protein with an average of 48 per cent. Post-ruminal nutritionally available lysine (NAL) concentration ranged from 2.1 to 2.4 per cent and from 0.9 to 1.24 per cent of the dry matter, respectively. As described previously, processing temperature, steeping time and temperature following roasting can dramatically affect the quality of roasted soybeans. Historically, roasting was done with mobile roasting units but larger, fixed location, commercial-scale facilities are becoming much more common. These fixed location facilities may be able to achieve more consistent roasting temperatures and can often make use of additional post-roasting equipment for steeping and cooling the soybeans. Tables 3 and 4 summarize the effects of roasting temperature and time on the quality of soybeans for ruminants.

Analyses for ruminal protein degradability and lysine availability are relatively complicated and time consuming so alternative tests are required for quality assurance programs on-site. The relative amount of heat applied to soybeans during processing can be estimated using the relatively simple protein dispersibility index (PDI) assay. This assay, which is commonly used to ensure the soybeans have not been over-processed prior to feeding to monogastrics, is also a method of ensuring the soybeans have been heated treated appropriately for ruminant applications. In most situations roasting plants do not have the ability to measure protein directly so a simplified version of the PDI assay has been developed which eliminates the need to measure protein content in the extract. Instead of measuring protein content chemically, the soluble protein in the water extract is estimated by measuring absorbance of light at 420 nm using a simple spectrophotometer (Satter et al., 1993). Any increase in light absorbance above a baseline level is indicative of heat damage or overheating. This is a rather crude test, but it is extremely simple and can be used as a quick test on-site.

The PDI procedure is relatively easy, inexpensive, and fairly correlated to in-vitro protein degradability, although it tends to lose sensitivity as the optimum heat treatment is approached. Satter et al. (1993) suggested that soybeans having a PDI value of 9 to 11 per cent be considered as optimally heated for ruminants; those with a PDI value of 11 to 14 per cent as marginally under-heated, and others with a PDI value of greater than 14 per cent as under-heated. Normally, under-heating is far more prevalent than overheating because it requires more energy and expense. In general, soybean roasters strive to produce a consistent product and as a result the PDI assay is becoming more commonplace as a quality assurance assay.

EXTRUSION

Extrusion is another commonly used method to treat full-fat soybeans for ruminant diets. Extrusion can be used to decrease soybean protein degradability in the rumen. For example, in a study by Aldrich and Merchen (1995), soybeans extruded at 104°C had an in situ bypass protein content of 54.3 per cent, 3.4-fold higher than raw soybeans. Further increases in extrusion temperatures up to 160°C resulted in higher protein undegradability (63.3 per cent at 149°C and 69.9 per cent at 160°C).

EXPELLER

Expeller meal can also be used as a source of protein in ruminant diets. If sufficient heat is generated during the process, the rumen undegradable protein content can be increased. Broderick (1986) compared expeller soybean meal from one source to solvent soybean meal and found the expeller process dramatically reduced the nitrogen solubility and consequently increased in-vitro undegradable protein content. The nitrogen solubility, in-vitro nitrogen degradation rate, and estimated escape protein were 6.44 per cent, 3.4 per cent/hour, and 64 per cent respectively for expeller soybean meal, and 27.22 per cent, 9.5 per cent/hour, and 39 per cent for untreated soybean meal. Similar results were obtained by Waltz and Stern (1989) who used an in-vitro

Table 3. Effect of Roasting Temperature and Time on Ruminal Undegradable Protein (RUP) and Nutritionally Available Lysine (NAL) of Roasted Soybeans.

Temperature, ˚C	Time, min.	RUP, % of crude protein	NAL, % of DM	Post-ruminal NAL, % of DM
0	0	29.7	2.43	0.72
100	60	36.7	2.27	0.83
	180	38.7	2.21	0.86
130	60	38.2	2.36	0.90
	180	48.0	2.14	1.03
140	10	33.9	2.44	8.30
	30	43.9	2.20	0.97
	60	49.4	2.17	1.07
	90	55.0	2.01	1.11
	120	59.2	1.89	1.12
150	10	36.6	2.39	0.88
	30	42.4	2.19	0.93
	60	58.4	1.99	1.16
	90	64.2	1.56	1.00
160	10	37.4	2.33	0.87
	30	53.2	2.07	1.10
	60	72.0	1.41	1.02
	90	71.1	1.14	0.81

Adapted from Faldet et al., 1992.

Table 4. Effect of Exiting Temperature and Steeping Time on Rumen Undegradable Protein (RUP) and Nutritionally Available Lysine (NAL) of Roasted Soybeans.

Exit Temperature, ˚C	Steeping Time, min.	RUP, % of crude protein	NAL, mg/g N	Post-ruminal NAL, mg/g N
0	0	33.0	280	92
110	0	34.0	320	109
	30	39.0	305	122
123	0	40.0	306	122
	30	44.0	287	126
135	0	46.0	295	136
	30	55.0	288	158
146	0	57.0	277	158
	15	63.0	262	165
	30	61.0	286	174
153	30	65.0	239	155
160	30	66.0	218	144

Adapted from Faldet et al.,1992.

continuous culture system and reported that expeller soybean meal had a lower extent and rate of ruminal protein degradation than untreated soybean meal. Broderick (1987) determined in-vitro ruminal protein degradation of various commercial expeller soybean meal products and reported a great variation in by-pass protein contents ranging from 38.5 to 69.8 per cent. Even in samples from the same source, undegradable protein contents varied from 54.1 to 69.8 per cent with an average of 61.4 per cent and standard deviation of 4.4 per cent. This suggests that the level of heat applied during the expelling process can vary and, therefore, the quality of the meal should be monitored during production and use.

LIGNOSULFONATE TREATMENT

Chemical treatment of soybean meal using lignosulfonate, a by-product from the wood pulping industry, can be used to increase the rumen undegradable protein in soybean meal. In this method, soybean meal is treated with 7 per cent (by weight) calcium lignosulfonate and then heated at 95°C for one hour before it is dried (Standford et al., 1995). A higher temperature (100°C) for 30 minutes can also be used in some commercial processes. Calcium lignosulfonate is produced from hardwoods via the acid-sulfite wood pulping process and contains a variety of wood sugars, primarily xylose (Windschitl and Stern, 1988). Initially, lignin present in the spent liquor was thought to protect the protein in the feed from ruminal microbial degradation that was mixed with 0.25-3.0 per cent spent sulfite liquor (U.S. Patent No. 4377596). However, Winowiski and Stern (1987) examined various factors involved in lignosulfonate-treated soybean meal and concluded that calcium lignosulfonate itself does not play any active role; rather heat and the presence of wood sugars, mainly xylose, are necessary for protein protection. In this process, the amount of sugar added, temperature, pH, moisture and time of reaction are critical to obtain the optimal effect (U.S. Patent No. 4957748).

Lignosulfonate treatment provides protection of soybean meal protein from ruminal degradation without affecting the total protein digestion. When soybean meal was treated with calcium lignosulfonate and compared to untreated soybean meal, the former reduced the in situ ruminal N digestion rate (2.05 vs. 4.70 per cent/hour) and increased by-pass protein content (65.3 vs. 41.9 per cent) (Stanford et al., 1995). Calsamiglia et al. (1995) reported that the in situ extent and rate of soybean meal protein degradation was reduced from 77.5 to 23 per cent and from 14.7 to 1.4 per cent/hour by calcium lignosulfonate treatment, and the intestinal digestion of undegradable protein was not affected (93.4 vs. 92.1 per cent) which resulted in increased intestinally absorbable dietary protein (IADP) (20.7 vs. 70.8 per cent). When lignosulfonate-treated soybean meal replaced soybean meal in a diet fed to lactating cows, the dietary protein degradation was dramatically reduced, but intestinal digestion of dietary undegradable protein and IADP were increased (Calsamiglia et al., 1995). This study effectively demonstrates that lignosulfonate treatment can be an effective method of protecting protein from ruminal degradation while maintaining a high level of digestibility by the animal.

HEAT-TREATED SOYBEANS AND SOYBEAN MEAL IN BEEF AND DAIRY CATTLE

Heat-Treated Soybeans

Dairy cows in early lactation (less than 8 to 10 weeks of lactation) mobilize body fat for energy because nutrient intake lags peak milk production. Protein is mobilized as well from tissue stores, but this occurs at a much lesser degree than for fat. The limiting amino acids for optimal milk production are lysine and methionine. Thus, cows in early lactation are under considerable nutritional stress and can benefit from increased amounts of absorbable amino acids produced by heat-treating soybeans prior to feeding. Socha (1991) reviewed 26 feeding trials published and reported that heat-treated whole soybeans compared to soybean meal or untreated soybeans increased milk production by 1.5 kilograms/day and fat corrected milk (FCM) by 1.3 kilograms/day. There was no effect on dry matter intake (DMI), but milk fat and protein decreased by 0.07 percentage units respectively (Table 5). In a large-scale lactation study, Faldet and Satter (1991) fed soybean meal, raw soybeans or roasted soybeans to dairy cows that were at the first week of lactation. They found that cows receiving roasted soybeans for 17 weeks of lactation produced 3.5 per cent more FCM (averaging 38.0 kilograms/day) than those supplemented with either soybean meal or untreated soybeans (33.4 and 34.7 kilograms/day). Feeding roasted soybeans affected neither milk fat percentage nor DMI, but decreased milk protein content compared to soybean meal.

Table 5. Effect of Heat-treated Soybeans on Lactating Dairy Cow Performance.

Treatment Comparison			Response over Control [7]				
Control or Forage	Treatment	# of Trial	Milk kg/d	FCM kg/d	Fat %	Protein %	DMI kg/d
SBM[1] or SB[2]	RSB[3] or ESB[4]	36	1.50	1.30	-0.07	-0.07	0.00
	RSB	16	1.60	2.00	0.06	-0.07	-0.10
	ESB	20	1.30	0.60	-0.17	-0.06	0.10
SBM	RSB	9	1.90	2.70	0.13	-0.10	-0.30
	ESB	11	1.60	1.00	-0.10	-0.14	-0.10
SB	RSB	7	1.40	1.20	-0.03	-0.05	0.30
	ESB	9	0.90	0.00	-0.23	0.00	0.40
SBM							
Alfalfa silage[5]	RSB or ESB	7	2.20	3.00	0.10	-0.09	-0.20
Other forage[6]	RSB or ESB	13	1.50	1.10	-0.05	-0.14	-0.20
SB							
Alfalfa silage	RSB or ESB	3	3.10	2.50	-0.12	-0.06	1.00
Other forage	RSB or ESB	13	0.70	0.20	-0.15	-0.01	0.20

Adapted from Socha, 1991.

[1] Soybean meal as a protein supplement in control diets to be compared to heat-treated soybeans.
[2] Raw soybeans as a protein supplement in control diets to be compared to heat-treated soybeans.
[3] Roasted soybeans.
[4] Extruded soybeans.
[5] Trials using alfalfa silage as the sole forage source.
[6] Trials using a combination of forages other than alfalfa silage.
[7] FCM=fat corrected milk; DMI=dry matter intake.

Both Grummer et al. (1994) and McNiven et al. (1994) reported that substitution of roasted for raw soybeans in diets fed to lactating cows increased 3.5 per cent FCM production by 1.4 and 1.6 kilograms/day, respectively. Their results were consistent with those of Chouinard et al. (1997) who compared roasted and extruded soybeans with raw soybeans in feeding early lactating dairy cows. They concluded cows fed both treated soybeans had higher solid corrected milk (SCM) yield than those consuming untreated soybeans (33.5 vs. 31.2 kilograms/day). Hsu and Satter (1995) compared roasted soybeans heated at various temperatures (123°, 135°, 146° and 153°C) and steeped for zero or 30 minutes in dairy cattle performance. They reported dairy cows improved their milk production only when fed a diet containing the roasted soybeans prepared at 146°C for 30 minutes when compared to untreated soybeans (38.4 vs. 36.4 kilograms/day).

The type of forage in the diet influences the responses to heat-treated soybeans in dairy cattle. Socha (1991) reported that cows fed rations containing alfalfa silage as the sole forage source produced 2.47 kilograms/day more FCM when roasted or extruded soybeans were added, compared to 1.1 kilograms/day on rations with forage sources other than alfalfa silage.

Satter et al. (1994) indicated that heat-treated soybeans could be a very effective supplement for lactating dairy cattle, particularly when the principal forages were hay or alfalfa silage. In contrast, Amentano et al. (1997) reported that total mixed rations based on alfalfa silage and heated soybeans for dairy cows were limited in their methionine content, suggesting the extent of methionine deficiency would be even worse in rations containing alfalfa silage and soybean meal or raw soybeans.

There is no need to reduce the particle size of whole roasted soybeans prior to feeding to dairy cattle. Dhiman et al. (1995) studied the effect of the particle size of roasted soybeans on milk production of dairy cows and concluded that there was no benefit in reducing the particle size of properly roasted soybeans beyond the whole bean and breaking the bean in half. Grinding roasted soybeans is not recommended.

There is limited data available on heat-treated soybeans for calves and steers, probably because amino acid requirements for these animals can be easily met by most feeds. All soybean products including heat-treated material can be used as a protein supplement for beef cattle but there is little to no requirement for additional heat processing of the soybeans for this category of livestock.

Heat-Treated Soybean Meal

Standard solvent-extracted soybean meal is an excellent source of protein for dairy cattle so published research data, particularly animal performance data, on heat-treated soybean meal is rather limited when compared to heat-treated whole soybeans. Reviewing published research with heat-treated soybean meal (expeller, extruded and roasted), Socha (1991) summarized that lactating cows increased milk production when heat-treated soybean meal was used as a protein supplement compared to untreated soybean meal. Cows fed heat-treated soybean meal in 14 trials produced 0.43 and 0.1 kilograms/day more milk and FCM while consuming 0.1 kilograms less DM when compared to cows supplemented with untreated soybean meal. Milk fat and protein decreased 0.09 and 0.02 percentage units compared to cows receiving untreated soybean meal as a protein supplement. Annexstad et al. (1990) substituted lignosulfonate-treated for solvent-extracted soybean meal in dairy cow rations. They reported primiparous cows consuming lignosulfonate soybean meal increased FCM yield from 31.1 to 32.5 kilograms/day and multiparous cows from 39.9 to 42.0 kilograms/day compared to those receiving solvent-extracted soybean meal.

A trial where 50 per cent lingnosulfonate soybean meal and 50 per cent corn replaced solvent-extracted soybean meal in dairy diets resulted in decreased dietary crude protein content from 16 to 13.2 per cent. Nakamura et al. (1992) found that cow performance was not affected (38.3 kilograms/day FCM yield for lignosulfonate soybean meal low-protein diet and soybean meal, high-protein diet). They concluded that lignosulfonate soybean meal supported the same production at half the amount of supplemental soybean meal. However, milk responses to heat-treated soybean meal have been inconsistent. Hoffman et al. (1991) reported that substituting expeller for untreated soybean meal in dairy cow rations affected neither the milk production nor the feed efficiency.

Santos and Huber (1996) reviewed 15 studies where standard solvent-extracted soybean meal was replaced with heat-treated soybean meal that had been subjected to additional heat treatment and found milk production did not change in 12 out of 15 comparisons. They theorized this lack of response to soybean meal with high levels of ruminal undegraded protein could be caused by decreased microbial synthesis, poor essential amino acid profiles in these product sources, low digestibility of the ruminal undegraded protein sources in the small intestine, and/or insufficient rumen degradable protein in the control diets.

Research in heat-treated soybean meal for calves and steers is limited. In some instances researchers have observed increased weight gain due to substituting solvent-extracted soybeans with heat-treated soybeans (Fairbrother and Brick, 1991), or lignosulfonate-treated soybean meal (Thomas et al., 1992 and Maiga et al., 1994). However, others have failed to detect any significant differences in DMI or weight gain when the treated soybean meal was fed (Daccarett et al., 1993; Chester-Jones et al., 1995 and Casper et al., 1994).

SOYBEAN HULLS

Ruminants are efficient converters of fibrous feed ingredients into meat or milk. Micro-organisms in the rumen ferment fibre to useful end products (volatile fatty acids and microbial protein) that are used for maintenance, reproduction, and growth by the steer and cow.

Dairy and beef cattle rations are markedly different in their proportions of fibrous feeds because of total dry matter intake and the final market product (beef versus milk). Beef cattle have no fibre requirements per se as long as rumen function and health can be maintained to prevent acidosis. In lactating dairy cows, fibre requirements are extremely important since these animals often consume in excess of 20 kilograms of total dry matter per day. Maximizing the use of alternative and by-product feeds that are high in fibre to obtain high levels of production has been a universal goal of ruminant nutritionists.

Soybean hulls or soy hulls are a by-product of the soybean meal processing industry and have many uses. In the animal feed industry, soy hulls have become an economical energy and/or fibre alternative. They have been successfully fed to swine (Kornegay, 1978; Gore et al., 1986), poultry (Castra et al., 1984; Muir et al., 1985) and rabbits (Martina, 1983). But their feeding value is relatively low in diets for monogastric animals because of their high-fibre content.

However, in ruminant animals, fermentation by microbes in the rumen makes soy hulls a valuable energy source. Soy hulls are readily fermentable in the rumen and total digestibility is more than 70 per cent for all nutrients (Faulkner et al., 1994). Soy hulls as a high-fibre energy supplement may provide a means of supplementing low-quality forages without incurring the negative associative effects that occur when low-fibre, highly fermented concentrates are added to forage diets (Highfill et al., 1987). Additionally, soy hulls are very palatable to animals and easily handled. One negative aspect of soy hulls is that they are light and tend to blow during loading into storage areas or feed wagons.

Soybean hulls are defined as a product consisting primarily of the outer covering of the soybean. They are called soybran flakes after steam treatment and rolling (Conrad and Odwongo, 1983). In addition, there are two other products containing soybean hulls available to the animal feed industry: soybean mill feed and soybean mill run. Soybean mill feed is composed of soybean hulls and the offal from the tail of the mill which results from the manufacture of soy grits or flour. It must contain not less than 13 per cent crude protein and not more than 32 per cent crude fibre. Soybean mill run is composed of soybean hulls and bean meats that adhere to the hulls which result from normal milling operations in the production of dehulled soybean meal. It must contain not less than 11 per cent crude protein and not more than 35 per cent crude fibre (AAFCO, 1997). In most soybean milling plants, all four products are marketed as soy hulls unless there is a specific request for each of the by-products.

Soy hulls contain high fibre (67 per cent neutral detergent fibre) and moderate crude protein (12.2 per cent) (NRC, 1996). Cellulose is the main component of the fibre consisting of 47 per cent DM; hemicellulose is close to 20 per cent of dry matter. Soy hulls are highly digestible in the rumen because of low lignin content (Garleb et al., 1987). Hsu et al. (1987) reported that the in situ DM digestibility of soy hulls was 90.6 per cent at 27 hours and total DM disappeared within 36 hours of incubation. Similarly, Belyea et al. (1989), using *in vitro* method, found soy hull cell walls were completely digested at 48 hours. The extent of NDF digestion was reported to be 95 per cent (Kloplenstein and Owen, 1987). However, *in vivo* ruminal DM and NDF digestibility were only 40.2 per cent and 52.4 per cent, respectively, when soy hulls were fed to sheep without hay or additional grain concentrate (Hsu et al., 1987).

Soy hulls possess a relatively high-energy value because of their highly digestible fibre. According to the NRC, soy hulls have a Total Digestible Nutrient (TDN) content of 77 per cent, net energy for gain of 1.22 Mcal/kilogram and net energy for lactation of 1.77 Mcal/kilogram, making it approximately equivalent to oats. Wagner et al. (1965) concluded that soybean hulls were about equal in feeding value to citrus pulp and oats in dairy feed. Johnson et al. (1962) demonstrated that soy hulls were equal in energy value to ground ear corn in heifer finishing cattle. Therefore, soy hulls are considered to be a bulky concentrate rather than roughage in spite of the high fibre content (Hintz et al., 1964). In rumen simulating continuous cultures, Bach et al. (1996) reported that a rapidly fermentable fibrous energy supplement like soy hulls may be preferable to starch supplements (such as corn) for cows fed a lush pasture diet where degradable protein is extremely high. Such supplementation could result in more efficient conversion of degraded plant proteins into bacterial nitrogen and fermentation with end-products that have a higher acetate to propionate ratio.

Soy hulls have low effective fibre content and thus cannot be used to replace large portions of dietary forage (Grant, 1997).

Feeding Soy Hulls to Beef Cattle

Normally there are three objectives of feeding soy hulls to beef and dairy cattle:

1) To provide an economical energy supplement
2) To minimize the potentially negative associative effects of non-fibre carbohydrates on ruminal digestion
3) To replace a portion of the fibre in the diets

Allison et al. (1992) compared performance of steers on a grass hay-based diet supplemented with corn-soybean meal or soy hulls. They found that steers fed the soy hull supplement had average daily gain of 1.01 kilogram/day compared to 0.95 kilogram/day for those supplemented with corn-soybean meal. The return over feed cost was $10.78 per 100 kilograms of weight gain higher for the soy hull diet than the corn-soybean meal diet mainly because of the lower cost of soy hulls.

There is very limited data available on the addition of soy hulls to feedlot cattle diets. Hsu et al. (1987) demonstrated in two feedlot trials that steers fed a corn or sorghum silage diet containing up to 50 per cent soy hull supplement had similar daily gain, but less feed efficiency when compared to corn supplement. Ludden et al. (1995) determined the value of soy hulls as a replacement for corn in finishing steer diets containing 95 per cent corn. They reported that the feed value of soy hulls was about 74 to 80 per cent that of corn.

Boggs (1996) concluded that soy hulls appeared to provide an excellent alternative as an energy supplement in steer diets that were at least 40 per cent silage. While they did not fully overcome the negative associative effects of a blended diet, they provided a feeding value equivalent to corn. When soy hulls are included in extremely high concentrate, low-forage diets, their feeding value may be greatly reduced. When soy hulls were fed at low-inclusion rates in high-forage (more than 50 per cent forage) beef cattle diets, the nutritive value of soy hulls was estimated to be similar to that of corn (Hibberd et al., 1986; Hibberd et al., 1987; Anderson et al., 1988).

Feeding Soy Hulls to Dairy Cattle

Soy hulls are commonly incorporated into diets for lactating cows at 8 to 12 per cent of the ration DM (Lundquist, 1995). The maximum rate of inclusion is about 20 to 25 per cent of total ration DM. The actual supplemental level is dependent on the stage of lactation, contents of dietary forage and/or non-forage fibre sources, and dietary particle size (Grant, 1997). If the ration contains very small particles and the ration contains a high proportion of coarse particles and high effective fibre content, higher levels of soy hulls can be fed. Cows in very early lactation (less than 30 days in milk) should probably not be fed soy hulls since at this stage as they are prone to displaced abomasum when effective fibre is low.

FEEDING SOYBEANS TO SHEEP AND GOATS

The data presented in this guide has focused primarily on applications in cattle but the data also applies to other ruminants such as goats and sheep in a very similar manner.

Soybean products are a very effective source of supplemental protein for sheep and goats and are often considered the preferred source of supplemental protein for these species. Atti and Mahouachi (2009) fed a concentrate containing 20 per cent soybean meal to lambs raised on dry pasture and housed in stalls. In both cases the lambs' growth rate and rate of gain of fat and muscle were excellent and similar to the faba bean treatment. Schmidely et al. (2005) fed extruded soybean at 0, 10 and 20 per cent of the dry matter to lactating goats. In this study, inclusion of extruded soybeans increased fat-corrected milk production (FCM), milk fat content and fat yield. Numerous studies have demonstrated that heat-processed soybean products (roasted whole soybeans, expelled, extruded or solvent-extracted soybeans) can all be used as the sole source of supplemental protein in the diets for either of these species of livestock.

Soybean hulls can also be used to replace part of the forage in sheep and goat diets. Araujo et al. (2008) replaced 33, 67, and 100 per cent of the NDF of the hay in the diet of lactating ewes. In this study feed intake, milk production increased with soybean hull inclusion.

Feeding up to 6 percent soybean oil to sheep has been shown to significantly increase CLA content in milk without negatively affecting milk production (Gómez-Cortés et al., 2008).

CONCLUSION

Soybeans serve as an excellent source of protein for all ruminants. Depending upon which fraction of the soybean is used, they can also be an excellent source of energy and fibre. Various methods have been used to treat soybeans and soybean meal in order to increase the rumen undegradable protein content. Of these methods, roasting, extrusion, expeller and lignosulfonate treatment are most commonly used in the feed industry. Controlling this reaction by optimizing the heating process is the key to successful protection of soybean and soybean meal protein. Substantial benefits in term of increased milk production and improved growth can be obtained by feeding properly treated soybeans or soybean meal as a protein supplement to dairy and beef cattle. Soy hulls are a high-fibre, yet readily digestible feed alternative for beef and dairy cattle. Soy hulls have an equivalent energy value to processed feed grains. Inclusion of soy hulls in dairy or beef diets may alleviate the negative associative effect of non-structural carbohydrates. Supplementation of soy hulls to rations of beef, dairy cattle, sheep or goats can improve animal performance and increase their economical advantage over grains when they are reasonably priced.

Soybeans in Specialty Diets

Soybean meal is commonly available and is considered to be a consistent feed ingredient for a wide range of diets. In most cases, soybean is the first ingredient that is considered as an additional protein supplement. This is true not only of common livestock, as described previously, but also for aquaculture, horse and pet food diets.

AQUACULTURE

Fish and aquaculture products have been a staple in human diets for thousands of years. Traditionally, this supply came from fish captured in the wild. However, with a growing human population and increased desire for fish in the diet, it is not possible to feed humans from wild fish alone. There are a large number of aquaculture species that are cultured and the fish farming industry is growing at a rapid rate.

Many of these cultured species are fed diets which contain large amounts of fish meal, a rendered fish product which is primarily composed of wild fish species caught for the purposes of producing fish meal. Fish meal is an excellent source of protein and oil for the production of aquaculture feeds and is considered to be highly palatable to the fish, thereby increasing feed intake and production rates. However, the amount of fish meal available for producing feeds for cultured aquaculture species is limited. The ocean can only produce so much fish for this purpose. As a result, fish meal prices have become erratic as markets struggle with the knowledge that demand will outstrip supply. Due to the high price of fish meal and concerns about supply, many aquaculture feed producers have looked to soybeans as a source of both dietary protein and oil.

Soybean products typically contain less protein than traditional fish meal, but there is a large, consistent supply available, making it an attractive product to aquaculture feed producers. In most cases, soybean products are used at the highest practical levels in the diet. There are several different classes of aquaculture species and each has unique dietary needs that impact the amount of soybean that can be incorporated into the diet.

Salmonids

Salmonid species include salmon and trout, and are the most widely farmed carnivorous fish primarily due to the high value of the meat and the relative ease of production. However, being carnivorous, they have limited ability to utilize carbohydrates and, therefore, have an exceptionally high requirement for protein and fat in the diet. Due to the intense nature of fish farming, a high-energy/high-protein diet is required to maximize feed intake/growth rate and, therefore, profitability. As a result, the amount of soybean meal is limited due to nutrient density. A normal salmon diet would contain about 44 per cent crude protein and up to 35 per cent fat. Even though soybeans are a relatively concentrated source of plant protein, the amount of soybean meal that can be used in the diet is limited due to nutrient density. Typically, soybean meal comprises about 5 to 10 per cent of farmed salmon diets and up to 15 per cent of rainbow trout diets. In some cases, where fish meal is in short supply, diets may include up to 25 per cent soybean meal, but this would be rare. The remainder of the protein is primarily derived from fish meal (which contains approximately 65 per cent crude protein) and some concentrated protein plant or animal sources. In some cases, protein concentrates or isolates are used in salmon diets, but the inclusion level is often limited by cost.

The amino acid profile of soybeans closely matches the requirements of salmonid species reasonably well, with the exception of methionine, making it a suitable replacement for at least a portion of the fish meal. Salmonids also require high levels of omega-3 fatty acids which they typically receive from fish meal or fish oil in the diet. Soybean oil contains reasonably high levels of α-linolenic acid (approximately 8 per cent of the fat) which the fish can elongate into longer chain omega-3 fatty acids. Solvent-extracted meal contains limited oil but full-fat or expelled soybean meal contributes both oil and protein into the diet.

Fish are particularly sensitive to the anti-nutritive affects of trypsin inhibitors. Therefore, soybean products must be appropriately heat treated as described in the soybean processing section. Likewise, they are also sensitive to over-processing, which results in reduced protein utilization. Protein solubility should be monitored to ensure the product has not been over-processed.

Typically, soybean meal is limited to 20 per cent of the diet of salmonid species as feed intake is often reduced above this level. The reasons for reduced feed intake are not clear, but may be related to anti-nutritional factors such as oligosaccharides. Extracting the oligosaccharides with alcohol not only increases protein concentration, but also appears to restore feed intake. Another possible cause of reduced performance at high inclusion levels is the presence of allergenic proteins. These allergenic proteins may stimulate the non-specific immune mechanisms of the fish that may cause the reduced performance.

Soybean meal contains relatively high levels of phytic acid, which is not effectively digested by salmonid species. This leads to reduced phosphorus utilization and increased phosphorus excretion. Adding phytase enzymes to the diet is often beneficial and can greatly increase phosphorus availability. However, most phytase enzymes are susceptible to heat denaturation during the extrusion process used to generate the feed and, therefore, should be applied to the product following extrusion.

Omnivorous Fresh Water Fish

Omnivorous fish such as tilapia, carp and catfish comprise a large portion of the cultured fish produced worldwide. They grow quickly and are relatively easy to culture, making them a popular product to farm. As omnivores, they are able to digest and utilize a wide range of dietary ingredients. Unlike carnivorous species such as salmon, they have a modest requirement for protein and are able to utilize carbohydrates as a source of energy.

Soybean meal can, and is, used as the primary protein source for most omnivorous fish worldwide offering a consistent product that is readily available and well utilized by the fish. The amino acid digestibility is high and the amino acid profile closely matches the needs of the fish. Soybean meal is deficient in methionine, which is easily added to the diet as a commercially available synthetic amino acid. Little work has been done to identify the digestibility of individual amino acids in these species, but the work that has been conducted indicates protein and the individual amino acids are approximately 90 per cent digestible. The energy digestibility (~3000 kcal/kg) is modest due to the presence of oligosaccharides which are poorly digested by these fish.

Solvent-extracted soybean meal, both the 44 per cent and 48 per cent crude protein products, are commonly used in all omnivorous fish diets. If supplemented with limiting amino acids such as methionine and in some cases lysine and threionine, soybean meal can often fully replace fish meal in the diet. Full-fat soybean products and expelled soybean products can also be used if the soybeans are appropriately heat-treated. However, omnivorous fish tend to have low fat requirements and this tends to limit the application of these products in those diets. Protein concentrates can also be used in omnivorous fish diets, but this is typically restricted due to cost.

Shrimp

There are eight major species of shrimp that are farmed. They include white shrimp (the most common in the western hemisphere), giant tiger shrimp (most common in the eastern hemisphere), northern brown shrimp, yellowleg shrimp, Chinese white shrimp, Indian white shrimp, western blue shrimp, and Japanese kuruma prawn. Shrimp have a complicated life cycle and the first few stages rely almost completely on algae and brine shrimp as a food source. During rearing, shrimp are fed commercially prepared feeds that range in protein and energy content depending on the species of shrimp being fed and the production method. Protein levels in the diets range from 30 to 50 per cent, with the higher levels being used in the more intensively cultured environments. Traditionally, fish, shrimp and squid meals have been the primary source of protein in shrimp diets, but due to limited availability and erratic prices, most producers are looking to replace a portion of dietary protein with a vegetable protein source. Soybean has been the natural substitute that most have considered due to its consistent supply and elevated protein content.

Amino acid requirements of shrimp are not well known and are often determined according to the amino acid composition of the body composition. Soybean amino acid content appears to be well-suited for use in shrimp feeds and as a result can be used to replace up to 50 per cent of the fish meal in the diet. Protein and amino acids appear to be well utilized by shrimp, but there is limited information available on individual amino acid digestibility in many species.

As with most other species, it is important that the soybean product is properly heat-treated to ensure the heat labile anti-nutritional factors have been denatured. There has been some indication that the oligosaccharides and the allergenic proteins found in soybeans may affect performance, but they have not been studied fully yet. In most cases, soybeans are limited to replacing approximately 50 per cent of the fish meal to ensure performance and product flavour is maintained.

Like carnivorous fish, most shrimp are not able to digest carbohydrates very well and rely on oil as the primary source of energy in the diet. Most shrimp diets contain approximately 5 to 8 per cent fat. Shrimp have specific requirements for polyunsaturated fats as they have limited ability to desaturate monounsaturated fats and, therefore, have a requirement for the polyunsaturated fats linoleic acid (C18:2) and linolenic acid (C18:3). Soybean oil contains sufficient linoleic acid and linolenic acid to meet the shrimps' dietary requirements, but it does not contain the longer-chained polyunsaturated fats eicsosapentaenoic (C20:5) and decosahexanenoic acid (C22:6), so diets are typically supplemented with sufficient fish meal or fish oil to meet the shrimps' requirements.

Since the oil requirement of shrimp is modest and they require some fatty acids that are not found in soybeans, full-fat soybeans have limited application in their diets. Expeller meals have potential application, but the residual fat content could limit use in shrimp diets. Since shrimp have limited ability to utilize complex carbohydrates, the dehulled, high protein solvent-extracted soybean meal will likely be the most predominant plant protein source used in shrimp diets.

PET FOODS - DOGS AND CATS

The pet food industry is a high-margin industry that is growing at a steady rate in North America, Europe and parts of Asia. However, a great deal of the decision-making regarding feed ingredients used in diets is driven primarily by marketing requirements for the final pet food product. Pet owners generally are very concerned about the ingredients in their pets' diets and are often willing to pay a premium for perceived quality. Both dogs and cats are carnivores, but are opportunistic and can digest a wide range of animal and plant-based ingredients. They are able to thrive on plant-based diets as long as they are formulated to meet the animals' amino acid, mineral, vitamin and essential fatty acid requirements. However, the pet owner makes the decision as to which ingredients the pet prefers and typically chooses to purchase diets containing a high percentage of animal products, and in the case of premium moist diets, ones that have the appearance and texture of meat-based products. As a result, the pet food industry relies heavily on the use of meat and milk-based products. However, the products must be of high quality as both the animal and the owner are sensitive to rancid fat, and off colour and smell.

Soybean meal is an excellent alternative to animal-based products and is used to a limited extent in many pet food products. Soybeans are a reliable source of high quality protein, with an amino acid profile that is well matched to the needs of the animal. The products are palatable to the animal, have high digestibility and can be used as the primary source of protein. However, in many cases, soybean is limited to only a portion of the diet as most consumers are looking for a product for their animal that has a minimum of plant-based products. Most soybean products do contain carbohydrates, primarily oligosaccarides, stachyose and raffinose, which are undigested by the animal and lead to increased flatulence as well as increased stool moisture and volume. Some pet owners are also concerned about the potential for the development of soybean allergies and prefer to purchase diets with little or no soybean present in the diet. In most cases, pet food manufacturers limit soybean products to approximately 15 per cent of the diet to avoid these concerns.

Dogs and cats are sensitive to the anti-nutritive affects of trypsin inhibitors and lectins but these are typically not a concern as the heat processing applied during the production of the soybean meal product, combined with that of extrusion or canning in producing the final pet food product, completely denatures these anti-nutrients. The negative effects of the complex carbohydrates are often eliminated by using a soybean concentrate. During the concentration of protein, both the soluble and insoluble fibre and carbohydrates are removed. Textured soy protein products are commonly used in pet foods as they are often devoid of these compounds and have the added benefit of taking on the appearance of meat products when used in canned products.

Many consumers are starting to recognize the health benefits associated with consuming soy and it is expected that they may start looking for those benefits in their pets' diets as well. Soybean products are high-quality, highly digestible, readily available, reasonably priced products and as consumers allow or even demand more soybean meal in pet foods, it will be able to fill the need.

HORSES

Some horse rations require supplemental protein. This includes supplementing rations containing low-protein forages for lactating mares or rapidly growing foals. Soybean meal is an excellent source of supplemental protein. Little has been published regarding feeding soybean products to horses but that which is available suggests soybean meal can be used to replace protein from alfalfa with no effect on performance (Wall et al. 1998). The soybeans should be properly heat-treated to eliminate anti-nutritional factors, but full-fat and solvent-extracted meals can both be used successfully in equine rations. Full-fat soybean products contain approximately 4.05 Mcal/kg, whereas dehulled solvent-extracted meal contains approximately 3.60 Mcal/kg. Amino acid composition, minerals and vitamin levels are shown in the composition tables found at the end of this guide. Soy tends to be the predominant source of supplemental protein for horse feed due to its high quality, palatability, consistent supply and economical price.

Economics of Feeding Soybean Products

In most cases, soybean meal is the preferred source of protein and competing protein sources are priced relative to soybeans. Depending on supply, in some cases, competing products may be discounted to encourage people to utilize the products. Factors that affect the value of soybean meal and competing protein sources include protein content, amino acid content and availability, and energy content. The value is also determined by local supply of alternative ingredients. For example, in Western Canada, there is a large quantity of canola crushed due to local production but there is limited local supply of soybeans, resulting in relatively low prices for canola meal. At the time of publication of this guide, canola meal in central Saskatchewan is trading for approximately 53 per cent of the price of soybeans on a per weight basis. In most locations, however, canola meal tends to trade for a value more reflective of protein content. Canola meal contains 36 to 38 per cent crude protein compared to soybean meal with 48 per cent, so the relative value should be 36/48 = 75 to 80 per cent, but in many cases canola meal trades for less than this value due to lower energy content and amino acid digestibility. Other protein ingredients would be priced in a similar manner. Figure 4 shows historical prices for soybean meal. The relative price of alternative protein sources are shown in Figure 5. These values, presented as a per cent of the value of 48 per cent crude protein soybean meal, were determined using the trading value of ingredients in Chicago and Buffalo in February 2010.

The ability to price soybean meal using the futures markets and the relative ease that the product can be sourced makes soybean meal an attractive product for feed manufacturers.

Figure 4. Soybean Meal Prices (Canadian $/tonne, Chicago near futures).

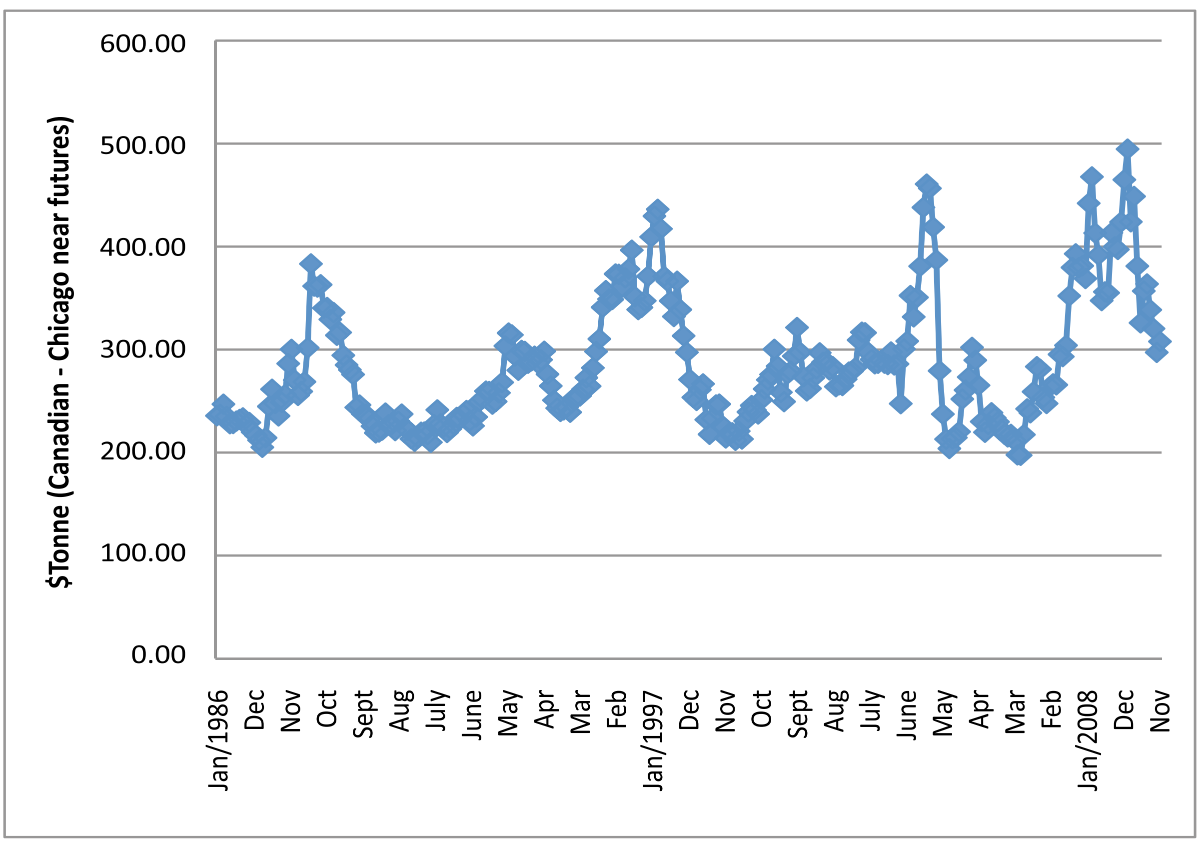
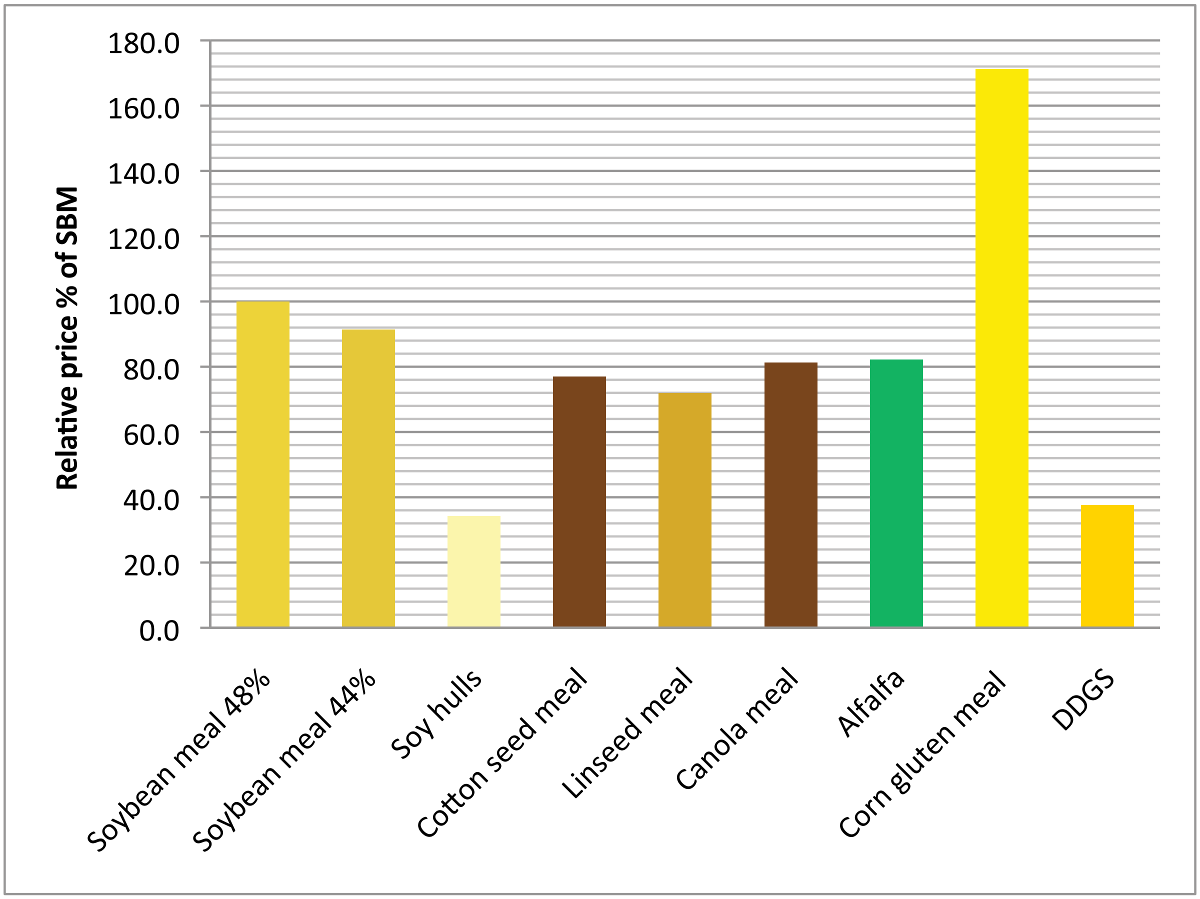


Figure 5. Relative Price of Protein Supplements Relative to 48 per cent Soybean Meal. Prices Based on Spring 2010 Prices in Chicago and Buffalo.



OPTIONS FOR FARMER-PRODUCED SOYBEAN PRODUCTS

In some cases it may be economically feasible to process soybeans on-farm and use the meal or oil for feeding livestock locally. This may be an attractive option where the farm has livestock that requires soybean meal, where there is a market for the oil (feed or biofuel), and the farm produces soybeans and is not located close to a commercial soybean plant. In addition, soybeans can be successfully roasted when they contain up to as much as 18 per cent moisture which helps to reduce soybean drying costs for the producer. Roasting soybeans may also allow the producer to avoid commercial storage costs as they can roast the soybeans and return them to their own on-farm bin.

On-farm roasting of soybeans is popular with dairy producers who are not located close to a soybean processing plant. Portable roasting units are available for direct ownership by the producer or they may choose to hire a company to bring a unit to their farm for custom processing. This can also be done at a larger fixed location commercial roasting facility. The costs associated with roasting vary and are affected to a large degree by energy costs. As of the summer of 2010, custom roasting was available for $32/tonne or $37/tonne if steeped, plus transportation.

The value of roasted soybeans varies with the intended application. They contain approximately 75 per cent of the protein of standard soybean meal, but have 26 per cent more net energy for lactation (a measure of the energy in soybean meal that can be used to produce milk) than soybean meal. In diets where energy is more

On-farm expeller press
Image courtesy of Energrow

of a premium, such as in high-producing dairy rations, roasted soybeans will be worth more than soybean meal. In cases where protein is higher valued, then roasted soybeans may have a discounted value relative to soybean meal. On June 7, 2010 dehulled soybean meal was trading for $365/tonne FOB Hamilton while roasted soybeans were trading for $405/tonne FOB Woodstock. When considering roasting beans, producers must realize all the costs associated with producing the roasted beans including: lost opportunity cost (what they could have sold the soybeans for), shrinkage (which varies depending on the moisture and cleanliness of soybeans) and processing costs (approximately $40/tonne). Once those have been calculated, they need to work with a nutritionist and determine what value the roasted soybeans have in their diet using a least cost feed formulation package. In a significant number of cases, producers find roasting soybeans to be a viable alternative to selling soybeans and purchasing soybean meal.

Expeller meal
Image courtesy of Energrow

For additional information, please refer to an article by Murray Snowdon from the New Brunswick Department of Agriculture and Aquaculture at www.gnb.ca/0170/01700003-e.asp.

In some cases, such as when oil prices are high relative to meal, it may be more beneficial to extract some of the oil and either use it on-farm or sell it. Small-scale soybean expellers are available for use on-farm. Both Komet™ style and traditional-scale expellers are available, which are able to extract approximately 75 per cent of the oil. Inexpensive expellers imported from China and India are readily available and can work if enough effort is put into setting up the system. However, these presses can be difficult to run on-farm as they require constant monitoring and the preconditioning/cooking steps must be carefully controlled to achieve reasonable levels of oil extraction. The Komet™ style of press appears to be more reliable and in some cases is equipped with a monitoring system that allows it to be run with a minimum level of supervision. One example of this is a system produced in Canada by Energrow (www.energrow.com). This company reports operational costs at $12 to $15 per tonne but the cost of capitalization and additional energy for cooking needs to be added to that value to determine the total cost of operation. On average, the cost of expelling using a system of this nature would be approximately $25/tonne of seed processed.

Expelling offers two economic benefits: the extracted oil is typically of much higher value than the meal and can be either sold to a local feed mill or livestock producer who requires additional oil, or the oil can potentially be used as a source of fuel (conversion to biodiesel or use in a straight vegetable oil system). At the time of this writing, fat destined for livestock feeds was selling for approximately 226 per cent of the price of 48 per cent soybean meal. The meal is also typically of higher value than the seed due to the increase in protein content. Also, extruded-expelled soybean meal was selling for approximately 110 per cent of the price of 48 per cent crude protein soybean meal.

In cases where a solvent extraction plant is not located close to the farm and soybean meal is needed for feed, expelling might be a viable option to add value to the soybeans. All costs associated with expelling must be considered when exploring the option for on-farm production, including opportunity cost, energy, capitalization, labour, and depreciation. The Ontario Ministry of Agriculture, Food and Rural Affairs has published an excellent set of spread sheets that consider not only the cost of expelling oil but also the value of producing fuel from the oil: www.omafra.gov.on.ca/english/engineer/energy.html.

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Soybean Nutrient Composition Tables

PER CENT (%)	Whole Soybean Roasted	Expeller Meal	Solvent Extracted Soybean meal	Dehulled Solvent Extracted Soybean meal	Soybean Hulls
Dry Matter	91	89	90	88	90.9
Crude Protein	43.0	42.0	44.0	47.8	13.9
Ether Extract	19.0	8.1[2]	0.5	1.0	1.4
Crude Fibre	5.0	6.5	7.0	3.0	34.2
NDF	22.1	21.7	14.9	9.8	60.3
ADF	14.7	10.4	10.0	6.2	44.6
NDIN (% of DM) [a]	6.1	9.6	0.7	0.7	3.5
ADID (% of DM) [b]	2.0	0.4	0.4	0.4	1.0
Ash	4.6	6.0	6.0	6.0	44.6
Methionine	0.54	0.60	0.65	0.70	0.14
Cysteine	0.55	0.62	0.67	0.71	0.19
Lysine	2.40	2.70	2.70	3.02	0.71
Tryptophan	0.52	0.58	0.60	0.70	0.14
Threonine	1.69	1.70	1.70	2.00	0.43
Isoleucine	2.18	2.80	2.50	2.60	0.44
Histidine	1.01	1.10	1.10	1.30	0.28
Valine	2.02	2.20	2.40	2.70	0.51
Leucine	2.80	3.80	3.40	3.80	0.74
Arginine	2.80	3.20	3.40	3.60	0.59
Phenylalanine	2.10	2.10	2.20	2.70	0.45
RUP, % of crude protein [c]					
Low forage diet [d]	29.1	58.0	24.3	30.8	34.4
High forage diet [e]	39.4	69.0	34.6	42.6	44.6
Intestinal digestibility, % of RUP	85	93	93	93	70
Arginine, % of RUP	6.79	7.40	7.38	7.32	5.18
Histidine, % of RUP	2.61	2.77	2.77	2.77	2.88
Lysine, % of RUP	5.98	6.27	6.28	6.29	6.27
Methionine, % of RUP	1.40	1.45	1.45	1.44	1.16

	Whole Soybean Roasted	Expeller Meal	Solvent Extracted Soybean meal	Dehulled Solvent Extracted Soybean meal	Soybean Hulls
VITAMINS					
Vitamin E (mg/kg)	31.0	6.6	3.0	3.3	N/A
Thiamin (mg/kg)	6.6	1.7	1.7	1.7	N/A
Riboflavin (mg/kg)	2.64	4.4	3.0	2.6	N/A
Pantothenic acid (mg/kg)	15.6	13.8	13.3	13.2	N/A
Biotin (ug/kg)	286	320	320	320	N/A
Folic acid (ug/kg)	450	450	450	700	N/A
Choline (mg/kg)	2420	2673	2743	2850	N/A
Niacin (mg/kg)	22.0	36.7	59.8	20.9	N/A
MINERALS					
Calcium (%)	0.25	0.20	0.25	0.20	0.49
Total Phosphors (%)	0.59	0.60	0.60	0.65	0.14
Available Phosphorus (%)	0.20	0.20	0.20	0.21	0.06
Sodium (%)	0.04	0.04	0.04	0.04	0.01
Potassium (%)	1.70	1.71	1.97	1.90	1.20
Chloride (%)	0.03	0.20	0.02	0.02	0.02
Magnesium (%)	0.21	0.25	0.27	0.27	0.22
Sulfur (%)	0.30	0.33	0.43	0.43	0.11
Manganese (ppm)	30.0	32.3	27.5	27.5	22.0
Iron (ppm)	75	160	120	120	580
Copper (ppm)	15	18	28	28	8
Zinc (ppm)	35	59	60	60	40
Selenium (ppm)	0.10	0.10	0.10	0.10	0.21
AMEn Poultry Kcal/kg	3350	2751*	2240	2458	N/A
ME, Swine Kcal/kg	3540	1360	3090	3140	1863
DE, Swine Kcal/kg	4140	3768**	3490	3685	2006
NE, Swine Kcal/kg	2627	N/A	1911	2006	1003
Ruminants					
TDN (%), 1X	88.8	88.6	80.0	81.4	67.3
DE Mcal/kg	4.72	4.35	4.05	4.16	3.01
NEL Mcal/kg	2.72	2.38	2.13	2.21	1.46
NEm Mcal/kg	2.73	2.49	2.29	2.37	1.58
NEg Mcal/kg	1.95	1.76	1.59	1.66	0.98

Source: Feedstuffs ingredient analysis Table: 2010 Edition, NRC, 2001, NRC, 1998 Sauvant et al., 2004
Prediction equations for energy content of expeller meals extrapolated from energy content of soybean meal and full fat soybeans shown above.

[a] Neutral detergent insoluble nitrogen
[b] Acid detergent insoluble nitrogen
[c] Rumen undegrable protein
[d] 25% forage, DMI = 2% of body weight
[e] 50% forage, DMI = 4% of body weight
* Poultry AMEn = 63.4* % fat + 2208
** Swine DE(Kcal/kg) = 37.1 * % fat + 3471
N/A, not reported in the cited sources


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