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FEED INDUSTRY GUIDE • 5th EDITION, 2015

CANOLA MEAL FEEDING GUIDE

CANOLA MEAL:
A BASIC INTRODUCTION

This technical guide on the use of canola meal in animal feeds is the latest in a series of canola meal publications produced by the Canola Council of Canada. Every few years, the guide is updated to incorporate new research information about canola meal and developments in feed technology. Since the previous edition in 2009, a considerable amount of new research on feeding canola meal has been conducted around the world, especially in Canada, the United States of America and Asia. New information and changes in this latest version of the guide include:

• Information on protein degradation of canola meal in the rumen and its impact on milk production

• Updated nutrient profile of canola meal obtained through a collection of meal samples from processors across Canada over a four-year period

• Updated values of energy content and inclusion levels of canola meal in the diets of swine and poultry

• Additional information on canola meal inclusion in fish diets

A copy of this publication can be found on the Canola Council of Canada's website **www.canolacouncil.org**, as well as on **Canolamazing.com**.

TABLE OF CONTENTS

CANOLA MEAL: A BASIC INTRODUCTION

Canola is one of Canada's most important crops. Every summer, about 20 million acres (8 million hectares) of prime Western Canadian farmland turn brilliant yellow as canola crops go into bloom. These vast fields yield millions of tonnes of tiny round seeds, containing approximately 44% oil, which is extracted for use as one of the world's healthiest culinary oils. After the oil is extracted, the seed solids are processed into a protein-packed meal coproduct that is an excellent addition to livestock feed.

Canola is an offspring of rapeseed (*Brassica napus* and *Brassica campestris/rapa*), which was bred through traditional plant breeding techniques to have low levels of erucic acid (< 2%) in the oil portion and low levels of glucosinolates (< 30 µmol/g) in the meal portion. The glucosinolates were reduced due to their negative impact on palatability and toxic effects in many livestock species.

The term "canola" (Canadian oil) was coined in order to differentiate it from rapeseed. Some countries, especially in Europe, use the term "double-zero rapeseed" (low erucic acid, low glucosinolates) to identify "canola quality" seed, oil and meal.

Production and Markets

Canola production in Canada has been steadily increasing, and currently sits at approximately 15 million tonnes of canola seed per year. The Canola Council of Canada is targeting an increase to 26 million tonnes per year by 2025, in response to rising world demand. The plan focuses on increasing yields in a sustainable way, while building consumer understanding of canola's value and achieving stable, open trading relationships.

About half of Canada's canola seed is exported, and the other half is processed in Canada (Table 1). Most countries that import canola seed mainly do so for the oil, which is the most valuable component. The seed is processed, and the resulting canola meal is used for the animal feed industry in these countries. Canola meal is widely available and traded, usually sold in bulk form as mash or pellets. Canadian canola meal is traded under the rules outlined in Table 2.

Canola and rapeseed meals are commonly used in animal feeds around the world. Together, they are the second-most widely traded protein ingredients after soybean meal. The major producers of canola and rapeseed meal are Australia, Canada, China, the European Union and India.

The use of canola meal varies considerably from market to market. Canola meal sold directly to the United States goes primarily to the top dairy-producing states. Canola seed exported to other countries for processing is used in a much more diverse fashion, including feeding to pigs, poultry and fish. Similarly, the meal that is used by the Canadian livestock industry goes primarily to dairy, swine and poultry rations.

Table 1. Canadian production, exports and domestic use of canola seed and canola meal (in 000's) Metric tonnes[1]

PRODUCTION, PROCESSING AND MARKETS	2010/11	2011/12	2012/13	2013/14
Canola seed production	12,789	14,608	13,868	17,960
Canola seed exports (total)	7,206	8,696	7,095	9,125
United States	467	580	400	1,027
Japan	2,312	2,315	2,318	2,128
China	916	2,525	2,670	4,026
Pakistan	845	622	0	169
Mexico	1,422	1,505	1,391	1,375
United Arab Emirates	833	687	233	274
Others	411	462	83	126
Domestic processing	6,310	6,997	6,715	6,979
Canola meal production	3,568	3,967	3,998	4,034
Canola meal – Canadian use	570	660	592	608
Canola meal exports (total)	2,998	3,307	3,406	3,426
United States	1,875	2,815	3,060	3,277
Others	1,124	492	346	150

[1]Statistics Canada

Table 2. Trading rules for canola meal (as set by Canadian Oilseed Processors Association [COPA])[1]

CHARACTERISTIC (AS FED)	CANADA AND U.S.	EXPORT
Protein, % minimum	36	—
Fat (oil), % typical minimum	2	—
Protein + fat, % minimum	—	37
Moisture, % maximum	12	12
Crude fibre, % maximum	12	12
Glucosinolates, µmol/g maximum	30	30
Sand and/or silica, % maximum	—	1

[1]COPA, 2013

KEY FACTORS IN CANOLA MEAL PROCESSING

Canola seed is traditionally processed using solvent extraction in order to separate the oil from the meal. This process, called prepress solvent extraction, typically includes:

• Seed cleaning

• Seed preconditioning and flaking

• Seed cooking

• Pressing the flake to mechanically remove a portion of the oil

• Solvent extraction of the press-cake to remove the remainder of the oil

• Desolventizing and toasting of the meal

Meal quality is influenced by several variables during the process, especially temperature.

The following section outlines the process of prepress solvent extration, with a summary of expeller pressed canola at the end of the section.

Seed Cleaning

In Canada, canola seed is graded according to strict grading standards established by the Canadian Grain Commission. These include specifications for maximum moisture content, seed damage and chlorophyll level. The seed delivered to the processing plant contains dockage materials, which are removed by cleaning operations prior to processing.

Seed Preconditioning and Flaking

Many canola processing plants in colder climates preheat the seed with grain dryers to approximately 35°C to prevent shattering, which may occur when cold seed from storage enters the flaking unit (Unger,

1990). The cleaned seed is first flaked by roller mills set for a narrow clearance to physically rupture the seed coat. The objective, therefore, is to rupture as many cell walls as possible without damaging the quality of the oil. The thickness of the flake is important, with an optimum size of 0.3–0.38 mm. Flakes thinner than 0.2 mm are very fragile, while flakes thicker than 0.4 mm result in lower oil yield.

Seed Cooking

Flakes are cooked/conditioned by passing them through a series of steam-heated drum- or stack-type cookers. Cooking serves to thermally rupture oil cells that have survived flaking; reduce oil viscosity and thereby promote coalescing of oil droplets; increase the diffusion rate of prepared oil cake; and denature hydrolytic enzymes. Cooking also adjusts the moisture of the flakes, which is important in the success of subsequent prepressing operations.

At the start of cooking, the temperature is rapidly increased to 80–90°C, which serves to inactivate the myrosinase enzyme present in canola. This enzyme can hydrolyze the small amounts of glucosinolates in canola, and produce undesirable breakdown products that affect both oil and meal quality.

The cooking cycle usually lasts 15–20 minutes, and the temperatures normally range between 80°C and 105°C, with an optimum of about 88°C. In some countries, cooking temperatures of up to 120°C have been traditionally used when processing high-glucosinolate rapeseed to volatilize some of the sulphur compounds that can cause odours in the oil. However, these high temperatures can negatively affect meal protein quality.

Pressing

The cooked canola seed flakes are then pressed in a series of screw presses or expellers. These units consist of a rotating screw shaft within a cylindrical barrel that contains flat steel bars set edgewise around the periphery, and are spaced to allow the oil to flow between the bars while the cake is contained within the barrel. The rotating shaft presses the cake against an adjustable choke, which partially constricts the discharge of the cake from the end of the barrel. This action removes part of the oil while avoiding excessive pressure and temperature. The objective of pressing is to remove as much oil as possible, usually 50–60% of the seed oil content, while maximizing the output of the expellers and producing a presscake that is ideal for solvent extraction.

Solvent Extraction

Since pressing alone cannot remove all of the oil from the canola seed, the press-cake is solvent-extracted to remove the remaining oil. The cake from the expellers, containing 18–20% oil, is sometimes broken into uniform pieces prior to solvent extraction, in which a solvent (hexane) is used that is specially refined for the vegetable oil industry. Various mechanical designs of solvent extractors have been developed for moving the cake and the miscella (solvent plus oil) in opposite directions to effect a continuous counter-current extraction. Basket and continuous-loop-type extractors are commonly used for canola. The principles are the same: The cake is deposited in the extractor, which is then flooded with solvent or miscella. A series of pumps spray the miscella over the press-cake, with each stage using a successively "leaner" miscella, thereby containing a higher ratio of solvent in proportion to the oil. The solvent percolates by gravity through the cake bed, diffusing into, and saturating, the cake fragments. The marc (hexane-saturated meal) that leaves the solvent extractor, after a fresh solvent wash, contains less than 1% oil.

Desolventizing and Toasting

The solvent is removed from the marc in a desolventizer-toaster. In a series of compartments or kettles, the majority of the solvent is flashed from the meal by heating it on a series of steam-heated plates. The final stripping of the solvent is completed by injecting live steam through the meal, a process termed toasting. During the desolventization-toasting process, the meal is heated to 95–115°C and moisture increases to 12–18%. The total time spent in the desolventizer-toaster is approximately 30 minutes. The meal is then cooled and dried to approximately 12% moisture by blowing air through it. The meal is next granulated to a uniform consistency using a hammer mill, and is either pelleted or sent directly to storage as a mash.

Effects of Processing on Meal Quality

The quality of the meal can be both enhanced and diminished by altering the processing conditions in the processing plant. Minimum processing temperatures are needed in order to deactivate the myrosinase enzyme, which, if not destroyed, will break down glucosinolates into their toxic metabolites (aglucones) in the animal's digestive tract. Canola processing can also cause thermal degradation of 30–70% of glucosinolates in the meal (Daun and Adolphe, 1997). However, if temperatures are too high for too long, then the protein quality of the meal can decrease. In Canada, most processors have very similar processing conditions, and canola meal quality does not vary widely. In cases in which considerable variation in processing temperatures may exist, it is important for canola meal users to routinely measure the protein quality of the meal or audit and approve suppliers.

As well, some of the by-products of canola processing may be added back into the canola meal. In the case of added gums and soapstocks, these oil-rich components will increase the energy content of the meal. In the case of added screenings, the meal quality may decrease. A good ingredient quality control program will pick up these differences in processing practices.

Temperature

Deactivation of the myrosinase enzyme is best accomplished during the canola seed cooking stage. The early research of Youngs and Wetter (1969) regarding steps to minimize glucosinolate hydrolysis by myrosinase has become the operating practice for processors around the world.

Moisture content of the seed during processing should be 6–10%. Above 10% moisture, glucosinolate hydrolysis will proceed rapidly, and below 6% moisture, the myrosinase enzyme is only slowly inactivated by heat. As well, during seed cooking, the temperature must be raised to 80–90°C as rapidly as possible. Myrosinase-catalyzed hydrolysis of glucosinolates will proceed with increasing temperature until the enzyme is deactivated, so that a slow rate of heating favours glucosinolate hydrolysis.

Excessive heating during processing can result in reduced animal digestibility of some amino acids, particularly lysine. Processors must exercise strict process control to ensure amino acid damage is minimized by not overheating the meal in the desolventizer-toaster. Examination of meal quality at various processing stages in several Canadian processing plants (Newkirk, et al., 2003) revealed that canola meal is a uniform and high-quality product until it enters the desolventizer-toaster phase. During this

stage, crude protein and lysine digestibility, as well as lysine content, were significantly reduced. This research by Newkirk, et al. (2003) suggests that the commonly used temperature in the desolventizer-toaster stage of 107°C causes some protein damage. Processing with a maximum temperature of 100°C in the desolventizer-toaster significantly increases lysine digestibility to similar levels found in soybean meal. Also, traditional toasting causes the meal to become much darker in colour. This is a quality concern for some feed manufacturers, who prefer using light-coloured ingredients due to feed customer preferences.

Additives

Crude canola oil contains a portion of phospholipid material, which is removed during oil processing. This material is commonly referred to as "gums," and in Canada, is added back to the meal in the desolventizer-toaster at a level of 1–2%. Also, in processing plants with associated oil refining, the acidulated soapstocks may be added to the meal at a level of 1–2%. These additions serve to reduce the dustiness of the meal and, more importantly, increase its metabolisable energy value. In some countries, the gums and soapstocks are used for other purposes, and not added to the meal. This is the main reason that Canadian canola meal has higher levels of oil than meal from many other countries.
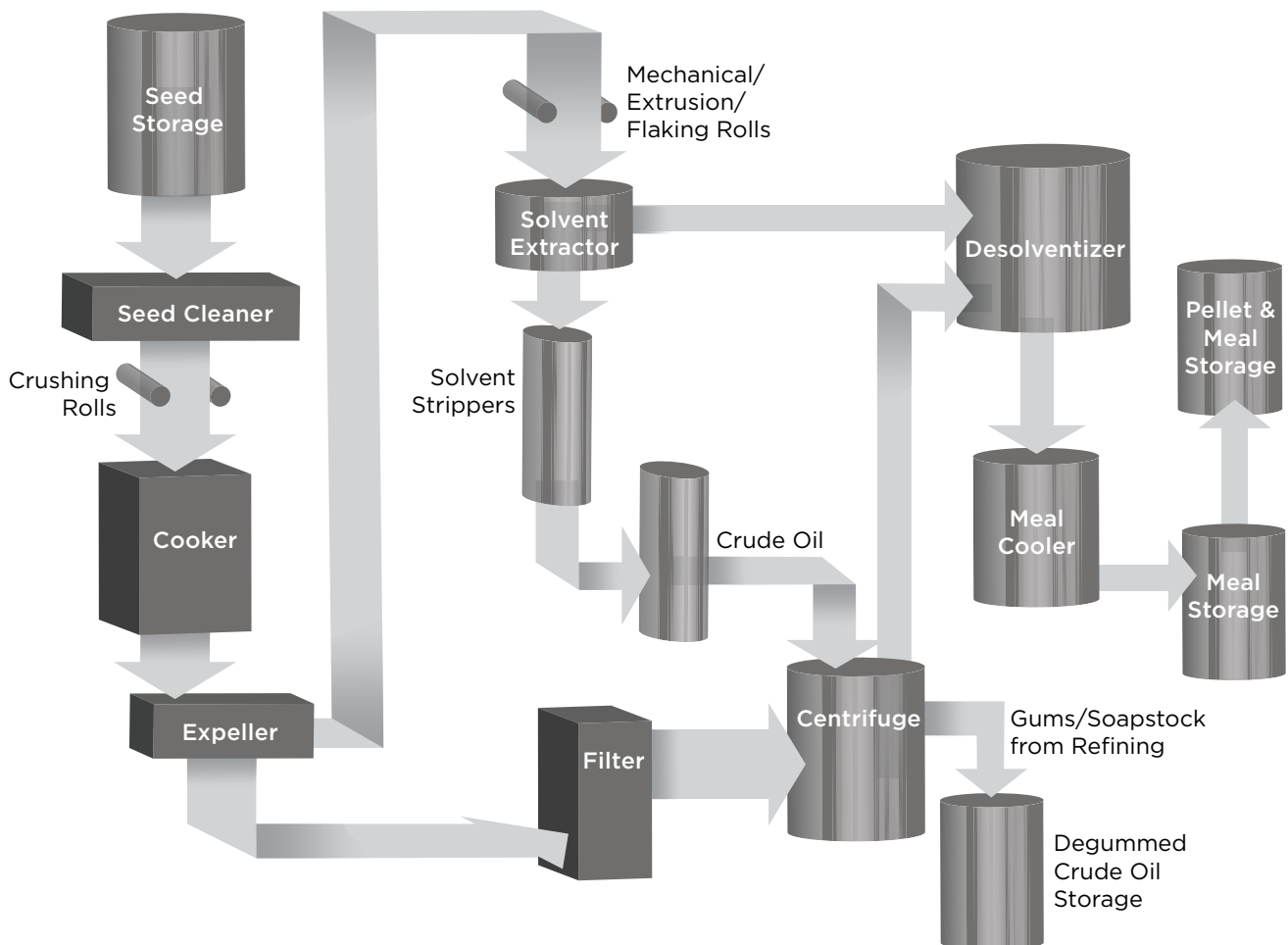
Expeller Pressed Canola

A small proportion of Canadian canola seed is processed by using expeller processing, also termed double pressing. The seed is expelled twice to extract oil rather than using solvent to extract the residual oil. Up to the point of solvent extraction, the process is similar to the traditional preprocess solvent extraction process. However, it excludes the solvent extraction,

desolventization, and drying and cooling stages. The resulting meal has higher oil content, which can range from 8–11%, and therefore has higher metabolisable, digestible and net energy content than traditional prepress solvent-extracted meal. The meal is not subjected to desolventization/toasting, the primary source of heat that can affect traditional solvent-extracted meal, but it is still subject to the

potential effects of heat due to the friction generated during the expelling process. The meal temperatures may achieve as much as 160°C, but due to the low moisture content and the short duration, protein quality is generally preserved. However, in extreme cases, or if the meal is not cooled quickly after extraction, protein quality can be affected.

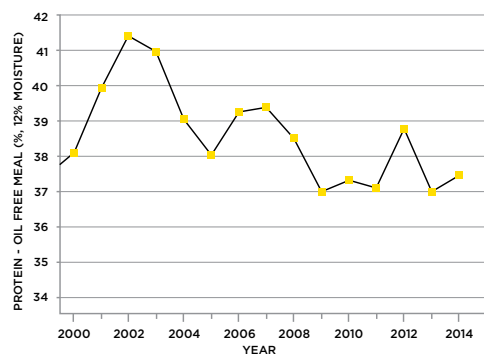**Figure 1. Schematic of prepress solvent extraction process**

CANOLA MEAL NUTRIENT COMPOSITION

Canadian solvent-extracted canola meal is derived from a blend of *Brassica napus*, *Brassica rapa* and *Brassica juncea* seed. The majority (> 95%) of the seed produced in Canada is *Brassica napus*. As with any crop, there is some variability in the nutrient composition of canola meal due to variation in environmental conditions during the growing of the crop, according to harvest conditions, and to a minor extent, by cultivar and processing of the seed and meal. The basic nutrient composition of canola meal is shown in Table 1. These results are based on an extensive survey of 12 manufacturing sites, conducted over a three- to four-year period. Some partial results had been published at the time this publication was produced (Broderick, et al., 2013; Adewole, et al., 2014).

Protein and Amino Acids

This publication uses a default value of 36% crude protein on a 12% moisture basis in the nutrient composition tables that follow. While the minimum crude protein guarantee for Canadian canola meal is 36% (12% moisture basis), the actual protein content can range between 36 and 39%. The minimum allows

for yearly variation in canola seed composition due to growing conditions.

The influence of weather and soil conditions on the protein content of Canadian canola meal from 2000 to 2014 is shown in Figure 1. As the chart indicates, the protein content of canola meal varies from about 37–42% when calculated on an oil-free, 12% moisture basis.

Table 1. Typical chemical composition of canola meal (12% moisture basis)[1]

COMPONENT	AVERAGE
Moisture (%)	12.0
Crude protein (N x 6.25, %)	36.7
Rumen escape protein (%)[2]	43.5
Ether extract (%)	3.3
Linoleic acid (%)	0.67
Linolenic acid (%)	0.32
Ash (%)	6.7
Calcium (%)	0.65
Phosphorus (%)	0.99
Crude fibre (%)	11.2
Acid detergent fibre (%)	16.2
Neutral detergent fibre (%)	25.4
Total dietary fibre (%)	32.4
Sinapine (%)	1.0
Phytic acid (%)	2.3
Glucosinolates (μ mol/g)	4.2

[1]Results based on a three-year survey (Slominski, 2015).
[2]Results based on a four-year survey (Broderick, 2015).

Figure 1. Protein content of canola meal 2000–2014 (12% moisture basis)[1,2]

[1]Values provided on an oil-free basis, as calculated from seed. [2]Barthet, Canadian Grain Commission, 2014

The amino acid profile of canola meal is well suited for animal feeding (Table 2). Like many vegetable protein sources, canola meal is limiting in lysine, but it is noted for having high levels of methionine and cystine. Amino acid content varies with protein content, and can be calculated by multiplying the crude protein content of the meal by the proportion of amino acid as a percentage of protein (as shown in Table 2).

Ether Extract

The ether extract content of Canadian canola meal tends to be relatively high at 3.5% (Table 1) compared to 1–2% in canola and rapeseed meals produced in most other countries. In Canada, it is general practice to include canola gums with canola meal at 1–2%. The gums are obtained during the refining of canola oil, and consist mainly of glycolipids and phospholipids and variable amounts of triglycerides, sterols, fatty acids, fat-soluble vitamins, etc. The inclusion of the canola gums with canola meal increases the energy value of canola meal. The inclusion of up to 6% gums in the meal has been shown to have no detrimental effects on the feeding value of the canola meal for broiler chickens or laying hens (Summers, et al., 1978). In studies involving beef cattle (Mathison, 1978), dairy cattle (Grieve, 1978) and swine (McCuaig and Bell, 1981), the inclusion of gums with canola meal at levels higher than those added by Canadian canola seed processors had no adverse effects on the feeding value of the meal for these classes of animals. Likewise, canola meal produced in Canada by oil refineries may also contain 1–2% of the free fatty acids derived from canola oil refining. In addition to the energy provided by the gums and free fatty acids, these components help to reduce the dustiness of the meal.

Table 3 provides the complete fatty acid analysis for canola oil. As the table shows, this oil contains only a

Table 2. Amino acid composition of canola meal on a 36% protein basis[1]

AMINO ACID	AVERAGE %	PROPORTION AS % OF CP
Alanine	1.57	4.36
Arginine	2.38	6.62
Aspartate + asparagine	2.61	7.25
Cystine	0.82	2.29
Glutamate + glutamine	6.53	18.14
Glycine	1.77	4.92
Histidine	1.22	3.39
Isoleucine	1.25	3.47
Leucine	2.22	6.19
Lysine	2.13	5.92
Methionine	0.70	1.94
Methionine + cystine	1.53	4.25
Phenylalanine	1.46	4.06
Proline	2.15	5.97
Serine	1.44	4.00
Threonine	1.54	4.27
Tryptophan	0.48	1.33[2]
Tyrosine	0.90	2.50
Valine	1.78	4.97

[1]Slominski, 2015
[2]Degussa, AMINOdat® 3.0 http://feed-additives.evonik.com (Evonik Industries GmbH)

small amount of saturated fatty acids, and high levels of oleic acid. Canola meal provides a 2:1 ratio of omega 6 to omega 3 fatty acids, and is a good source of omega 3 fatty acids.

Canola oil is sometimes used in diets to enrich the fatty acid profile of milk, meat or eggs (Gallardo, et al., 2012; Gül, et al., 2012; Chelikani, et al., 2004).

Carbohydrates and Fibre

The carbohydrate matrix of canola meal is quite complex (Table 4). The fibre content is higher than for some vegetable proteins, as the hull cannot be readily removed from the seed. Much of the fibre is in the form of acid detergent fibre (ADF), with neutral detergent fibre (NDF) levels about 10% higher than ADF. The non-fibre component is rich in sugar, which is mostly provided as sucrose (Table 4).

Minerals

Most references on the mineral content of canola meal use the values derived by Bell and Keith (1991), which were reconfirmed in a survey by Bell, et al. (1999), and again by the current survey (Broderick, et al., 2015; Slominski, et al., 2015). The data show that canola meal is a relatively good source of essential minerals (Table 5) compared to other oilseed meals.

Canola meal is an especially good source of selenium and phosphorus. Similar to other vegetable sources of phosphorus, a portion of the total is in the form of phytate.

Vitamins

Information on the vitamin content of canola meal is very limited, but it appears to be rich in choline, biotin, folic acid, niacin, riboflavin and thiamine (Table 6). As is recommended with most natural sources of vitamins in animal feeds, users should not place too much reliance on these values, and use supplemental vitamin premixes instead.

Anti-nutritional Factors

Rapeseed meal, the parent of canola meal, is recognized as an ingredient that may need to be

Table 3. Fatty acid composition of canola oil[1]

FATTY ACID	% OF TOTAL FATTY ACIDS
Total saturated	6.0
C22:1 Erucic acid	0.2
Total monounsaturated	61.9
C18:2 Linoleic acid (Omega 6)	20.1
C18:3 Linolenic acid (Omega 3)	9.6
Total polyunsaturated	29.7

[1]Przybylski, et al., 2005

Table 4. Carbohydrate and dietary fibre components of canola meal (12% moisture basis)[1]

COMPONENT	%
Non-Fibre Fractions	
Fructose + glucose	0.6
Sucrose	5.2
Oligosaccharides	2.3
Starch	5.1
Dietary Fibre Fractions	
Crude fibre (CF)	11.2
Acid detergent fibre (ADF)	16.2
Neutral detergent fibre (NDF)	25.4
Total dietary fibre (TDF)	32.4
Non-starch polysaccharides (NSP)	18.9
Cellulose	7.9
Non-cellulosic polysaccharides	11.0
Glycoprotein (NDF-insoluble crude protein)	4.6
Lignin and polyphenols	8.9
Lignin	5.8

[1]Slominski, 2015; Broderick, 2015

limited in diets for livestock and fish due to certain anti-nutritional factors, primarily glucosinolates. These factors have been reduced in canola meal to levels that do not pose threats to performance and feeding for most species.

Glucosinolates are a large group of secondary plant metabolites common to all cruciferous plants. While nontoxic on their own, breakdown products of glucosinolates can adversely affect animal performance. The low glucosinolate content of canola, compared to previous cultivars of rapeseed, constitutes the major improvement in meal quality achieved by plant breeders. Canola glucosinolates are composed of two main types, aliphatic and indolyl (or indol) glucosinolates. Aliphatic glucosinolates make up approximately 85% of the glucosinolates present in canola meal, while indolyl glucosinolates account for the other 15% (Slominski, 2015). The average total glucosinolate content of Canadian canola meal, based on three years of data, is 4.2 μmol/g (Slominski, 2015). By comparison, traditional rapeseed meal contains 120–150 μmol/g of total glucosinolates. The reason that glucosinolates are expressed on a molecular (μmol/g) basis rather than on a weight (mg/kg) basis is that glucosinolates have significantly different molecular weights, depending on the size of their aliphatic side chain. Since the negative effect on the animal is at the molecular level, the most accurate estimate of this effect must be gauged by expressing glucosinolate concentration on a molecular basis.

The level of glucosinolates in Canadian canola seed has continued to decrease in recent years, due to selection pressure by canola plant breeders. The level of glucosinolates in Canadian canola seed prior to processing has averaged around 10 μmol/g over the last eight years.

Table 5. Mineral content of canola meal (12% moisture basis)[1,2,3]

MINERAL	AVERAGE
Calcium (%)	0.65
Phosphorus (%)	0.99
Phytate P (%)	0.64
Non-phytate P (%)	0.35
Sodium (%)	0.07
Chlorine (%)	0.10
Potassium (%)	1.13
Sulphur (%)	0.63
Magnesium (%)	0.54
Copper (mg/kg)	4.7
Iron (mg/kg)	162
Manganese (mg/kg)	58
Molybdenum (mg/kg)	1.4
Zinc (mg/kg)	47
Selenium (mg/kg)	1.1[2]

[1]Slominski, et al., 2015
[2]Sauvant, et al., 2002
[3]Dairy One (www.dairyone.com)

Table 6. Vitamin content of canola meal (12% moisture basis)[1]

VITAMIN	MG/KG
Biotin	0.96
Choline	6,500
Folic Acid	0.8
Niacin	156
Pantothenic acid	9.3
Pyridoxine	7.0
Riboflavin	5.7
Thiamine	5.1
Vitamin E	13

[1]Values as reported by NRC, 2012.

Glucosinolate content is then concentrated in the meal; after that, it is further reduced during processing to values averaging 4.2 µmol/g.

Tannins are present in canola meal at a range of 1.5–3.0%, with brown-seeded varieties having higher levels than yellow-seeded varieties. The tannins in canola meal are primarily insoluble and associated with the hull, and do not appear to have the same negative effects on palatability and protein digestibility that they do in other plants (Khajali and Slominski, 2012).

Canola meal contains about 1% sinapine, a choline ester of sinapic acid. Sinapine is noteworthy, as it has been shown to produce a fishy flavour in chicken eggs from some strains of brown-egg-laying hens (Khajali and Slominski, 2012). Breeding programs have resulted in most strains of brown egg layers no longer being affected by sinapine. (See "Canola Meal in Poultry Diets" Chapter 6.) Research conducted by Qiao and Classen (Qiao and Classen, 2003) showed that while sinapine may have a bitter taste, at the levels found in canola meal, it did not affect feed intake or growth rate.

Nutritional Composition of Canola Expeller Meal

Several terms are used interchangeably to differentiate solvent-extracted versus expeller-extracted meals. Terms commonly used to describe the meal include expeller meal, double-press meal and presscake.

Currently in Canada, a small percentage of seed is processed using the expeller method. Smaller oilseed plants as well as those associated with some biodiesel plants use double-press expeller processing rather than solvent extraction. Since the oil is extracted simply by mechanical means, the resulting meal contains significantly more oil than that of standard solvent-extracted canola meal. Due to differences in processing techniques by the smaller biodiesel plants, expeller meal can be more variable than solvent-extracted canola meal. Larger production facilities, on the other hand, tend to produce meal that is more consistent. The nutritional profile of the meal is similar to that of canola meal, except that it contains 8–11% fat and therefore much higher energy values. The nutritional composition of expeller meal is provided in Table 7. Fat content can vary widely, so it is important that the expeller cake is analysed for fat, and the energy value adjusted accordingly. High levels of fat will also dilute other nutrients in the resultant meal, relative to solvent-extracted canola meal.

Nutrient Composition of Canola Seed

The key nutrient values for canola seed are shown in Table 8. These values were obtained from recent publications (Assadi, et al., 2011; Leterme, et al., 2008). Most nutrient values for canola seed can be calculated from the nutrient values in canola meal and oil, considering that approximately 56% of the seed is meal and 44% is oil. The exception is energy content, because the energy value of canola seed cannot be estimated reliably from the addition of the energy values for canola oil and meal. For swine and poultry, the seed has less energy than the sum of its oil and meal components. This is likely because whole canola seed is not processed to the same degree as canola oil and meal; so it is, therefore, not as well digested. Heat treatment and particle size reduction of canola seed by micronization, extrusion or expansion is often used to increase its energy digestibility.

Table 7. Typical chemical composition of expeller canola meal (12% moisture basis)[1]

COMPONENT	AVERAGE
Moisture (%)	5.0
Crude protein (N x 6.25: %)	34.8
Rumen escape protein (%)[2]	48.5
Ether extract (%)	9.5
Linoleic acid (%)	1.9
Linolenic acid (%)	0.9
Ash (%)	6.2
Crude fibre (%)	11.8
ADF (%)	16.7
NDF (%)	23.8
Calcium (%)	0.59
Phosphorus (%)	0.89
Glucosinolates (µmol/g)	9.5

[1]Slominski, 2015
[2]Broderick, 2015

Table 8. Reported chemical composition of canola seed (12% moisture basis)

COMPONENT	FEEDIPEDIA, 2015	NRC, 2001	ASSADI, ET AL., 2011	MONTOYA AND LETERME, ET AL., 2008
Moisture %	6.8	10.1	5.0	5.7
Crude protein (N x 6.25: %)	18.4	18.0	20.0	20.7
Ether extract (%)	40.5	35.6	43.8	38.6
Linoleic acid (%)	8.3	7.3	8.5	7.9
Linolenic acid (%)	4.1	3.4	4.2	3.9
Ash (%)	3.8	4.0	3.7	4.1
Crude fibre (%)	8.9	—	—	—
ADF (%)	12.7	9.7	—	10.6
NDF (%)	17.9	15.7	16.6	12.9
Calcium (%)	0.43	0.38	—	—
Phosphorus (%)	0.64	0.60	—	—

THE VALUE OF CANOLA MEAL IN RUMINANT DIETS

Canola meal is widely used in feeds for dairy cattle and is also used in diets for beef cattle. It is considered to be a premium ingredient for dairy and beef due to its high quality of protein for milk production and growth.

Palatability

Canola meal is a highly palatable source of protein for ruminant animals, and this is demonstrated repeatedly in feeding trials. Ravichandran, et al. (2008) examined the impact of feeding canola meal versus rapeseed meal with differing levels of residual glucosinolates to 5-month-old calves. Calves fed canola meal with fewer than 20 mmol/g of glucosinolates consumed virtually the same quantity as control calves fed diets without canola meal (1.10 kg vs. 1.08 kg, respectively). However, calves fed a concentrate containing high-glucosinolate rapeseed meal (> 100 µmol/g) only consumed 0.76 kg.

Recent studies have revealed that intakes in dairy cows can be maintained or enhanced when canola meal is substituted for soybean meal or distillers' grains. Broderick and Faciola (2014) replaced 8.7% of soybean meal with 11.7% canola meal. Cows consumed 0.5 kg more dry matter (DM) with the canola meal diet. Maxin, et al. (2013) substituted 20.8% canola meal for 13.7% soybean meal, with cows consuming 23.6 and 24.0 kg of dry matter for the two diets, respectively. Swanepoel, et al. (2014) fed up to 20% of DM as canola meal to high-producing cows in exchange for high-protein distillers' grains, with no reduction in dry matter intake.

For beef cattle, intakes were higher in backgrounded beef cattle given diets with 10% canola meal than diets containing corn distillers' grains or wheat distillers' grains (Li, et al., 2013).

Energy

Like most concentrate ingredients, canola meal is a good source of energy. Values listed by the National Research Council (NRC, 2001; NRC, 2015) are indicated in Table 1. Unfortunately, these energy values may not be correct. This energy has been undervalued in many feed formulation programs that use lignin to discount the digestibility of the cell wall. Models such as NRC (2001, 2015) that use a factorial approach to the calculation of energy discount the energy value of canola meal on the basis of unavailable energy in the cell wall.

NRC (2001) estimates of unavailable neutral detergent fiber (NDF) approach 65%, with the potentially available NDF estimated at 35%. Depending on rate of passage, the actual amount digested would be even less. Using an indigestible NDF assay, Cotanch, et al. (2014) demonstrated that the unavailable NDF in canola meal was 32% of the total. This value is nearly the inverse of the value estimated by NRC, 2001. This corroborates some older studies that show that approximately half of the NDF is actually digested in lactating dairy cows (Mustafa, et al., 1996, 1997), and higher percentages are digested in sheep (Hentz, et al., 2012) and beef cattle (Patterson, et al., 1999a).

Similarly, results from numerous feeding studies in dairy likewise suggest that the digestibility and energy value of canola meal are unduly reduced in some

Table 1. Average energy values for canola meal (12% moisture basis)[1]

ENERGY COMPONENT	VALUE
Total digestible nutrients (TDN, %)	68.0
Digestible energy (DE, Mcal/kg)	2.82
Metabolisable energy (ME, Mcal/kg)	2.30
Net energy maintenance (NEM, Mcal/kg)	1.48
Net energy gain (NEG, Mcal/kg)	0.90
Net energy lactation (Mcal/kg)	1.44

[1]NRC, 2001; NRC, 2015

models. Brito and Broderick (2007) replaced 12% soybean meal and 4.5% high-moisture corn with 16.5% canola meal with no other diet changes. There were no observed differences in fat-corrected milk/dry matter, and no differences in weight gain. Also, Swanepoel, et al. (2014) saw no differences in dry matter intake (DMI) or body condition score when up to 20% canola meal was substituted for high-protein corn distillers' grains. Energy output in milk was higher with the diets containing canola meal. In a study comparing distillers' grains, high-protein distillers' grains, soybean meal and canola meal, there were no differences in energy-corrected milk/dry matter or changes in body condition score (Christen, et al., 2010). Further research is ongoing to determine the correct energy value that should be assigned to canola meal.

Protein and Amino Acids in Canola Meal

Canola meal is prized in rations for ruminants for its amino acid profile. The values given in Table 2 were obtained for the rumen-undegraded protein (RUP) fraction as well as the intact canola meal using the procedure developed by Ross, et al. (2013). These results show that canola meal contributes a significant amount of methionine, which is often the first limiting amino acid in production. In addition, the RUP fraction profile more closely matches requirements for maintenance and milk than other vegetable proteins (Schingoethe, 1991). Further studies are currently underway to obtain more information on canola meal using this procedure for the RUP fraction.

Rumen Undegraded Protein (RUP) in Canola Meal

Older research suggested that the degradability of canola meal was high, due to the high soluble-protein content relative to some other vegetable proteins.

However, Hedqvist and Udén (2006) revealed that portions of the soluble-protein fraction were not degraded in the rumen. Since then, a number of studies have confirmed that only a portion of the soluble protein is degraded, with all in agreement that the proportion degraded is less than half of the total soluble protein (Table 3).

The RUP content of canola meal is very much dependent on the system of analysis that is used. Older methods, such as in sacco loss from nylon bags, do not take into account the contribution of the soluble-protein fraction to the RUP available to the animal (Table 3), or small particles that can wash out of the bags (Maxin, et al., 2013). Newer systems of modeling and analyses are adjusting for this contribution of RUP.

Table 2. Essential amino acid composition of canola meal and the canola meal escape protein fraction as determined by Cornell University[1]

AMINO ACID	AMINO ACIDS AS % OF DM		AMINO ACIDS AS % OF TOTAL PROTEIN	
	RUP FRACTION	INTACT MEAL	RUP FRACTION	INTACT MEAL
ARG	2.23	2.17	6.19	6.03
HIS	0.91	0.92	2.53	2.56
ILE	1.28	1.24	3.56	3.44
LEU	2.68	2.52	7.44	7.00
LYS	1.76	1.84	4.89	5.11
MET	1.55	1.27	4.31	3.53
PHE	1.49	1.44	4.14	4.00
TRP	0.51	0.48	1.42	1.33
VAL	1.54	1.44	4.28	4.00

[1]Ross, et al., 2013

Table 4 provides RUP (% of the protein) values for solvent-extracted canola meal relative to soybean meal from a number of recent studies. Each source represents a different method of analysis. Overall, the RUP of canola meal as a percent of the protein tends to be somewhat higher than that of soybean meal, and the relationship between the RUP values of these two proteins can be used to adjust formulation programmes so that canola meal is more accurately represented.

NRC (2001) does not provide data for solvent-extracted canola meal. Values have been shown to vary with method and with the model used (Table 4), but all are higher than reported by NRC (2001) for mechanically extracted canola meal. Results from Broderick, et al. (2012), most consistent with the NRC (2001) system, are 26% higher than the value calculated in NRC (2001) tables with DMI at 4% of body weight/day.

As part of a large survey undertaken by Broderick and team, an in vitro inhibitor method (Colombini, et al., 2011) was used to evaluate 36 samples of canola meal from 12 manufacturing sites each year over a four-year period (Broderick, 2015). These results are presented in Table 5. There were some improvements in the method, starting in 2013, which influenced results obtained for the calculated RUP of proteins analysed in 2013 and 2014.

Minerals and Vitamins

The mineral and vitamin profile for canola meal has been previously highlighted in the chapter on nutrient composition. As indicated, canola meal is a rich source of phosphorus, with most of this mineral in the form of

Table 3. Degradation of the soluble-protein fraction of protein from canola or rapeseed meal

REFERENCE	DEGRADED, % OF SOLUBLE	ESCAPE, % OF SOLUBLE
Bach, et al., 2008	37	63
Hedqvist and Udén, 2006	44	56
Stefanski, et al., 2013	43	57

Table 4. RUP (% of protein) values for canola meal and soybean meal as determined by several newer methods of analysis

REFERENCE	CANOLA MEAL	SOYBEAN MEAL	CANOLA/SOY RATIO
Tylutki, et al., 2008	41.8	38.3	1.09
Jayasinghe, et al., 2014	42.8	31.0	1.38
Maxin, et al., 2013 (uncorrected)	42.8	27.4	1.56
Broderick, 2015[1]	40.4	25.7	1.57
Maxin, et al., 2013 (corrected)	52.5	41.5	1.27
Hedqvist and Udén, 2006	56.0	27.0	2.07
Ross 2015[2]	52.3	45.2	1.16
Average	48.1	33.3	1.47

[1]Comparisons and soybean meal results based on the method of Colombini, et al., 2011.
[2]Personal Communication. Based on 27 samples. Values generated using the method of Ross, et al., 2013.

phytate phosphorus. Unlike monogastric animals, this form is available to ruminants, due to the presence of bacterial phytases that degrade phytate (Spears, 2003).

In fact, studies have shown that phytate phosphorus is more highly available to ruminants than non-phytate phosphorus. Garikipati (2004) provided diets to dairy cows in which approximately half of the phosphorus was in the form of phytate. The overall digestibility of

Table 5. Yearly means for protein, soluble protein and calculated RUP values of an extensive survey of canola meal as well as the relative value over the same time periods[1]

	AVERAGE OF 36 VALUES FROM 12 SITES/YEAR			
YEAR	CRUDE PROTEIN, % 12% MOISTURE BASIS	SOLUBLE PROTEIN, % OF TOTAL PROTEIN	CALCULATED RUP	RELATIVE VALUE OF SOYBEAN MEAL = 100
2011	36.7	25.5	43.8	163
2012	36.7	28.8	44.3	187
2013	37.4	28.4	38.3	144
2014	35.7	27.3	35.0	132

[1]Broderick, 2015

the phosphorus was 49%. However, the digestibility of the phytate-bound phosphorus was 79%. Skrivanova, et al. (2004) likewise found that the digestibility of phosphorus by 10-week-old calves was 72%, with 97% of the phytate portion digestible.

Feeding Canola Expeller Meal

The nutritional value of canola expeller meal is similar to that of solvent-extracted meal except for its higher energy values due to fat content, and potentially lower effective rumen protein degradability associated with the processing methods. Like solvent extracted canola meal, canola expeller meal is a suitable ingredient for cattle feeding. Table 6 compares the effects on milk production of feeding canola meal, canola expeller meal or heated canola expeller meal in research that was conducted at the University of Saskatchewan, and more recently at Pennsylvania State University. Results indicate that the inclusion of canola expeller meal in diets for lactating dairy cows results in similar levels of milk production (Beaulieu, et al., 1990 and Hristov, et al., 2011), or an additional 0.9 to 2.3 kg/d of milk

(Jones, et al., 2001), when compared to feeding solvent-extracted canola meal.

Expeller meal has also been favorably compared to other vegetable proteins, and can improve the fatty acid profile of milk. Johansson and Nadeau (2006) examined the effects of replacing a commercial protein supplement with canola expeller meal in organic diets, and observed an increase in milk production from 35.4 kg/d to 38.4 kg/d. In this study and others, the feeding of canola expeller meal tended to reduce the saturated fat content of the milk and increase the level of oleic acid (C18:1). A reduction in the palmitic acid content (C16:0) from 30.3%–21.9% of the fat, and an increase in oleic acid from 15.7%–20.9%, was observed. Similarly, Jones, et al. (2001) observed a shift in fatty acid profile when canola expeller meal was fed. Hristov, et al. (2011) replaced conventional meal with canola expeller meal in diets for lactating dairy cows. The expeller meal decreased saturated fatty acids and increased the oleic acid content of milk fat. This would suggest the fat remaining in the expeller meal is somewhat resistant to the degradation in the rumen, and therefore a portion is absorbed directly from the small intestine.

Feeding Canola Seed and Canola Oil

In the past, there has been interest in feeding rumen-protected canola oil and canola seed. Research has shown that these products can be used in the creation of designer meat and milk. A study by Chicholowski, et al. (2005) demonstrated the benefits of feeding ground canola seed as compared to canola expeller-meal to ruminants. Supplementation with

ground canola seed resulted in a reduced omega 6 to omega 3 ratio and a higher proportion of conjugated linoleic acid (CLA) and *trans* vaccenic acid (precursor to CLA) in the milk, suggesting a healthier product can be produced in this manner, while having no impact on milk production.

Johnson, et al. (2002) also observed increased CLA and oleic acid in the milk when the diets were supplemented with whole canola and cottonseed. Bayourthe, et al. (2000) observed significant reductions in saturated fat in the milk when dairy cows were fed whole, ground or extruded canola seed. They also observed similar reductions in saturated fatty acid content of milk when calcium salts of canola fatty acids were added to the diet. With the exception of whole canola seed, supplementation with high-fat canola products also improved milk production, indicating that adding processed canola seed or protected canola oil is an effective method of altering the fatty acid profile of milk products.

As well, oil from canola has been shown to improve the fatty acid profile of fat in meat animals. Rule, et al. (1994) demonstrated that full-fat canola increased the monounsaturated and omega 3 fatty acid content of beef subcutaneous fat and muscle fat. He, et al. (2013) similarly demonstrated an improved fatty acid profile in beef in association with the lipid fraction of the meal. The incorporation of canola oil into the diet of growing goats increased muscle omega 3 fatty acid, reduced organ fat and improved oxidative stability of the meat relative to palm fat (Karami, et al., 2013).

Canola oil is high in unsaturated fatty acids. Unsaturated fatty acids have been implicated in milk fat depression through the production of *trans* fatty acid intermediates in the rumen. The likelihood of the rumen forming these intermediates depends on the fatty acid as well as the level of fat contribution from all ingredients. He and Armentano (2011) showed that feeding oleic acid and linolenic acid produced less milk fat depression than the same amount of fat from linoleic acid. Canola oil is high in unsaturated fatty

Table 6. Milk production of dairy cows fed canola meal, canola expeller meal or heated canola expeller meal

REFERENCE	PARITY	SAMPLING PERIOD	TREATMENT	MILK YIELD[1], KG
Beaulieu, et al., 1990	Multiparous and Primiparous	Unknown	Canola meal	28.0
			Canola expeller	28.0
Jones, et al., 2001	Multiparous	70 ± 17 DIM at beginning of trial	Canola meal	28.6
			Canola expeller	30.9
			Heated canola expeller	30.0
Jones, et al., 2001	Primiparous	73 ± 17 DIM at beginning of trial	Canola meal	23.6
			Canola expeller	24.0
			Heated canola expeller meal	25.2
Hristov, et al., 2011	Multiparous	Early lactation	Canola meal	41.7
			Canola expeller meal	39.7

[1]3.5%fat corrected milk

acids (93%) but rich in oleic acid. The crude oil may also contain higher levels of free fatty acids than refined oil, due to the removal of these phospholipids during the oil refining process. After the oil is refined, the residual gums and soapstocks are added back to the meal. He, et al. (2012) demonstrated that mixtures of free fatty acids that contained higher concentrations of linoleic acid were more likely to contribute to milk fat depression than mixtures rich in oleic acid. Recent research (Boerman and Lock, 2014) showed that the rate and extent of formation of *trans* fatty acid intermediates were similar with free fatty acids and triglycerides of the same composition.

Influence of Canola Meal on Milk Production in Dairy Cattle

Most of the research related to the feeding value of canola meal for ruminants has involved dairy cattle. Canola meal is an excellent protein supplement for lactating dairy cows, and has been the subject of three recent meta-analyses.
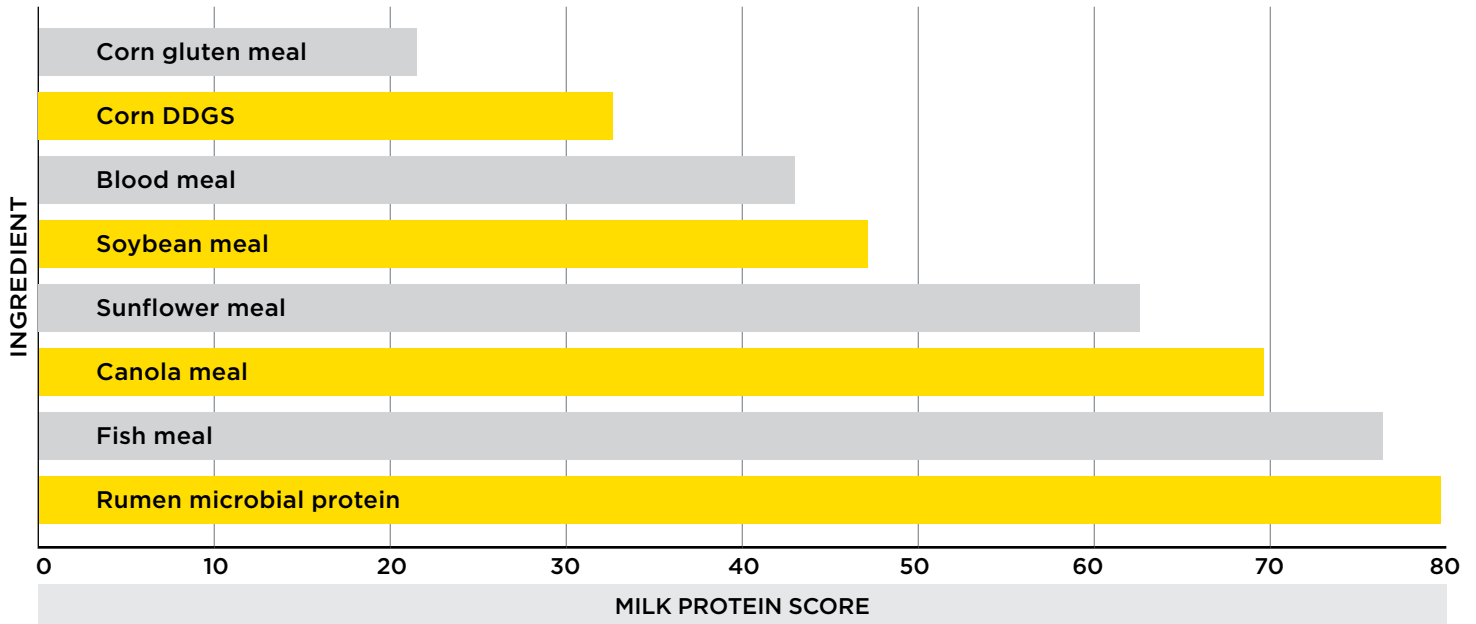
Huhtanen, et al. (2011) compared canola meal to soybean meal. Their data set consisted of 292 treatment results that had been published in 122 studies. The data set was restricted to include only studies in which increasing protein in the ration was accomplished by adding canola meal as compared to soybean meal. For each additional kilogram of protein supplied in the diet, milk production increased by 3.4 kg with canola meal, and 2.4 kg with soybean meal, showing a 1 kg advantage to canola meal.

Martineau, et al. (2013) used a somewhat different approach. These researchers looked at the effects of replacing protein in the diet from alternative meals with the same amount of protein from canola meal. There were 49 different peer-reviewed trials included in the data set that they used. The average level of canola meal tested was 2.3 kg, with the feeding level from 1 to 4 kg in the various studies. At the average level of inclusion, canola meal increased milk yield by 1.4 kg when all the proteins compared were considered, but only by 0.7 kg when canola meal was substituted for soybean meal. Milk protein yield followed the same pattern.

The same group of researchers (Martineau, et al., 2014) then conducted an additional meta-analysis study to compare canola with other proteins with respect to concentrations of plasma amino acids. The responses to canola in these studies proved that the meal increased plasma concentrations of total amino acids, total essential and all individual essential amino acids. Furthermore, blood and milk urea–nitrogen levels were reduced. This meta-analysis strongly suggests that CM feeding increased the absorption of essential amino acids, which was responsible for the increased milk protein secretion and the increased protein efficiency.

A measure of protein quality for dairy cattle is "milk protein score," which relates the amino acid composition of protein sources compared to the amino acid composition of milk protein. The milk protein score of common ingredients — as calculated by Schingoethe (1991) for corn-, corn silage– and alfalfa-based diets — is shown in Figure 1. Canola meal has the highest score of all the vegetable protein sources.

Figure 1. Milk protein score of common feed ingredients for dairy cattle (Schingoethe, 1991)

Level of Feeding

There appears to be no practical restrictions to the amount of canola meal that can be included in diets for lactating dairy cows. For example, Swanepoel (Swanepoel, et al., 2014) provided dairy cows producing more than 44 kg of milk with diets that contained 20% canola meal, and found that intakes remained high. Also, Brito, et al. (2007) replaced 12% soybean meal and 4.5% corn meal with 16.5% canola meal in diets for high-producing cows. Dry matter intake increased by 0.3 kg, while milk yield increased by 1.1 kg.

Using Canola Meal in Combination with Distillers Dried Grains

The recent surge in production of ethanol has resulted in large quantities of distillers' dried grains with solubles (DDGS) becoming widely available to the feed industry. The amino acid composition of corn DDGS is poor, which can make using the product difficult. However, studies have shown that canola meal can be effectively used in combination with DDGS to restore amino acid balance and maximise animal performance (Mulrooney, et al., 2009; Swanepoel, et al., 2014), Table 7. Blends of canola meal and wheat DDGS have also been demonstrated to support high levels of milk production (Chibisa, et al., 2012, 2013).

Table 7. Comparisons of canola meal and corn DDGS as protein sources for dairy cows

	% OF ADDED PROTEIN SOURCE			
Canola meal	100	66	34	0
DDGS	0	34	66	100
	MILK YIELD, KG/DAY			
Mulrooney, et al., 2009[1]	35.2	35.8	34.5	34.3
Swanepoel, et al., 2014[2]	47.3	47.9	47.1	44.9

[1]Highest level of canola meal was 6.7% of the diet dry matter.
[2]Highest level of canola meal was 20.0% of the diet dry matter.

Studies have been conducted in Saskatchewan comparing canola meal with wheat DDGS alone (Mutsvangwa, 2014a, 2014b). Rumen fermentation, abomasal flow of protein and dairy cow performances were similar for the two products.

Chinese Feeding Trials

The dairy industry in China has been steadily growing, and with it, the need for reliable protein ingredients. In recognition of this need, the Canola Council of Canada supported several feeding demonstration trials in China in 2011. All of the studies involved well-managed herds, and milk production averaged 35 L in all but one study, in which production was 25 L, levels very similar to those found in North American studies.

Results from the demonstration trials are provided in Table 8. Even at fairly low inclusion rates, when canola meal replaced high-priced protein ingredients, milk production was maintained or increased.

Using Canola Meal in Beef Cattle Rations

Canola meal has been demonstrated as an acceptable protein supplement for beef cattle, replacing several other vegetable protein products. This acceptance is based on a number of research trials that demonstrate the value of canola meal for promoting the growth of young calves, as well as growing and finishing cattle.

Li, et al. (2013) supplemented diets for backgrounded heifers with canola meal, wheat DDGS, corn DDGS or high-protein corn DDGS with urea. All protein supplements improved performance and increased dry matter intake. Total tract digestibility was highest with canola meal, and total protein entering the duodenum was highest for the high-protein corn DDGS plus urea. Yang, et al. (2013) found that

Table 8. Trials conducted in which canola meal was substituted for other protein sources[1]

LOCATION	DETAILS	CHANGE IN MILK
Farm 1	352 cows; switchback study; straight substitution of soybean meal by canola meal (1.7 kg/cow/day)	−0.2L
Farm 2	325 cows; switchback study; straight substitution of soybean meal by canola meal (1.0 kg/cow/day)	0.6L
Farm 3	320 cows; switchback study; straight substitution of soybean meal by canola meal (0.7 kg/cow/day)	0.3L
Farm 4	1,700 cows; equalized for production and fed for 80 days; straight substitution of soybean meal by canola meal (2.4 kg/cow/day)	1.0L
Farm 5	330 cows; equalized for production; straight substitution of soybean meal and cottonseed meal by canola meal (1.7 kg/cow/day)	1.2 L

[1]There were no differences in milk composition in any of the trials (Wang, 2013).

supplementation with canola meal improved intake and weight gain in backgrounded steers. Steers given canola meal had numerically higher average daily gains than those given corn DDGS, and statistically higher gains than steers that received wheat DDGS.

Petit and Veira (1994) determined that supplementing grass silage with canola meal increased weight gains in growing beef steers. The same group of researchers fed supplemental canola meal to finishing steer calves, and noted increased daily gain and fewer days on feed.

He, et al. (2013) fed finishing cattle diets that contained 15 and 30% canola meal in place of barley grain. Both expeller and solvent-extracted meals were evaluated at both levels of inclusion. There were no differences in average daily gain. Diets with the highest level of canola meal increased dry matter intake and reduced feed efficiency relative to the lower level and the barley control. While it's unusual to feed such high levels of canola meal, the study showed that the cattle had no aversion to it.

Canola meal has been used to supplement protein in gestating and lactating beef cows. Patterson, et al. (1999a, 1999b) evaluated beans, sunflower meal or canola meal as a protein supplement for beef cows grazing poor-quality pasture. Results for calf birth weight, calf weaning weight and cow body condition changes were similar for all meals. Weight loss during gestation was lowest with canola meal. A study conducted by Auldist, et al. (2014) revealed that grazing beef cows produced more milk when canola meal was partially substituted for wheat in the feed supplement.

Using Canola Meal in Rations for Calves

Canola meal can be given to growing dairy and beef calves without restriction. Anderson and Schoonmaker (2004) compared canola meal to pulses (field peas,

chickpeas and lentils) as proteins for post-weaning beef calves. Diets contained 16% crude protein. The calves given the canola meal diet gained slightly less (1.67 as compared to 1.89 kg/day), but had better feed/gain ratios (4.1 vs. 3.8) with the diet containing 9.4% canola meal. In a recent dairy calf study, Terré and Bach (2014) evaluated intakes of 18% crude protein starter diets and growth rates of calves given diets in which the primary protein source was either canola meal or soybean meal. Intakes and rates of gain were similar for the two diets. The researchers concluded that flavouring agents were not required for calves given diets with canola meal.

Unlike canola meal, soybean meal contains high concentrations of phytoestrogens. Gordon, et al. (2012) provided diets containing either soybean meal or canola meal to dairy heifers from 8 to 24 weeks of age. Heifers were then placed on a common diet until 60 weeks of age, at which time they were bred. Pregnancy rates were 66.7% for the heifers given canola meal during prepubertal development, but only 41.7% for the heifers that had received soybean meal. In a Canadian study, Miller-Cushon, et al. (2014) found that preweaning calves offered low-protein starter pellets and either canola meal or soybean meal pellets chose to consume more soybean pellets than canola meal pellets. This points to needed research to assess comparative intakes of calf starter with all ingredients mixed in the diet.

Using Canola Meal for Small Ruminants

Canola meal is an ideal supplement for the production of wool and mohair, due to the high-sulphur amino acid requirement of these animals (Reis, et al., 1990). In addition, canola meal has been shown to support weight gain in these meat animals. Lupins have traditionally been the vegetable protein of choice for

lambs in Australia, but Wiese (2004) determined that canola meal is superior to lupins in supporting weight gain (272 vs. 233 grams/day) and feed efficiency. More recently, Malau-Aduli, et al. (2009) also found that canola meal was superior to lupins for weight gain in lambs. In a Canadian study (Agbossamey, et al., 1998), canola meal was superior to fish meal in diets for growing lambs.

Canola meal supports growth in small ruminants as well. Mandiki, et al. (1999) fed lambs diets containing up to 30% canola-quality rapeseed meal (6.3 µmols/g of glucosinolates in the concentrate). There were no effects on weight gain or feed intake, despite the fact that thyroid weight was marginally higher and thyroid hormone production was marginally lower at the higher dietary inclusion levels of rapeseed meal.

The processing temperature of canola meal may be important in feeding sheep and possibly other small ruminants. Konishi, et al. (1999) demonstrated that excessive heat processing of canola meal suppressed phytate degradation in the rumen and led to lower availability of dietary phosphorus. The extent to which phytate degradation decreased was greater in canola meal than in soybean meal. Petit, et al. (1997) observed a somewhat different effect of heat treatment. They compared dietary nutrient degradability of raw and extruded whole soybeans and canola seed in the rumen of growing lambs. They found that extrusion of canola seed increased dry matter and nitrogen degradability but decreased soybean nitrogen degradability.

THE VALUE OF CANOLA MEAL IN SWINE DIETS

The breeding of canola from rapeseed has made canola meal a conventional feedstuff for swine, especially for grower-finisher pigs, and more recently in weaned pigs. Canola meal is well accepted by swine, and with proper diet formulation can be included at increasingly high levels in the diet during all phases of growth.

The adoption of more accurate feed quality evaluation systems for energy and amino acids in North America offsets any unexpected performance reduction associated with canola meal that may have been observed in the past due to constraints in nutrient digestibility. Specifically, amino acids should be characterized as standardized or true ileal digestible amino acids (Stein, et al., 2007). Furthermore, the net energy (NE) system characterizes more accurately the energy value of canola meal relative to other feedstuffs. Implementation of the NE system is critical for effective use of coproducts such as canola meal in swine diets (Zijlstra and Beltranena, 2013b), although canola meal has been introduced successfully in swine diets using the digestible energy (DE) and metabolisable energy (ME) systems for valuation of dietary energy. Restrictions for inclusion levels of canola meal may remain in practice, but are being continually disproven and challenged by researchers in recent years. This new information will allow for canola meal to reach its potential in least-cost feed formulation.

Current data clearly show that diets containing canola meal, when properly formulated, will support high levels of efficient growth performance. The nutritional value of canola meal for swine is being understood increasingly well, and the major limitation for value and inclusion is the available energy content, especially when measured as net energy. Improper feed quality evaluation information for digestible nutrients in canola meal has resulted in some problems with poorer pig performance in the past. Ultimately, the relationship between ingredient cost and nutrient content will determine the appropriate level of inclusion of canola meal in well-formulated diets.

Feed Intake

The effect of a feed ingredient on feed intake of pigs is difficult to objectively evaluate, given the many factors involved (Nyachoti, et al., 2004). Variables such as basic palatability of the ingredient, dietary inclusion level, other ingredients in the feed mix, feed energy and fibre content (bulk density), and feed mineral balance will influence feed intake. For canola meal, several factors with the potential to reduce feed intake exist, such as glucosinolates, tannins, sinapine, fibre and mineral balance, which are explained in more detail in the "Canola Meal Nutrient Composition" chapter of this guide. Certainly, glucosinolates represent a major negative influence on feed intake in pigs. Aside from their anti-nutritive effects, glucosinolates have a bitter taste to many animals. Canola meal produced in Canada, with its very low levels of glucosinolates (4.2 µmol/g), has a very neutral taste. Other causes than glucosinolates likely play a role in situations in which reduced feed intake of canola meal diets is observed.

Landero, et al. (2012) conducted feed preference trials with weaned pigs given the choice of either soybean meal or canola meal. A strong preference was observed for soybean meal, which agrees with previous literature; however, when no choice was given, canola meal could be included at up to 20% in the diet without impacting feed intake or growth performance. Additionally, Sanjayan, et al. (2014) successfully fed increasing levels of canola meal with excellent performance results.

Energy

Canola meal is often considered a poor source of energy for swine diets, due to the high amount of fibre and a complex carbohydrate matrix with limited digestibility. Diet formulation based on net energy (NE) allows for the proper inclusion of canola meal in swine

diets so as to not impact performance. Energy values published by the National Research Council (NRC, 2012) are given in Table 1 and are based on

Table 1. Available energy values of canola meal (12% moisture basis) for swine[1]

DE (kcal/kg)	3,154
ME (kcal/kg)	2,903
NE (kcal/kg)	1,821

[1]NRC, 2012

historical information. Recently, Maison, et al. (2015) determined DE values of 3,378 Mcal/kg of dry matter and 3,127 Mcal/kg of dry matter for ME.

Amino Acid Digestibility

A key to using high levels of canola meal in swine diets is to balance the diets correctly for digestible amino acids. The digestibility of key amino acids in canola meal is lower than in soybean meal. As a result, when canola meal replaces soybean meal in the diet, the overall levels of digestible amino acids, especially lysine and threonine, will decrease if the diet is balanced to total amino acid levels only. Diets in earlier feeding trials with canola meal were balanced to the same levels of crude protein, total essential amino acids and energy. However, a lower growth rate compared to soybean meal–fed pigs was observed (Baidoo, et al., 1987; Bell, et al., 1988; Bell, et al., 1991; McIntosh, et al., 1986), because levels of digestible lysine decreased as canola meal inclusion level in the diets increased.

Presently, swine diets are routinely formulated to levels of digestible amino acids rather than total amino acids. Recent feeding trials with canola meal in starter, grower and finisher pigs, in which the diets were balanced to the same levels of digestible lysine (Hickling, 1994; Hickling, 1996; King, et al., 2001; Mateo, et al., 1998; Mullan, et al., 2000; Patience, et al., 1996; Raj, et al., 2000; Robertson, et al., 2000; Roth-Maier, 2004; Siljander-Rasi, et al., 1996; Sanjayan, et al., 2014; Landero, et al., 2012; Landero, et al., 2011b; Smit, et al., 2014a; and Smit, et al., 2014b), resulted in
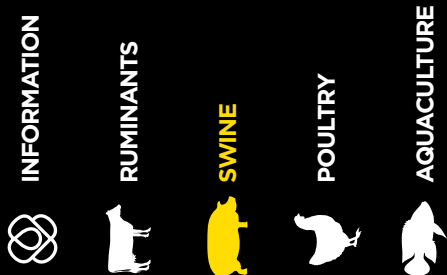
a growth rate equivalent to what is typically found with soybean meal as the primary protein source, even at very high inclusion levels of canola meal.

Furthermore, experiments showed that amino acids in swine diets should be formulated on the basis of true, or standardized, amino acid digestibility (Nyachoti, et al., 1997). Standardized ileal digestibility (SID) of amino acids is now the preferred unit of measurement for swine (Stein, et al., 2007). Using SID reliably corrects for basal endogenous losses related to the animal's digestive process, as well as indigestibility related to the

Table 2. Standardized ileal digestibility (SID) of amino acids in canola meal fed to growing pigs

AMINO ACID	SID % OF DM
Alanine	80.3
Arginine	90.7
Aspartate + asparagine	78.6
Cystine	81.8
Glutamate + glutamine	89.5
Glycine	77.7
Histidine	87.2
Isoleucine	81.2
Leucine	81.4
Lysine	80.3
Methionine	85.4
Phenylalanine	73.8
Proline	84.6
Serine	83.4
Threonine	77.9
Tyrosine	78.4
Valine	78.3

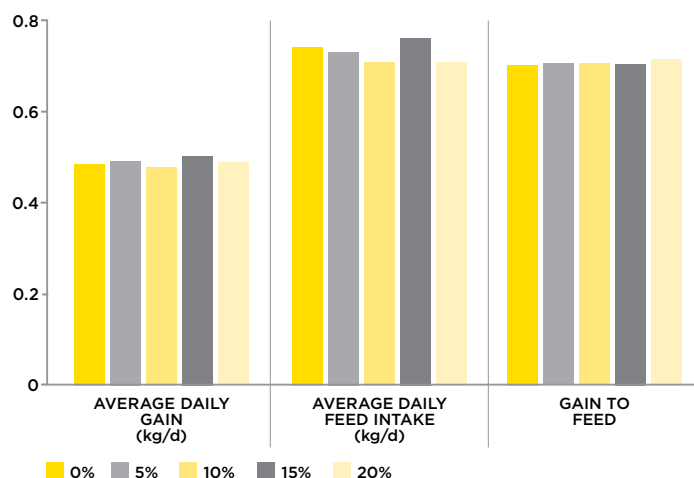Trindade Neto, et al.; 2012, Sanjayan, et al., 2010

feed ingredient. Table 2 on the previous page provides results from a recent study conducted to determine the standardized ileal digestibility of amino acids.

Enzymes

Enzyme addition is an avenue to increase the available energy in diets that include canola meal. Multi-carbohydrase enzymes have been developed and used as a means to extract energy from the cell wall of non-starch polysaccharides. Sanjayan, et al. (2014) included multi-carbohydrase enzymes in the diets of weaned pigs fed increasing inclusions of canola meal. Growth performance was not improved, but enzyme addition did increase apparent total tract digestibility (ATTD) of crude protein at 20% and 25% canola meal inclusion in the experimental diets.

As with many oilseed meals, much of the phosphorus in canola meal is bound by phytic acid. Phytic acid reduces the availability of the phosphorus to 25–30%

Figure 1. Performance results for canola meal inclusion up to 20% in the diets of weaned pigs, formulated for NE and SID AA values[1,2]

0% | 5% | 10% | 15% | 20%

[1]Landero, et al, 2011b

[2]At the time of this study, the inclusion of canola meal at 20% reduced feed price by $11.90 per MT and feed cost per unit of body weight gain by 2 cents/kg (Zijlstra, 2015. Personal communication).

of the total (NRC, 2012). It is common practice to add phytase enzyme to diets for pigs and poultry to improve the availability of phosphorus. Akinmusire and Adeola (2009) determined that the digestibility of phosphorus in canola meal increased from 31–62% when phytase was included in the diet. One study (González-Vega, et al., 2013) also demonstrated that the addition of phytase enzyme increased the availability of calcium in canola meal from 47 to 70%, while increasing phosphorus availability to 63%.

Glucosinolate Tolerance

Glucosinolates are a main anti-nutritional factor found in canola meal for swine. In the initial years of feeding canola meal, the maximum level of glucosinolates that pigs can tolerate in the diet was defined by several researchers. In a review of earlier research on canola meal, a maximum level in pig diets of 2.5 µmol/g of glucosinolates was suggested (Bell, 1993). Two subsequent studies generally supported this recommendation (Schöne, et al., 1997a, 1997b). In the first study, growing pigs weighing approximately 20–50 kg were fed a variety of diets containing the same levels of canola meal, but varying in total glucosinolate content from 0–19 µmol/g (Schöne, et al., 1997a). A greater level than 2.4 µmol/g of glucosinolates in the diet had negative effects on feed intake, growth rate and thyroid function. In the second study, the maximum safe glucosinolate level was determined at 2.0 µmol/g of diet (Schöne, et al., 1997b). Given that Canadian canola meal contains, on average, 4.2 µmol/g of glucosinolates, this would correspond to a maximum canola meal inclusion level of 47% in growing pig diets, a value greater than necessary for commercial formulation to meet amino acid requirements for a cereal-based diet. Recent studies have demonstrated that grower-finisher pigs will perform well on diets containing up to 30% canola

meal (Smit, et al., 2014a), reaching a calculated glucosinolate content of 1.3 µmol/g of diet. The maximum tolerable level of glucosinolates in swine diets remains of interest, and breeding efforts in canola have focused on further reduction of glucosinolates in canola seed. Current levels of glucosinolates are demonstrating few to no limitations for canola meal inclusion in grower-finisher diets.

Starting Pigs (6–20 kg)

Up until recently, the most current available literature demonstrated reduced performance in young pigs fed canola meal at levels greater than 5% (Bourdon and Aumaître, 1990; Lee and Hill, 1983). However, new research has brought to light a very different story on canola meal inclusion in weaned pigs. Landero, et al. (2011) demonstrated that canola meal can be fed to weaned pigs, with an initial body weight of 8.1 kg, at levels up to 200 g/kg without negatively impacting performance. This was demonstrated again in 2014 by Sanjayan, et al., where canola meal was included at 25% of the diet in weaned pigs (initial body weight of 7.26 kg), with highly acceptable performance results after the first week of the trial. The main difference about these two studies, compared to the earlier work, is that both research groups formulated diets based on NE and SID amino acids.

Growing and Finishing Pigs (20–100 kg)

In the growing and finishing phases of pig growth, canola meal can be used at high dietary levels and will support excellent pig performance. An array of studies have shown that when diets are balanced for net energy and SID amino acid levels, performance is the same as with soybean meal with dietary inclusion levels of canola meal up to 25% (Brand, et al., 2001; Hickling, 1994; Hickling, 1996; King, et al., 2001; Mateo, et al., 1998; Patience, et al., 1996; Raj, et al., 2000;

Robertson, et al., 2000; Roth-Maier, 2004; and Siljander-Rasi, et al., 1996). Results from two of these studies are presented in detail in Tables 3a and 3b.

The Canola Council of Canada sponsored a series of feeding trials with growing and finishing pigs in Canada, Mexico and the Philippines to demonstrate that balancing the diets to digestible amino acids will improve pig performance results. Smit, et al. (2014b) fed grower-finisher pigs, initial weight of 29.9 kg, five phase diets containing varying levels of canola meal up to 240 g/kg, while also including 150 g/kg of dried distillers grains with solubles in all diets. Pigs fed 240 g/kg versus those fed 60 g/kg reached market weight three days later, but had no difference in carcass traits. Smit, et al. (2014a) then fed grower-finisher pigs canola meal at up to 300 g/kg. There was a slight reduction in performance and carcass traits between pigs fed 200 g/kg and those fed 300 g/kg, although feed efficiency was improved.

Canadian Feeding Trials

Three feeding trials were conducted in Western Canada — one each in Manitoba, Saskatchewan and Alberta. The trials were conducted at different times of the year and with pigs from different genetic backgrounds. The overall diet compositions were similar among the three locations. The diets were balanced to digestible lysine and threonine minimums, which were considered to be the first and second limiting amino acids. (The diets were balanced to ideal protein amino acid composition.) Supplemental lysine HCl was used to meet digestible lysine minimums. The digestible threonine minimums were met with plant-based feedstuffs in the diet by increasing the level of crude protein in the canola meal treatment diets. The diets were isocaloric, achieved by increasing the amount of wheat relative to barley in the canola meal

Table 3a. Canadian feed trial results: Average performance of growing pigs (20–60 kg) and finishing pigs (60–100 kg) fed diets supplemented with soybean meal (SBM) and canola meal (CM)[1]

INGREDIENTS	GROWER			FINISHER		
	SBM	MEDIUM CM	HIGH CM	SBM	MEDIUM CM	HIGH CM
Barley	62	53	48	60	48	40
Wheat	13	20	24	19	29	35
Soybean meal	20	16	13	16	10	5
Canola meal	—	6	10	—	8	15
Canola oil	1	1	1	1	1	1
L-lysine	0.04	0.07	0.10	0.06	0.12	0.15
Other	4	4	4	4	4	4
Nutrients						
Crude protein (%)	17.6	17.8	17.9	16.4	16.5	16.6
DE (kcal/kg)	3,200	3,200	3,200	3,200	3,200	3,200
Total lysine (%)	0.94	0.94	0.95	0.81	0.82	0.83
Digest. lysine (%)	0.75	0.75	0.75	0.65	0.65	0.65
Total met + cys (%)	0.61	0.64	0.66	0.54	0.59	0.63
Digest. met + cys (%)	0.49	0.52	0.54	0.43	0.48	0.51
Total thr (%)	0.66	0.66	0.67	0.56	0.58	0.59
Digest. thr (%)	0.47	0.47	0.47	0.40	0.40	0.40
Performance						
Avg daily feed, kg	1.905	1.928	1.887	3.061	3.113	3.083
Avg daily gain, kg	0.456	0.765	0.767	0.841	0.830	0.822
Feed/gain ratio	2.52	2.52	2.46	3.64	3.75	3.75

[1]Hickling, 1994

Table 3b. Canadian feed trial results (continued)

TOTAL PERIOD	SBM	MEDIUM CM	HIGH CM (20–100 KG)
Avg daily feed, kg	2.461	2.498	2.465
Avg daily gain, kg	0.799	0.798	0.795
Feed/Gain ratio	3.08	3.13	3.10
Dressing (%)	78	78	78
Carcass backfat index	107	107	107

treatment diets. The diet composition and combined results of the feed trials are shown in Tables 3a and 3b (Hickling, 1994). Pig performance was equivalent, both numerically and statistically, for all three diets. Contrary to popular belief, there was no decrease in feed intake with increasing canola meal levels in the diet. There was no difference in the quality of the pig carcasses as measured by dressing percentage and backfat index.

Mexican Feeding Trials

Three feeding trials were conducted in three Mexican states — Nuevo León, Sonora and Michoacán (Hickling, 1996). The objective was to duplicate the performance found in the Canadian feeding trials, but using Mexican ingredients (two of the feed trials used sorghum as the grain base in the diet and one trial used corn) and Mexican conditions (environment, pig genetics and management). Also, the canola meal used in the trials was produced from Canadian canola seed by Mexican oilseed processors. The design was very similar to the Canadian trials. Three dietary treatments were used — a control, a medium canola meal diet and a high canola meal diet. The diets were balanced for minimum digestible amino acids, ideal protein and equal energy levels. The diets and results are shown in Table 4. As with the Canadian results, equivalent growth, feed efficiency and carcass quality performance were observed in all three dietary treatments. Performance between locations varied due mainly to pig genetics and seasonal effects.

Breeding Swine

Canola meal has been readily accepted in diets for sows and gilts, both in gestating and lactating periods. Flipot and Dufour (1977) found no difference in reproductive performance between sows fed diets with or without 10% added canola meal. Lee, et al. (1985) found no significant difference in reproductive performance of gilts through one litter. Studies at the University of Alberta (Lewis, et al., 1978) have shown no difference in reproductive performance of gilts through two reproductive cycles when fed diets containing up to 12% canola meal. Somewhat more recently, levels of 20% canola meal did not affect performance of lactating sows (King, et al., 2001). The results suggest that canola meal may represent the main supplemental protein source in gilt and sow

diets for all phases of reproduction. Canola meal may be restricted in sow diets that are formulated to maximum fibre levels in order to limit hind gut fermentation. For the most part, however, producers are now accepting canola meal as an appropriate alternative supplemental dietary protein source for sows. Still, there is some unfounded concern over daily feed intake of nursing sows fed canola meal–based diets. These concerns are not supported by research.

Brown and Setchall (2001) noted that soybean meal contains high levels of phytoestrogens, and that researchers need to be vigilant of their biological effects. Csaky and Fekete (2004) found that levels of soybean phytoestrogens can be highly variable in meal depending on season, source and variety. These researchers noted that these compounds have been demonstrated to interfere with reproductive performance in both males and females. More studies are needed in pigs to determine if alternative proteins such as canola meal might improve reproductive performance.

Feeding Canola Expeller Meal

Canola expeller meal is an excellent source of energy and protein in swine rations. Bran, et al. (2001) studied the effects of adding canola expeller cake to the grower-finisher rations. The diets were composed of as much as 29.2% expeller meal, and no effects on feed intake, feed conversion or live weight gain were found, indicating that the meal is an effective ingredient. In 2012, Landero, et al. fed increasing levels of expeller-pressed canola meal to young pigs one week post weaning, and determined that when diets were formulated to equal NE and SID values, expeller meal can replace soybean meal at a level of 200 g/kg. As is the case with other species, it is important to have the fat content of the meal analysed prior to formulation and the energy content assigned accordingly.

Table 4. Mexican feeding trial results: Average performance of growing pigs (20–60 kg) and finishing pigs (60–100 kg) fed diets supplemented with soybean meal (SBM) and canola meal (CM)[1]

INGREDIENTS	GROWER						FINISHER					
	SBM		MEDIUM CM		HIGH CM		SBM		MEDIUM CM		HIGH CM	
Sorghum	72	—	68	—	667	—	76	—	72	—	70	—
Corn	—	72	—	67	—	66	—	76	—	72	—	70
Soybean meal	24	24	19	20	16	17	20	19	13	12	10	9
Canola meal	—	—	8	8	12	12	—	—	10	10	15	15
Tallow	—	—	1	1	2	1	—	—	1	1	2	1
L—lysine	—	—	0.33	—	0.47	—	—	—	0.50	0.50	0.70	0.70
Other	4	4	4	4	4	4	4	5	4	5	3	5

Nutrients

	GROWER SBM	GROWER MEDIUM CM	GROWER HIGH CM	FINISHER SBM	FINISHER MEDIUM CM	FINISHER HIGH CM
Crude protein (%)	17.6	17.7	17.9	16.0	16.2	16.4
DE (kcal/kg)	3,150	3,150	3,150	3,160	3,160	3,160
Total lysine (%)	0.92	0.93	0.94	0.81	0.82	0.83
Digest. lysine (%)	0.75	0.75	0.75	0.65	0.65	0.65
Total met + cys (%)	0.58	0.63	0.65	0.55	0.58	0.61
Digest. met + cys (%)	0.45	0.47	0.49	0.41	0.44	0.46
Total thr (%)	0.71	0.71	0.72	0.63	0.63	0.64
Digest. thr (%)	0.53	0.53	0.53	0.47	0.47	0.47

Performance

	GROWER SBM	GROWER MEDIUM CM	GROWER HIGH CM	FINISHER SBM	FINISHER MEDIUM CM	FINISHER HIGH CM
Avg daily feed, kg	2.17	2.23	2.18	3.22	3.21	3.12
Avg daily gain, kg	0.778	0.773	0.764	0.851	0.833	0.824
Feed/Gain ratio	2.78	2.87	2.86	3.79	3.85	3.79

TOTAL PERIOD (20–100 KG)	SBM	MEDIUM CM	HIGH CM
Avg daily feed, kg	2.72	2.74	2.67
Avg daily gain, kg	.818	.807	.797
Feed/Gain ratio	3.32	3.39	3.35
Meat yield (%)	48.6	48.8	49.3
Carcass backfat, CM	2.38	2.33	2.15

[1]Hickling, 1996

Fat content of expeller meal varies between and within sources, so the product should be routinely tested and the energy value adjusted accordingly. Woyengo, et al. (2009) determined there was a DE of 4,107 kcal/kg for expeller canola meal, with 12% fat on a dry-matter (DM) basis. The energy content of the meal in kcal/kg can be calculated as DE = 2,464 + (% fat * 63); ME = 2,237 + (% fat * 62); and NE can be calculated using the following equation: 1,800 + (% fat * 70) = kcal/kg. For example, a meal with 10% fat would have an NE of 1,800 + (10 * 70) = 2,500 kcal/kg. Woyengo, et al. (2009) likewise assessed the SID of amino acids in expeller canola meal, and these results are shown in Table 5.

Feeding Canola Seed and Oil

Canola oil is routinely fed to all types of pigs. Crude canola oil is often an economical energy source as well as a dust suppressant in the feed. Canola seed is also fed as a protein and energy source, although it is usually limited to 10% dietary inclusion, since higher levels will result in softer fat in the carcass (Kracht, et al., 1996). Canola seed should be ground before feeding. It can effectively be fed raw, although heat treatment may prove beneficial as long as excessive heat is not used during processing, which will reduce amino acid digestibility. A nutrient analysis should also be conducted on canola seed, as it may be seed that is not suitable for canola processors.

Montoya and Leterme (2010) estimated an NE content of full-fat canola seeds of 3.56 Mcal/kg (DM basis), but noted a possible underestimation due to a demonstrated reduction in feed intake and performance at dietary inclusion levels above 10% for growing pigs.

Table 5. Standardized ileal digestibility of amino acids in expeller-pressed canola meal fed to growing pigs[1]

AMINO ACID	SID % OF DM
Alanine	78.6
Arginine	87.4
Aspartate + asparagine	87.2
Cystine	76.3
Glutamate + glutamine	88.0
Glycine	76.8
Histidine	83.2
Isoleucine	83.2
Leucine	83.0
Lysine	71.9
Methionine	85.7
Phenylalanine	86.2
Proline	83.3
Serine	77.6
Threonine	73.6
Tryptophan	83.9
Tyrosine	86.7
Valine	77.2

[1]Woyengo, et al; (2010, Seneviratne, et al. (2014)

Practical Inclusion Levels of Canola Meal in Swine Diets

The recommended practical inclusion levels for canola meal in pig diets, together with the reasons, are given in Table 6.

Table 6. Recommended practical inclusion levels (%) of canola meal in pig diets

ANIMAL DIET TYPE	INCLUSION LEVEL	REASONS FOR INCLUSION LEVEL
Pig starter	20	High performance results reported at 20% inclusion
Hog grower/finisher	25	High performance results reported at 25% inclusion
Sow lactation	20	No data available beyond 20% inclusion
Sow gestation	—	No data available
Boar breeders	—	No data available

THE VALUE OF CANOLA MEAL IN POULTRY DIETS

Canola meal is fed to all types of poultry throughout the world. It provides an excellent amino acid profile and protein content and is an alternative or complement to other protein ingredients like soybean meal. Canola meal provides greater value in egg layer and turkey diets over broiler feeds due to greater emphasis placed on protein rather than on energy in these diets. However, canola meal can be a cost-effective alternative in high-energy broiler diets. Care must be taken to formulate diets on a digestible amino acid basis to ensure excellent performance with birds fed high canola meal inclusions.

Feed Intake

Various publications have demonstrated that poultry, both broilers and layers, will maintain appropriate feed intake levels when given diets high in canola meal that are formulated for digestible amino acids. Oryschak and Beltranena (2013) demonstrated that proper diet formulation can allow for canola meal to be included at 20% of the diet with no effect on feed intake. Rogiewicz, et al. (2015) also demonstrated excellent performance of hens fed 15–20% canola meal. Feed intake was maintained for broilers fed up to 20% canola meal from days 1 to 35 of life (Naseem, et al., 2006), and broiler growers can be fed 30% canola meal (Newkirk and Classen, 2002; Ramesh, et al., 2006).

Energy

Canola meal does have a lower energy value for poultry compared with the most common vegetable protein source, soybean meal. In certain diets, broilers specifically, the greater emphasis placed on the value of energy would limit the inclusion of canola meal. Egg layer diets and early-phase, high-protein turkey diets based on least-cost formulation include canola meal in the ration at a higher price. Recent research shown in Table 1 suggests that the energy value of canola meal for broilers in the grower/finisher stage is 200 kcal greater than previously published (Beltranena, 2015).

Table 1. Available energy values for canola meal (12% moisture basis)

ANIMAL		AVERAGE VALUE
Broiler chickens	AMEn (kcal/kg)	2,200[1]
Laying hens	AMEn (kcal/kg)	2,200[1]
Turkeys	AMEn (kcal/kg)	2,007[2]

[1]Beltranena, 2015
[2]Jia, et al., 2012

Several researchers have fed dietary enzymes in an attempt to increase protein, phosphorus and carbohydrate digestibility in canola meal (Kocher, et al., 2000; Mandal, et al., 2005; Meng, et al., 2005; Meng and Slominski, 2005; Meng, et al., 2006; Ravindran, et al., 1999; Ramesh, et al., 2006; Simbaya, et al., 1996; Slominski and Campbell, 1990). Most studies examining the inclusion of cellulase or non-starch polysaccharides (NSP) degrading enzymes to improve canola meal digestibility have only demonstrated limited benefits. Meng and Slominski (2005) examined the effects of adding a multi-enzyme complex (xylanase, glucanase, pectinase, cellulase, mannanase and galactonase) to broiler diets. The enzyme combination increased total tract NSP digestibility of canola meal, but no improvements were observed in other nutrient digestibilities or animal performance. Jia, et al. (2012) fed broiler diets containing canola meal and a multi-carbohydrase enzyme to determine their effect on AMEn values (Table 1). The inclusion of feed enzyme with canola meal increased its AMEn value from 1,904 to 2,018 kcal/kg for broilers. The low AMEn values reported in this literature may be in part due to the feeding of canola meal containing only 1.8% fat (dry-matter basis). Practically, the use of dietary enzymes is common in poultry feeds, especially those containing barley and wheat; although the data is not completely conclusive, some enhancement of canola meal digestion may occur.

Amino Acid Availability

A key to feeding high-inclusion levels of canola meal to poultry is to balance the diets on an available amino acid basis. Apparent ileal digestibility coefficients for amino acids are presented in Table 2.

Table 2. Apparent ileal digestibility coefficients of amino acids in canola meal fed to poultry

AMINO ACID	BROILERS[1]	LAYERS[1]	TURKEYS[2]	DUCK[2]
Alanine	0.79	0.79	0.75	0.66
Arginine	0.88	0.89	0.79	0.71
Aspartate + asparagine	0.76	0.76	0.72	0.60
Cystine	—	—	0.67	0.67
Glutamate + glutamine	0.87	0.87	0.86	0.81
Glycine	0.77	0.76	0.72	0.59
Histidine	0.81	0.81	—	—
Isoleucine	0.77	0.76	0.75	0.65
Leucine	0.81	0.79	0.79	0.73
Lysine	0.79	0.82	0.76	0.66
Methionine	0.92	0.93	0.86	0.80
Phenylalanine	0.80	0.79	0.75	0.73
Serine	0.74	0.72	0.74	0.70
Threonine	0.71	0.70	0.73	0.64
Tyrosine	0.79	0.78	—	—
Valine	0.77	0.75	0.72	0.62

[1]Huang, et al., 2006
[2]Kluth and Rodehutscord, 2006

Layers

Canola meal is a commonly fed and economically effective feed ingredient in commercial egg layer diets. Various studies have looked at the effects of feeding canola meal on egg production and associated parameters (Perez-Maldonado and Barram, 2004; Kaminska, 2003; Badshah, et al., 2001; Kiiskinen, 1989; Nasser, et al., 1985; Robblee, et al., 1986). Feeding canola meal supports high levels of egg production and has no negative effect on number of eggs produced. Feed intake and egg size also show no difference when canola meal is fed. A negative effect on egg size was noted in some earlier studies (Summers, et al., 1988a, b), but in more recent experiments, this has not been the case (Perez-Maldonado and Barram, 2004; Marcu, et al., 2005; Badshah, et al., 2001; Classen, 2008).
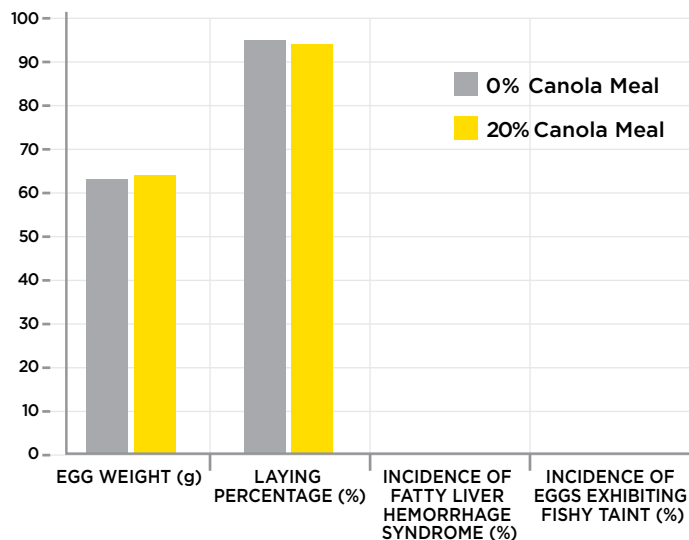
As with swine diet formulation, ileal digestible amino acids must be considered. Oryschak and Beltranena (2013) demonstrated that proper diet formulation can allow for canola meal to be included at 20% of the diet with no negative effects on egg production, egg quality or egg fatty acid content (Figure 1). Rogiewicz, et al. (2015) also demonstrated excellent performance of hens fed 15–20% canola meal. Previous published research showed a reduction in egg weight when canola meal was substituted for soybean meal, but diet formulation on a crude protein basis resulted in

insufficient lysine content in the canola meal diet (Kaminska, 2003). Work by Novak, et al. (2004) supported the hypothesis that insufficient lysine can affect egg weight. They increased lysine intake from 860 mg/d to 959 mg/d and observed an increase in egg weight from 59 g to 60.2 g, but the added lysine had no effect on egg production rate. Figure 1 shows the results of a recent study conducted at the University of Alberta, in conjunction with Alberta Agriculture and Rural Development, indicating excellent performance while maintaining egg weight throughout the 36 weeks of the study. Based on these recent findings, canola meal can be fed effectively at elevated levels in laying diets without negatively affecting egg production, egg weight, egg quality or fatty acid content as long as the diets are formulated on digestible amino acid content.

Traditionally, including canola meal in laying-hen diets was limited to a maximum of 10%, due to a potential

Figure 1.Performance results from feeding canola meal (CM) to laying hens on egg weight, laying percentage, incidence of fatty liver hemorrhage syndrome and presence of fishy taint in eggs. (Average over 36 weeks of production)[1]

[1]Oryschak and Beltranena, 2013

association between liver hemorrhage mortality and feeding canola meal (Butler, et al., 1982; Campbell and Slominski, 1991). Authors suggested that this could have been the result of residual glucosinolate content found in early varieties of canola (Campbell and Slominski, 1991). Plant breeding has steadily reduced the level of glucosinolates to the point where they are currently one-third of those found in the first canola varieties that we fed in these studies. More recent studies with current low-glucosinolate meal varieties failed to observe incidence of liver hemorrhage even when as much as 20% canola meal was included in the diet (Oryschak and Beltranena, 2013; Figure 1). This fact was again demonstrated by Savary and Anderson (2011). Canola meal was included in the diets of brown and white egg layers at levels of 0%, 10% and 20% with no effect on liver damage and mortality rates. Laying hens have repeatedly demonstrated an ability to handle high levels of canola meal as long as total diet glucosinolate levels are below 1.43 µmol/g (Bell, 1993).

A wrongfully attributed effect of feeding canola meal to some strains of brown-shelled egg layers was the incidence of fishy smell in their eggs (Butler, et al., 1982). Canola meal contains sinapine, which is composed of sinapic acid and choline. In the digestive tract of birds with a genetic deficiency, choline is converted to trimethylamine. These strains of brown hens were unable to produce trimethylamine oxidase, the enzyme necessary to convert the odours trimethylamine to non-odorous trimethylamine N-oxide, which is then excreted in the urine (Ward, et al., 2009). If this enzyme is not present due to the layers' genetic defect, then TMA will pass into the yolk of the egg and impart a fishy flavour. This genetic deficiency has been well studied, and many commercial breeders have developed lines of brown egg layers that no longer carry this defect (Honkatukia, et al., 2005; Classen, 2008, personal communication). The data

presented in Figure 1 (Oryschak and Beltranena, 2013) was conducted with Brown Nick hens. There was not one observation of fishy smell in the eggs produced in this trial. Canola meal has therefore not been fed, or fed at extremely minimal amounts in brown egg hen diets. This type of formulating results in unnecessary exclusion of canola meal and greater feed costs.

Breeding Chickens

Canola meal has no negative effects on egg fertility or hatchability of leghorn breeders (Kiiskinen, 1989; Nasser, et al., 1985). The average weight of the one-day-old chick decreased with increasing canola meal, and the weight of the thyroid gland of one-week-old chicks was greater with increasing canola meal levels in these older studies. The decrease in chick weight did not result in impairment of productive function of the chicks during their subsequent egg production. A more recent study by Ahmadi, et al. (2007) evaluated the effects of adding 0%, 10%, 20% or 30% rapeseed meal to the diet of broiler breeders, and it is unclear as to what the glucosinolate content of the diets was. However, they concluded that rapeseed meal can be used effectively in broiler breeder diets without affecting production, egg weight or chick quality. Due to the potential effect on egg and chick weight and the lack of current studies on feeding canola meal to broiler breeders, many feed manufacturers do not use canola meal, or limit it to low-inclusion levels in poultry breeder feeds. The high-protein and -fibre content of canola meal makes it an ideal feedstuff to manage weight gain in broiler breeder diets.

Broiler Chickens

Current low levels of glucosinolates in canola meal do not have any negative effects on broiler mortality or feed intake. Two recent studies have shown that

canola meal can be effectively fed in broiler diets up to 30% without negatively affecting growth performance as long as the diets are formulated on a digestible amino acid basis (Newkirk and Classen, 2002; Ramesh, et al., 2006). The lower assumed energy value in canola meal compared with other protein sources such as soybean meal has limited its use in broiler feeds. But lower cost per gram of key available amino acids and phosphorus has nutritionists considering greater dietary inclusions of canola meal in broiler diets.

It was argued that feeding rapeseed meal (high glucosinolate) to broilers resulted in an elevated incidence of leg problems, especially tibial dyschondroplasia. The leg problems have been alleviated somewhat, but not completely, by feeding canola meal. This could suggest that glucosinolates were partially, but not entirely, responsible. Summers, et al. (1990, 1992) showed that the situation is related more to sulphur levels (a component of glucosinolates) rather than to the toxic effect of glucosinolates themselves. They noted that feeding organic sulphur, in the form of cystine, caused a greater incidence of leg problems. It is known that sulphur interferes with calcium absorption. Supplementing the diet with extra calcium helps to a certain extent, but care is advised, as too much dietary calcium can depress feed intake.

Feed intake in broilers has been correlated with the cation-anion balance of a diet in some pioneering investigations into feeding canola meal to poultry (Summers and Bedford, 1994). Canola meal contains slightly less potassium (1.2%) than soybean meal (1.9%), so that the electrolyte balance is lower in a diet based on canola meal compared with soybean meal. When total cation-anion balance is considered, the higher sulphur levels in canola meal result in an even lower positive balance of dietary cations (Summers and Bedford, 1994). These authors suggested that the decrease in feed

intake when including canola meal in broiler feeds could be related to cation and anion levels in the diet. However, attempts to increase levels of dietary cations by adding extra calcium carbonate had marginal success, probably due to the feed intake–depressing effects of high calcium inclusions (Khajali and Slominski, 2012). Adding potassium bicarbonate to diets is a better alternative, as this corrects the problem at its source.

Turkeys

A study by Waibel, et al. (1992) demonstrated that canola meal is an excellent protein source for growing turkeys. It is common commercial practice to feed high levels of canola meal to growing and finishing turkeys. The Waibel study illustrates the importance of balancing rations appropriately when substituting protein sources. When canola meal was added at 20% of the diet without maintaining equal energy and essential amino acid levels, growth and feed conversion efficiency were decreased. However, when extra animal fat was added and amino acid levels were kept constant, performance was equal to or superior to the control diet. As with other species, it is important that diets be formulated on a digestible amino acid basis. In some regions, canola meal is often included in turkey diets at levels beyond the 20% level. In this case, it is important to ensure the dietary electrolyte balance of the final diet is in the appropriate range. Recently, Zdunczyk, et al. (2013) demonstrated the inclusion of 180 g/kg of low-glucosinolate rapeseed meal in diets of turkeys, and found no difference in performance when compared to soybean meal. The dietary electrolyte balance of canola meal (Na + K–Cl) is approximately 307 mEq/kg. However, canola meal contains a significant amount of sulphur, and this should also be considered: (Na + K) – (Cl + S) = 103 mEq/kg) (Khajali and Slominski, 2012).

Table 3. Standardized ileal digestibility (SID) of amino acids in expeller canola meal fed to broilers[1]

AMINO ACID	SID % FOR BROILERS
Alanine	79.7
Arginine	83.7
Aspartate + asparagine	77.5
Cystine	74.2
Glutamate + glutamine	86.5
Glycine	82.7
Histidine	84.9
Isoleucine	83.3
Leucine	79.5
Lysine	78.7
Methionine	83.7
Phenylalanine	80.4
Proline	72.6
Serine	82.8
Threonine	83.3
Tyrosine	79.5
Valine	83.6

[1]Woyengo, et al., 2010

Ducks and Geese

Canola meal is commonly fed to ducks and geese, and there are no reported issues in addition to feeding other types of poultry. In fact, geese have a greater digestive capability than other types of poultry, and appear to digest canola meal more efficiently (Jamroz, et al., 1992). The amino acid digestibility of canola meal in ducks is shown in Table 2 on page 37. Canola meal and soybean meal have similar amino acid digestibility in ducks (Kluth and Rodehutscord, 2006).

Canola Expeller Meal in Poultry Rations

Canola meal is an excellent source of protein for poultry, but the energy content of solvent-extracted canola meal can limit its use in the diets of rapidly growing poultry. Due to the remaining oil content, canola expeller meal contains more energy than solvent-extracted meal, with an AMEn of 2,694 kcal/kg (Woyengo, et al., 2010), and it can be included as the sole source of protein in the diet without additional fat. A recent study out of Australia examining feeding expeller-pressed canola meal subject to various processing temperatures determined the AMEn in broilers to be a mean value of 2,260 kcal/kg (Toghyani, et al., 2014). Expeller meal provides a high level of the essential fatty acid linoleic acid, thus exceeding the requirements of the birds without the need for supplemental fat. Oryschak and Beltranena (2013) fed 20% expeller-pressed canola meal to Brown Nick hens, and demonstrated excellent egg production, egg quality and egg fatty acid content. Canola expeller meal can also be fed as an effective protein source for turkeys. Palander, et al. (2004) studied the effects of feeding canola expeller meal in growing turkeys on protein digestibility, and found digestibility coefficients similar to solvent-extracted meal. Fat content of expeller meal does vary between sources (8–11% crude fat) due to the efficacy of the type of press used, so the product should be tested and the energy value adjusted

accordingly. The AMEn of expeller meal can be estimated using the equation 1,800 + (% fat * 80) = kcal/kg. This assumes that each percentage point of fat contains 80 kcal. For example, an expeller meal with 10% fat would have an approximate AMEn of 1,800 + (10 * 80) = 2,600 kcal/kg.

Feeding Canola Seed and Oil

Canola oil is routinely fed as an energy source to broiler chickens. In addition to its energy value, it is an excellent source of linoleic acid. Broiler starter diets that are based on barley or wheat instead of corn can be somewhat deficient in linoleic acid, especially when other saturated dietary fat sources are fed, such as tallow, for example. In these situations, it is common to add 1.0–1.5% canola oil to the diet. Full-fat canola, after particle-size reduction (rolling), is a mainstay protein and energy ingredient in broiler feeds in some countries, like Denmark.

Canola Meal Practical Inclusion Levels of Canola Meal in Poultry Diets

The recommended practical inclusion levels for canola meal in poultry diets, together with the reasons, are listed in Table 4.

Table 4. Recommended practical inclusion levels (%) of canola meal in poultry diets

ANIMAL DIET TYPE	INCLUSION LEVEL (%)	REASONS FOR INCLUSION LEVEL
Chick starter	20	High performance results reported at 20% inclusion
Broiler grower	30	No data beyond 30% inclusion
Egg layer	20	High performance results reported at 20% inclusion
Turkey grower	20	No data available beyond 20%
Breeder	30	High performance results reported at 30% inclusion
Duck and goose	15	No data available beyond 15% inclusion

THE VALUE OF CANOLA MEAL IN AQUACULTURE DIETS

Canola meal has become an important ingredient in aquaculture diets around the world. China, being the largest producer of fish products, is also the largest importer of Canadian canola seed. The canola meal resulting from the seed processing in China is often used in the aquaculture industry. Likewise, Vietnam and Thailand are important markets for the direct import of Canadian canola meal, with much of this imported volume going to feed fish. Because many farmed fish species are carnivorous, the world stocks of fish meal are diminishing, thus pressuring the industry to find alternative vegetable-based proteins that can provide amino acids for their high protein requirements. While some challenges remain, canola meal has been demonstrated to fit well in many fish diets.

Feed Intake

Canola meal is a palatable source of protein for aqua diets. A recent publication by Fangfang, et al. (2014) demonstrated that inclusion of up to 30% canola meal was acceptable in the diets of tilapia, and excellent palatability was observed, with intake exceeding the high–soybean meal control diet. Hung and Van Minh (2013) fed canola meal at up to 20% inclusion in the diets of snakehead fish, and observed no differences in feed intake across all treatments, including a soybean meal control. In another study, Van Minhet, et al. (2013) showed no change in feed intake when canola meal was fed at 30% of the diet in Pangasius catfish. Lastly, the feed intake of rainbow trout was unaffected by the addition of canola meal at levels up to 30% of the diet (Collins, et al., 2012).

The palatability of canola may be due to soluble peptides present in the meal. In support of this, Hill, et al. (2013) reported that the inclusion of 1% soluble canola protein concentrate in diets fed to sunshine bass significantly increased feed intake and weight gain.

Energy and Fibre

Protein-to-energy ratios in fish diets are high compared to birds and mammals, and thus, aqua diets are typically higher in crude protein than pig or poultry diets. For example, salmonid diets typically contain more than 40% crude protein. Since canola meal contains 36% crude protein, this may limit the feasible inclusion rate of canola meal to less than 20% when formulating practical diets for salmonids. However, in omnivorous or herbivorous fish, such as carp and tilapia, dietary crude protein requirements are less than 36%, and this limitation does not apply.

The digestibility of energy in canola meal is highly variable, due to the varied digestive systems of fish species farmed around the world. As well, processing systems used to treat vegetable protein sources influence the extent of digestibility, and these have varied widely from study to study. The digestible energy content of canola meal has been determined to range from 2,300–2,750 kcal/kg for salmonid fish (NRC, 1993). The energy value will also vary somewhat due to the amount of lipid that is present in the meal. NRC (2011) lists apparent digestibility of energy in rapeseed meal at 76% for rainbow trout, 57% for Nile tilapia and 83% for cobia. Burel, et al. (2000) determined that the digestibility of rapeseed meal by rainbow trout was 69% for solvent-extracted meal, and 89% for heat-treated meal. Allan, et al. (2000) found that the digestibility of energy in solvent-extracted and expeller canola meal was 58.1% and 58.6%, respectively, for silver perch.

While dietary fibre is beneficial to ruminants, like swine and poultry, it is considered to be an anti-nutritional factor in fish, as most species reared in aquaculture do not naturally consume high levels of fibre in their diets. Canola meal contains relatively high levels of fibre, including approximately 7.9% cellulose, and 8.9% lignin and polyphenols. This results in a crude fibre content of 11.2% for commercial canola meal produced in Canada (Slominski, 2015). These fibre fractions cannot be used by finfish, and may diminish the nutritional value of other dietary ingredients through dilution (Poston, 1986). Thus, removal of the fibre fraction of canola meal could enhance its value in nutrient-dense aqua feeds, thus increasing the nutrient density of the meal.

In summary, canola meal will fit more easily into diets for herbivorous/omnivorous species such as carp and tilapia, which have lower protein requirements than carnivorous species such as salmon and trout, and a larger natural consumption of plant-based material.

Protein and Amino Acid Availability

The digestibility of protein from canola meal is high for most fish species. NRC (2011) lists the apparent digestibility of protein in rapeseed meal for the following species: 91% for rainbow trout, 85% for Nile/blue tilapia and 89% for cobia. Hajen, et al. (1993) determined that the digestibility of canola meal protein by chinook salmon was 85%, which was higher than the digestibility of soybean meal (77%), and approximately the same as the digestibility of soy protein isolate (84%). In some species, salmonids in particular, the protein in canola meal is beneficial, but the presence of fibre and anti-nutritional factors limit its value in feeding.

The amino acid balance of canola protein is the best of the commercial vegetable protein sources currently available (Friedman, 1996). Drew (2004) noted that the amino acid profile of canola protein could be compared to minced beef. With the use of protein efficiency ratio (PER; or weight gain per gram of protein fed) as a measure, canola protein has a PER of 3.29 compared to 1.60 for soybean meal and 3.13 for casein (Drew, 2009). Furthermore, canola meal protein is approximately one-tenth the cost of fish meal on a per-kilogram-of-protein basis.

Anti-Nutritional Properties of Canola Meal

Canola meal contains small amounts of heat-labile (glucosinolates) and heat-stable (phytic acid, phenolic compounds, tannins, saponins and fibre) anti-nutritional factors (Table 1 in Nutrient Composition chapter, page 3). These factors can diminish the nutritional value of canola meal in finfish.

Glucosinolates appear to be better tolerated by many fish species, carp for example, than by swine and poultry. Canadian canola meal currently contains very limited amounts of remaining glucosinolates (4.2 µmol/g). Several publications have identified upper limits of inclusion of glucosinolates in the diet for fish. The most conservative limit, set at 1.4 µmol/g of diet for trout, would still allow for a relatively high inclusion of canola meal (30%).

The heat-stable anti-nutritional factors vary widely in structure and their nutritional effects. They prevent the use of canola meal in salmonid diets at inclusion levels over approximately 10% of the diet (Higgs, et al., 1983; Collins, et al., 2012). Heat-stable anti-nutritional factors in canola meal can be eliminated or reduced by the fractionation of canola meal to produce canola protein concentrate and canola protein isolate. Canola meal may be converted into canola protein concentrate (CPC) by aqueous extraction of protein (Mwachireya, et al., 1999; Thiessen, et al., 2004). CPC contains approximately the same crude protein concentration as fish meal, as well as high levels of lysine and methionine relative to corn gluten and soybean meal. The process used to concentrate the protein results in a CPC that is completely devoid of phytate and saponins, and contains extremely low levels of glucosinolates. The crude protein digestibility was reported to be up to 97% in rainbow trout, and the digestibility of key amino acids (lysine, methionine and arginine) was greater than 90%. The apparent digestible energy content of CPC was 4,310 kcal/kg compared to 3,360 kcal/kg for soybean meal.

In addition, many aqua diets are formulated to contain phytase (NRC, 2011), the enzyme necessary to cleave phosphorus from phytic acid. The addition of carbohydrase enzymes in aqua diets has been just briefly studied. In 1997, Buchanan, et al. demonstrated

that the addition of a carbohydrase enzyme included in a diet containing canola meal fed to black tiger prawns increased digestibility and growth.

Canola Meal for Salmonids

Canola meal is a common feed ingredient in salmon and trout diets, although inclusion is limited due to several factors, mainly the high protein requirements of salmonids and the presence of heat-stable anti-nutritional factors. Collins, et al. (2013) completed a meta-analysis of various vegetable protein ingredients fed to salmonids to determine impact of inclusion rate. Thirty data points from 12 studies were used to assess the effect of canola meal inclusion in rainbow trout diets. Overall, inclusion rates of up to 20% did not affect fish growth rate significantly.
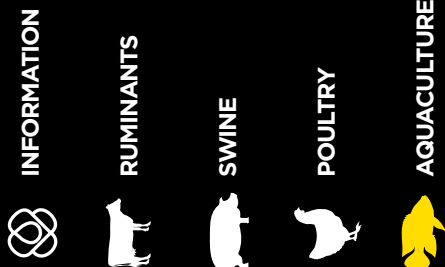
Canola protein concentrate is a very suitable ingredient in salmonid diets. Replacement of 50% or 75% of fish meal in diets fed to rainbow trout with CPC resulted in no significant differences in any of the performance measures (Thiessen, et al., 2004). The feed efficiency and PER values of the control and the 75% replacement CPC diet were essentially identical over the 63-day period of the experiment. These results demonstrated that CPC can replace up to 75% of fish meal protein with no significant decrease in growth or feed efficiency. However, the growth of Atlantic salmon and rainbow trout were significantly decreased when they were fed diets containing 20 and 22.5% canola protein concentrate, respectively (Collins, et al., 2012; Burr, et al., 2013), suggesting that there is a practical maximum inclusion rate lower than 20% CPC in salmonid diets. Drew, et al. (2004) noted the importance of a feed attractant when diets contain high levels of vegetable protein, in order to maintain feed intake.

Canola Meal in Warm-Water Fish

Canola meal is increasingly used in aquaculture diets for species such as catfish, carp, tilapia, bass, perch, sea bream, turbot and shrimp. Lim, et al. (1997) found that canola meal can be included in channel catfish diets at up to 31% with no negative effects on performance. Van Minh, et al. (2013) fed Pangasius catfish 30% canola meal with great performance results. Canola meal and rapeseed meal are also commonly included in carp diets, which are frequently vegetable protein based (Zhang, et al., 2013). Veiverberg, et al. (2010) replaced meat and bone meal with canola meal in diets for juvenile grass carp, and found no difference in growth rate or feed conversion. Fillet yield was higher with the canola meal diet than with the control.

Higgs, et al. (1989) determined that canola meal could be effectively used at a 10% inclusion level in juvenile tilapia diets without significantly depressing growth rate or feed conversion efficiency. Abdul-Aziz, et al. (1999), on the other hand, fed up to 25% canola meal in tilapia diets with no effect on performance. Fangfang, et al. (2014) demonstrated 30% inclusion in tilapia with no impact on growth performance. In another study, Luo, et al. (2012) replaced 75% of the fish meal in diets for Nile tilapia (55% of the diet) with no adverse effects on growth performance. While some changes in liver enzyme levels were apparent, the authors concluded that up to 75% of the fish meal can be replaced with no harmful effects.

There were similar findings with other fish species. Glencross (2003) found that canola meal could comprise up to 60% of the diet for red sea bream without detrimental effects on performance. Growth rates were not different from the fish meal control when sunshine bass were given diets with 20% canola meal, although feed conversion ratio was elevated (Webster,

et al., 2000). Hung, et al. (2013) demonstrated that canola meal could replace soybean meal at a level of 20% inclusion in the diets of snakehead fish without any negative impacts on performance.

Canola protein concentrate (CPC) has a protein concentration similar to fish meal, with few anti-nutritional factors (Drew, 2004), and is also an acceptable ingredient in warm-water species. In an experiment with Nile tilapia, fish were fed diets containing 24.7% CPC, replacing fish meal, soybean meal and corn gluten meal (Borgeson, et al., 2006). The fish receiving the CPC diets grew significantly faster than those receiving the control diets (2.29 vs. 1.79 g/d). This suggests that CPC might allow a greater amount of fish meal replacement in aquafeeds without affecting fish growth performance.

While the presence of anti-nutritional factors in canola requires consideration for its use in some aquaculture diets, the use of canola protein and oil also has significant advantages over the use of fish meal and oil, in that they are lower in polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/F) as well as dioxin-like polychlorinated biphenyls (DL-PCB). When fish meal and oil were completely replaced with canola protein concentrate and canola oil, the levels of PCDD/F and PCBs were significantly reduced in prepared diets (4.06 vs. 0.73 pg/g, as-is basis) and in the fillets (1.10 vs. 0.12 pg/g, as-is basis) of fish fed these diets during a six-month growth trial (Drew, et al., 2007). The recommended maximum human intake of organochlorine contaminants is 14 pg/kg body weight/week according to the European Commission's Scientific Committee on Food. Based on these levels, a 50-kg person could safely consume 640 g per week of trout fed the fish meal–and-oil diet, compared to 5,880 g per week of the trout fed the canola protein–and-oil diet. This suggests that

decreasing the level of fish meal and oil present in aquafeeds by the use of canola oil and meal could significantly impact the safety of farmed fish and increase consumer acceptance of these products.

Canola Meal for Shrimp and Prawns

Canola meal has been successfully used in diets for shrimp and prawns in many parts of the world. In an older study conducted in China, Lim, et al. (1998) found that 15% canola meal in shrimp diets resulted in no significant performance differences, but that 30% and 45% inclusion levels resulted in growth rate and feed intake depression.

Since then, knowledge related to the nutrient requirements of these species has been gained. Research conducted in Mexico (Cruz-Suarez, et al., 2001) revealed that canola meal can be incorporated into the diet at 30%, replacing fish meal, soybean meal and wheat, with no change in performance of juvenile blue shrimp. In Malaysia, researchers found that shrimp given a mixture of soybean meal and canola meal required a feed attractant to obtain growth rates equivalent to diets containing fish meal (Bulbul, et al., 2015), but the plant protein blend could replace 60% of the dietary fish meal without altering performance. Researchers in Australia (Buchanan, et al., 1997) fed prawns diets with 0, 20 or 64% canola meal. Results indicated that an enzyme cocktail was required for the higher level of canola meal to produce growth rates equivalent to the control diet without canola meal.

A non-nutritional concern about using canola meal in shrimp feeds is the negative effect that the fibre has on feed pellet water stability. A pellet binder may be needed to compensate for this effect.

Canola Seed and Oil

Mixtures of extruded pea and canola seed are available in Canada, and supply both protein and oil. Adding 240 kg/tonne of this product, replacing fish meal and fish oil, resulted in similar growth rates in rainbow trout, but poorer feed efficiency. The loss of feed efficiency was overcome by the inclusion of a proteolytic enzyme cocktail. Safari, et al. (2014) found that ground canola seed was a promising ingredient for crayfish.

With the high demand for commercially reared fish and crustaceans, there is a shortage of fish oil, and this is expected to increase in the future. Replacement of fish oil with vegetable oils has been widely documented, generally with very little impact on growth performance of fish (Glencross and Turchini, 2011). According to Turchini, et al. (2013), canola oil and rapeseed oil are the most widely used vegetable oils in diets for salmon and trout. Canola oil is highly desired due to its low levels of the C18:2 (omega 6) fatty acid, helping to maintain an omega 3:omega 6 ratio naturally found in fish. Turchini, et al. (2013) replaced up to 90% of the fish oil with canola oil in diets for rainbow trout, with no loss in performance, and only minimal change to the total omega 3:omega 6 ratio in fillets.

Another approach to using vegetable oil is to provide it in diets during the growth phase, and then provide diets high in fish oil during the final stages of growth. This allows fish to grow on the less expensive oils, and to deposit tissue lipid more reflective of fish in the final stages of growth. Izquierdo, et al. (2005) provided sea bream with vegetable oil–rich diets, then switched to fish oil for the finishing period. Canola oil fed during the growth phase, followed by fish oil in the finishing phase, allowed the sea bream to develop an ideal fatty acid profile in tissue, whereas fish fed soybean meal in the growth phase deposited significant amounts of linoleic acid that could not be adequately reduced during fish oil feeding in the finisher phase.

Canola Meal Practical Inclusion Levels

The recommended practicalinclusion levels for canola meal usage in aquaculture diets together with reasons are given in Table 1.

Table 1. Recommended practical inclusion levels (%) of canola meal in aquaculture diets

ANIMAL DIET TYPE	INCLUSION	REASONS FOR INCLUSION LEVEL
Salmon, trout	20	High performance results reported at 20% inclusion
Catfish	30	No data available beyond 30%
Tilapia	30	No data available beyond 30%
Red sea bream	60	No data available beyond 60%
Shrimp and prawns	15–30	High performance results reported with 15–30% inclusion

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ACKNOWLEDGMENTS

The Canola Council of Canada would like to thank the following individuals for their contribution to this feed guide:

Dr. Bogdan Slominski, University of Manitoba

Dr. Essi Evans, Essi Evans Technical Advisory Services

Dr. Arnold Pierce, Preferred Animal Nutritional Services, Inc.

Dr. Glen Broderick, Broderick Nutrition and Research, LLC.

Dr. Ruurd Zijlstra, Univesity of Alberta

Dr. Eduardo Beltranna, Alberta Agriculture and Forestry

Dr. Murray Drew, University of Saskatchewan