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FEED INDUSTRY GUIDE ▪ 6th EDITION, 2019

CANOLA MEAL FEEDING GUIDE

CANOLA MEAL

This technical guide on the use of canola meal in animal feeds is the latest in a series of publications produced by the Canola Council of Canada.

Every few years, this Canola Meal Feeding Guide is updated to incorporate new research information about canola meal utilization as well as developments in feed technology. Since the previous edition in 2015, a considerable amount of additional research regarding the feeding of canola meal has been conducted in many different animal species and in a variety of settings around the world.

New information and changes in this latest version of the guide include:

- Updated nutrient profile of canola meal obtained through a collection of meal samples from processors across Canada over a seven-year period
- Information on protein degradation, fibre digestion and amino acid supply of canola meal in the rumen and its impact on milk production
- Updated values of energy content and inclusion levels of canola meal in the diets of swine and poultry
- Information on canola meal inclusion in aquaculture 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.

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CH. 1 - CANOLA MEAL: A BASIC INTRODUCTION

Canola is one of Canada's most important crops, and is also the second most traded protein in the world. The vast, fertile fields of Western Canada are the primary canola production regions. In early summer, canola fields dot the countryside with brilliant yellow flowers, yielding about 20 million metric tonnes of canola each fall. These tiny round seeds, containing approximately 44% oil, are 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.

The name "canola" (Canadian oil) was coined in order to differentiate it from rapeseed. Canola is an offspring of rapeseed (*Brassica napus* and *Brassica campestris/rapa*), but was bred through traditional plant breeding techniques to have low levels of anti-nutrients, specifically erucic acid (< 2%) in the oil portion and low levels of glucosinolates (< 30 μmol/g) in the meal portion. The near removal of the glucosinolates resulted in a meal that was highly palatable to livestock. Some European countries use the term "double-zero rapeseed" (low erucic acid, low glucosinolates) to characterize the modified "canola quality" seed, oil and meal.

Production and Markets

Canola production in Canada has been steadily increasing, and currently sits at approximately 20 million metric tonnes of canola seed per year. The Canadian canola industry is targeting an increase in yield to 26 million metric 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.

As Figure 1 shows, canola crop research has results in almost a doubling of yields in the last 20 years. The industry's goal is to reach 52 bushels/acre (22.7 kg/bu) by 2025.

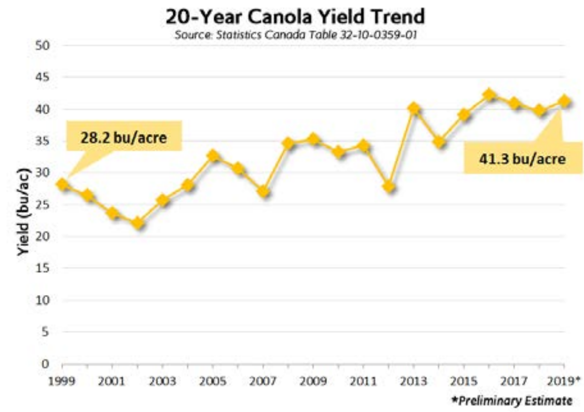


Figure 1. Yields/acre of canola seed from 1998 through 2018

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 Canada, Australia , 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]

	--------CROP YEAR--------			
	2014/2015	2015/2016	2016/2017	2017/2018
Total seed production	16,410	18,377	19,599	21,328
Total seed export	9,137	10,268	11,052	10,771
China	4,032	4,016	3,999	4,319
Japan	2,177	2,179	2,214	2,584
Mexico	1,491	1,382	1,565	1,474
United Arab Emirates	220	587	807	637
Pakistan	515	1,081	932	678
European Union	100	434	798	0
United States	576	368	622	652
Other countries	26	221	114	427
Domestic seed processing	7,360	8,315	9,191	9,269
Domestic meal use	571	581	504	606
Total meal Export	3,601	4,097	4,672	4,534
United States	3,411	3,576	3,604	3,246
China	11	320	908	1,248
Other Export	179	201	160	40

[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 minimum	-
Protein-fat (combined), % by mass	-	37 minimum
Fat (oil) (typical), solvent extracted, % by mass	2 minimum	-
Fat (oil) (typical), expeller pressed, % by mass	10 minimum	-
Moisture, % by mass	12 maximum	12 maximum
Crude Fibre, % by mass	12 maximum	12 maximum
Sand and/or silica, % by mass	-	1 maximum

[1]COPA (Canadian Oilseed Processors Association, 2019)

MEAL PRODUCTION METHODS

Most canola seed is processed using solvent extraction in order to separate the oil from the meal. This process, also called prepress solvent extraction, typically includes (Figure 2):

- 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
- Drying and cooling of the meal

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%.

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.

Canola meal quality from processing plants within Canada does not vary widely. Small scale processing, where there is considerable variation in processing temperatures may produce meal of varied quality.

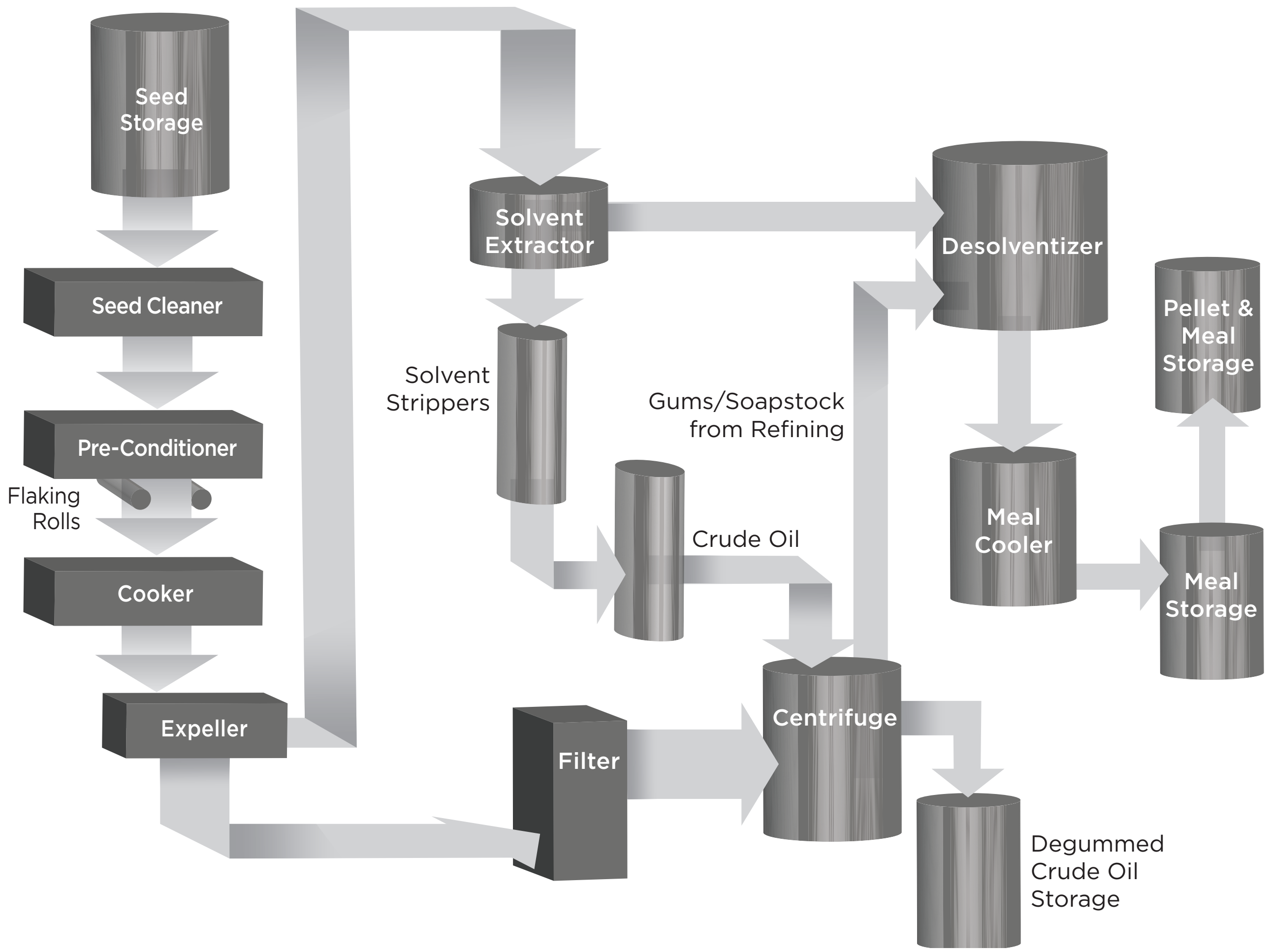


Figure 2. Schematic of prepress solvent extraction process

CH. 2 - CANOLA MEAL NUTRIENT COMPOSITION

Nutrient Composition of Solvent Extracted Meal

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, 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 13 processing sites, conducted over a seven-year period.

Protein and Amino Acids

For trading purposes, the minimum crude protein value of solvent extracted canola meal is 36%, on a 12% moisture basis. 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 2018 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 (Figure 1).

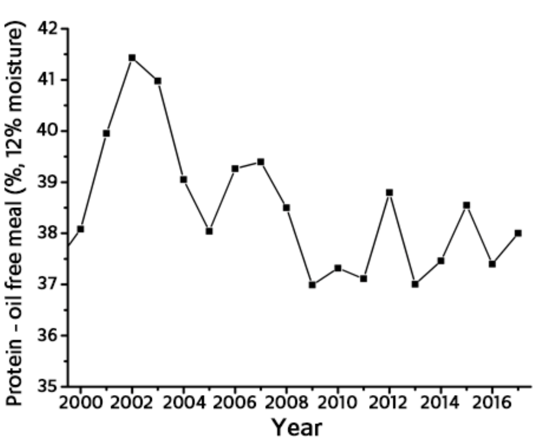


Figure 1. Protein content of canola meal from 2000 to 2017. Canadian Grains Commission, 2018.

Table 1. Composition of solvent extracted canola meal as determined from a 7 year survey of 13 Canadian processing plants[1]

COMPONENT	12% MOISTURE BASIS	DRY MATTER BASIS
Moisture, %	12	0
Crude protein (N x 6.25), %	36.9	42.0
Rumen escape protein, % of protein (NRC method)[2]	43.5	43.5
Rumen escape protein, % of protein (CNCPS method)[3]	53.0	53.0
Ether extract, %	2.81	3.20
Oleic acid, %	1.74	1.98
Linoleic acid, %	0.56	0.64
Linolenic acid, %	0.24	0.27
Ash, %	6.42	7.30
Calcium, %	0.67	0.76
Phosphorus, %	1.03	1.17
Total dietary fibre %	33.6	38.2
Acid detergent fibre, %	16.3	18.6
Neutral detergent fibre, %	25.5	29.0
Sinapine, %	0.88	1.00
Phytic acid, %	2.02	2.30
Glucosinolates, µmol/g	3.14	3.57

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 cysteine. The amino acid profile was corrected to a 36% protein basis, and is therefore likely lower than actual. 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).

Fat Content

The ether extract content of Canadian canola meal tends to be relatively high at 3.2% (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 glycolipids and phospholipids back with the meal during refining the oil. Likewise, canola meal may further contain 1–2% of the free fatty acids that are derived from canola oil refining. These components increase the energy value of the meal, and help to reduce dustiness.

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

AMINO ACID	% OF MEAL	% OF CRUDE PROTEIN
Alanine	1.58	4.38
Arginine	2.19	6.08
Aspartate + Asparagine	2.49	6.92
Glutamate + Glutamine	6.22	17.28
Glycine	1.73	4.81
Histidine	1.08	3.00
Isoleucine	1.38	3.84
Leucine	2.38	6.60
Lysine	2.04	5.66
Methionine	0.69	1.93
Methionine + Cysteine	1.33	3.69
Phenylalanine	1.34	3.71
Proline	2.49	6.92
Serine	1.32	3.66
Threonine	1.43	3.97
Tryptophan[2]	0.48	1.33
Tyrosine	0.90	2.51
Valine	1.61	4.46

[1]Radfar et al, 2017
[2]Evonik AminoDat platinum

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

FATTY ACID	% OF TOTAL FATTY ACIDS
C16:0 Palmitic acid	3.8
C16:1 Palmitoleic acid	0.2
C18:0 Stearic acid	1.9
C18:1 Oleic acid	61.4
C18:2 Linoleic acid (omega-6)	20.1
C18:3 Linolenic acid (omega-3)	9.3
C22:1 Erucic acid	<0.1
Total Saturated	7.0
Total Monounsaturated	64.4
Total Polyunsaturated	28.6

[1]Zambiasi, et al., 2007

Table 3 provides the complete fatty acid analysis for canola oil. As the table shows, this oil contains only a small amount of saturated fatty acids, and a high concentration 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).

Table 4. Carbohydrate and dietary fibre components of canola meal[1,2,3]

	12% MOISTURE BASIS	DRY MATTER BASIS
Non-fibre carbohydrates		
Monosaccharides (Fructose and Glucose), %	1.55	1.76
Disaccharides (sucrose), %	5.58	6.34
Oligosaccharides, %	2.23	2.53
Starch, %	0.43	0.49
Fibre carbohydrates, %		
Acid detergent fibre, %	16.32	18.55
Neutral detergent fibre, %	25.51	28.99
Total dietary fibre, %	34.53	39.24
Non-starch polysaccharides, %	20.15	22.90
Cellulose , %	7.65	8.69
Non-cellulosic polysaccharides, %	12.50	14.21
Glycoprotein (NDF insoluble crude protein) , %	4.30	4.89
Lignin and polyphenols, %	8.68	9.86
Lignin, %	5.82	6.61

[1]Adewole et al., 2016
[2]Broderick et al, 2016
[3]Slominski and Rogiewicz, unpublished

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., 2016; Adewole et al., 2016). 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 (NRC 2012, 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 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% (Adewole et al., 2016).

Table 5. Mineral content of canola meal[1,2,3]

	12% MOISTURE BASIS	DRY MATTER BASIS
Calcium, %	0.65	0.74
Phosphorus, %	0.99	1.13
Phytate P, %	0.64	0.73
Non-phytate P, %	0.35	0.40
Sodium, %	0.07	0.08
Chlorine. %	0.10	0.11
Potassium, %	1.13	1.28
Sulfur, %	0.63	0.72
Magnesium, %	0.54	0.61
Copper, mg/kg	4.7	5.3
Iron, mg/kg	162.0	184.0
Manganese, mg/kg	58.0	66.0
Molybdenum, mg/kg	1.4	1.6
Zinc, mg/kg	47	53
Selenium, mg/kg	1.1	1.3

[1]Adewole et al., 2016
[2]Sauvant et al, 2002
[3]Dairy One (www.dairyone.com)

Table 6. Vitamin content of canola meal[1]

	12% MOISTURE BASIS	DRY MATTER BASIS
Biotin, mg/kg	0.95	1.08
Choline, g/kg	6.5	7.4
Folic acid, mg/kg	0.8	0.9
Niacin, mg/kg	15.6	17.7
Pantothenic acid, mg/kg	9.3	10.6
Pyridoxine, mg/kg	7.0	8.0
Riboflavin, mg/kg	5.7	6.5
Thiamine, mg/kg	5.1	5.8
Vitamin E, mg/kg	13.0	14.8

[1]NRC, 2012.

The average total glucosinolate content of Canadian canola meal, based on seven years of data, is 3.6 µmol/g (Slominski and Rogiewicz, unpublished). By comparison, traditional rapeseed meal contains levels as high as 120 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 concentrations 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 seven years. Glucosinolate content is then concentrated in the meal; after that, it is further reduced during processing to values averaging 3.6 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).

Nutritional Composition of Expeller Canola 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.

The nutritional profile of the meal is similar to that of canola meal, except that it contains 8–12% fat and therefore has 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 analyzed 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.

Table 7. Typical chemical composition of expeller canola meal[1,2]

	12% MOISTURE BASIS	DRY MATTER BASIS
Moisture (as measured), %	4.02	0
Crude protein (N x 6.25), %	34.28	38.95
Rumen escape protein, % of protein (NRC method)[2]	48.5	48.5
Rumen escape protein, % of protein (CNCPS method)[3]	59.1	59.1
Ether extract, %	10.96	12.44
Oleic acid, %	6.85	7.75
Linoleic acid, %	2.20	2.50
Linolenic acid, %	0.91	1.03
Ash, %	6.96	7.90
Calcium, %	0.62	0.71
Phosphorus, %	0.96	1.09
Total dietary fibre	37.07	42.12
Acid detergent fibre, %	16.72	19.00
Neutral detergent fibre, %	26.83	30.49
Glucosinolates, µmol/g	8.85	10.06
Methionine, % of crude protein	1.93	1.93
Lysine, % of crude protein	5.93	5.93
Threonine, % of crude protein	3.69	3.69

[1]Adewole et al., 2016
[2]Broderick et al., 2016
[3]Ross et al., 2013

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.

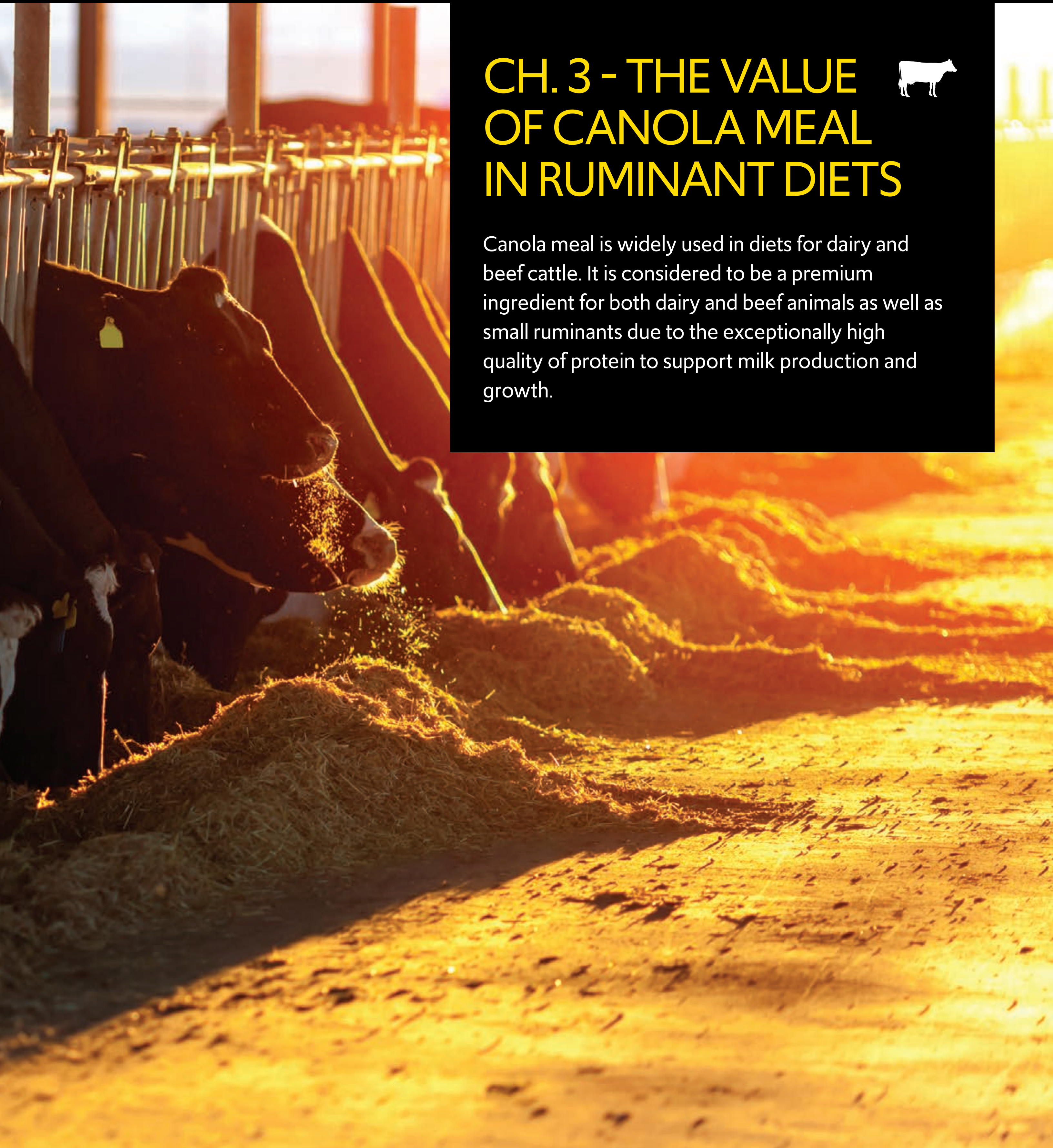
Table 8. Reported chemical composition of canola seed (non-moisture nutrients calculated on 12% moisture basis).

	--------REFERENCE--------			
	1	2	3	4
Moisture, %	6.8	10.1	5.0	5.7
Crude protein, %	18.4	18.0	20.0	20.7
Ether extract, %	40.5	36.5	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	-	-

[1]Feedipedia, 2018 (www.feedipedia.com)
[2]NRC, 2001
[3]Assadi et al, 2011
[4]Montoya and Leterme, 2008

CH. 3 - THE VALUE OF CANOLA MEAL IN RUMINANT DIETS

Canola meal is widely used in diets for dairy and beef cattle. It is considered to be a premium ingredient for both dairy and beef animals as well as small ruminants due to the exceptionally high quality of protein to support milk production and growth.



Palatability for Ruminants

Canola meal is a highly palatable source of protein for ruminant animals, and this has been 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 that contained less than 20μmol/g of glucosinolates consumed virtually the same quantity of feed as control calves fed diets without canola meal (1.10 kg vs. 1.08 kg/day, respectively). However, calves fed a concentrate containing high-glucosinolate rapeseed meal (> 100 μmol/g) only consumed 0.76 kg. Another study conducted with calves (Hadam et al., 2015) saw no differences in feeding behavior or intake in calves during the transition from weaning to solid feed. Intakes of the starter diet from 1 to 35 days of age were numerically lower with the canola meal diet when compared to a diet where the major protein source was soybean meal (269 vs 315 g/head/day).

Beef cattle likewise have been shown to find canola meal to be a palatable feed ingredient. In a recent study, Nair et al. (2014) found that when barley grain was swapped out for canola meal at either 15 or 30% of the total dry matter (DM) during backgrounding, cattle consumed greater amounts of feed with the addition of the canola meal. In a continuation of that study (Nair et al., 2015) with finishing cattle, intakes were improved when canola meal was included in the diet at concentrations of 10 or 20% of the DM. 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). He et al (2013) determined that there was no reduction in dry matter intake (DMI) when canola meal replaced barley grain at 30% of the diet DM during the growing or finishing phase with beef cattle in feedlot. Both solvent extracted and expeller canola meal treatments were tested in that experiment, with the same result.

Recent studies have revealed that intakes in dairy cows can be maintained or enhanced when canola meal replaces 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 DM with the canola meal diet. Maxin et al. (2013a) substituted in 20.8% canola meal in replacement of 13.7% soybean meal, with cows consuming 23.6 and 24.0 kg of DM 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 DMI.

Energy for Ruminants

Like most concentrate ingredients, canola meal is a good source of energy, providing nutrients for microbial growth, and supporting animal productivity. In the past, the energy value of canola meal has been undervalued (NRC, 2001; NRC, 2015) and remains in error in many publications. Several popular feed formulation programs use lignin to discount the digestibility of the cell wall. For example, NRC (2001) estimates of unavailable neutral detergent fibre (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 a newly developed indigestible NDF assay, Cotanch et al. (2014) demonstrated that the unavailable NDF in canola meal was 32% of the total NDF after 120 hours of rumen incubation, and that the potentially digestible cell wall was therefore 68%. Again, actual digestibility would be lower due to potentially digestible cell wall exiting the rumen before digestion is complete. Based on the results of a 4-year survey of 12 processing plants (144 samples), Paula et al. (2017b) determined that NDF digestibility at 288 hours of rumen incubation to be 80.2% of NDF, and estimated actual rumen digestibility at 3 times maintenance intake to be 60.2%. These results corroborate 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).

Solvent extracted canola meal has the same net energy value for maintenance and gain as barley, based on a feedlot study (Nair et al, 2015). Canola meal replaced barley at 15 and 30% of diet DM, allowing for the calculation of net energy by substitution. In a study comparing distillers' grains, high-protein distillers' grains, soybean meal and canola meal, there were no differences in energy-corrected milk/DM or changes in body condition score (Christen et al., 2010). Also, Swanepoel et al. (2014) saw no differences in DMI or body condition score when up to 20% canola meal replaced high-protein corn distillers' grains. Energy output in milk was higher with the diets containing canola meal, indicating that the energy value of canola meal was at least as great as the high protein distillers' grains. Based on these newer results, the energy value of canola meal is provided in Table 1.

Table 1. Average energy values for canola meal (DM basis)

	CANOLA MEAL PROCESSING METHOD	
	SOLVENT EXTRACTED	EXPELLER
Total digestible nutrients (TDN), %	68.2	74.6
Digestible energy (DE), Mcal/kg	3.20	3.61
Metabolizable energy (ME) Mcal/kg	2.69	2.96
Net energy of Lactation (NE-L 3X), Mcal/kg	1.71	1.93
Net energy of maintenance (NE-M), Mcal/kg	1.84	2.01
Net energy of gain (NE-G), Mcal/kg	1.20	1.36

Protein and Amino Acids in Canola Meal for Ruminants

Canola meal has long been prized in rations for ruminants for its valuable protein. The amino acid profile of the meal was recognized early on to more closely match requirements for maintenance and milk than other vegetable proteins (Schingoethe, 1991). 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), based on a subset of results from the 2011-2014 survey. These results show that canola meal contributes a significant amount of methionine, which is often the first limiting amino acid in production.

Table 2. Essential amino acid composition of canola meal and canola meal RUP fraction as determined by Cornell University using the Ross method[1]

	% OF DM		% OF TOTAL PROTEIN	
	RUP FRACTION	INTACT MEAL	RUP FRACTION	INTACT MEAL
Arginine	2.23	2.17	6.19	6.03
Histidine	0.91	0.92	2.53	2.56
Isoleucine	1.28	1.24	3.56	3.44
Leucine	2.68	2.52	7.44	7.00
Lysine	1.76	1.84	4.89	5.11
Methionine	1.55	1.27	4.31	3.53
Phenylalanine	1.49	1.44	4.14	4.00
Threonine	1.51	1.47	4.19	4.09
Tryptophan	0.51	0.48	1.42	1.33
Valine	1.54	1.44	4.28	4.00

[1]Ross, 2015

Rumen Undegraded Protein in Canola Meal

Many feed libraries unknowingly have incorrect values for the RUP and rumen degradable protein (RDP) values for feed ingredients, and changes are slowly being made to correct this. In the past, soluble protein was assumed to be largely degraded in the rumen. In fact the rumen degradability of soluble protein is highly variable.

Newer research acknowledges a portion of soluble protein from feed ingredients remains undegraded, and that this varies with the protein source. For canola meal, the undegraded soluble fraction is high. The two major storage proteins in canola are napin and cruciferin. Napin is a low molecular weight protein that is soluble (Perera et al., 2016) but apparently not readily degraded.

Hedqvist and Udén (2006) first revealed that portions of the soluble protein fraction were not degraded in the rumen for some vegetable proteins. Since then, this has been confirmed by several other researchers at different institutions (Bach et al., 2008; Stefanski et al., 2013; Ross et al., 2013).

The extent of degradation of the soluble fraction for canola meal and rapeseed meal was shown to average only 40% of the total, with the undegraded soluble fraction contributing to the RUP component of the meal protein (Table 3).

Table 3. Degradation of the soluble protein portion of the total protein from canola meal 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

The RUP content of canola meal is thus 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., 2013b). Newer systems of modeling and analyses are now adjusting for these contributions to RUP. This updated insight into the rumen metabolism of protein has allowed diets to be formulated with lower concentrations of protein. Canola meal has been particularly advantageous to supporting milk production and growth when diets are formulated on the basis correct RUP values.

Even more relevant to the feeding value of canola meal are comparisons of RUP values between canola meal and other proteins, in particular soybean meal. Table 4 provides RUP (% of the protein) values for solvent-extracted canola meal relative to soybean meal from a number of recent studies. Each reference cited represents slightly 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 programs so that canola meal is more accurately represented.

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
Broderick et al, 2016	46.3	30.5	1.51
Hedqvist and Uden, 2006	56.3	27.0	2.07
Jayasinghe et al., 2014	42.8	31.0	1.38
Maxin et al., 2013b	52.5	41.5	1.27
Ross,2015[1]	53.2	45.2	1.18
Tylutki et al., 2008	41.8	38.3	1.09

[1]Results for 27 samples of canola meal, submitted as a subset of survey samples

Rumen Microbial Protein Production

Several studies have provided results for microbial protein synthesis when canola meal was included in the diet. Brito et al. (2007) and Paula et al (2018) both measured abomasal flow of nutrients and microbially derived protein. In both studies, it was determined that there were no differences in microbial protein yield when canola meal was used to replace soybean meal as a source of protein. Similarly, Paula et al (2017a) determined that there were no differences in microbial protein yield for soybean meal or canola meal diets in a dual flow fermentation study. Krizsan et al (2017) noted that increasing concentrations of heat-treated canola meal resulted in greater amounts of rumen escape protein and lesser amounts of rumen microbial protein. However, the heat treated canola meal replaced barley in the diets, and this altered the available starch needed to support microbial growth.

Canola Fatty Acids in the Rumen

Unsaturated fatty acids in the rumen have the potential to allow for the accumulation of biohydrogenation intermediates that can interfere with milk fat synthesis, as well as inhibit microbial growth. However, not all unsaturated fatty acids are equivalent in their effect. As noted in Chapter 2, solvent extracted canola meal contains approximate 3.5% ether extract, an amount greater than that found in some other common vegetable proteins. This highly unsaturated source of fatty acids is made up largely of the mono-unsaturated fatty acid, oleic acid (C18:1). Oleic acid is less likely to produce the fatty acid intermediates that produce milk fat depression.

He and Armentano (2011) added large amounts of vegetable oils (5% of DM) varying in fatty acid composition to the diet of lactating cows. Fat yield declined from 1.14 kg/cow/day to 1.02 kg/cow/day for the diets with the added C18:1 and linolenic acid (C18:3) but fell to 0.86 kg/cow/day with linoleic acid (C18:2). In a follow up study, again with high concentrations of added fat, He et al. (2012) determined that C18:2 was a more potent fatty acid than C18:1 for causing milk fat depression. Stoffel et al. (2015) provided cows with a number of diets differing in fatty acid composition, but the added fat sources were provided at levels that would be typical of practical feeding situations. The effects on milk fat percentage and milk fat yields were strikingly different for the diets. Milk fat yield was 1.44 with the high C18:1 diet as compared to 1.31 kg/cow/day for the high C18:2 diet. Fat yield with the low oil control diet was 1.41 kg/cow/day.

Minerals and Vitamins

The mineral and vitamin profile for canola meal has been previously addressed in Chapter 2 and tabulated values can be found there. There are some key points relative to the mineral content that deserve to be highlighted.

Phosphorus

Canola meal is a rich source of phosphorus, with most of this mineral in the form of phytate phosphorus. Unlike monogastric animals, this form is available to ruminants, due to the presence of bacterial phytases in the rumen that rapidly 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 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.

Iodine

Iodine has long been recognized as a mineral that can be added to feed and applied topically to fight a number of infectious organisms that cause issues like hoof disease and mastitis. However, increasing ration iodine generally results in greater concentrations entering the milk, with high iodine in milk being a concern for human nutrition. Cruciferous plants such as canola and rapeseed contain glucosinolates that reduce iodine uptake by the thyroid gland and mammary gland (Flackowsky et al., 2014).

Even though levels of glucosinolates are extremely low in current day canola meal and double zero rapeseed meal, several studies have shown that milk iodine concentrations are reduced when these protein sources are provided at higher levels of intake (Vesely et al, 2009, Troan et al., 2018). Troan et al. (2018) provided cows with diets containing 0, 6, 14 or 20% expeller rapeseed meal, which contained a total of 1.07 μmol/g of glucosinolates. They determined that the proportion of iodine consumed that was transferred to milk was 25, 19, 13 and 10% for the four respective diets. The benefit of this was shown in a study by Weiss et al. (2015). Feeding 13.9% canola meal in the test diet and 2.0 mg of iodine resulted in milk iodine levels that were close to that found when 0.5 mg/kg of iodine was provided in diets where canola meal was excluded. However, blood serum iodine concentrations were much higher with canola meal (Table 5) and this would permit the health benefits of higher iodine inclusion to be manifested, without producing unacceptable levels of iodine in milk.

Table 5. Effects of feeding canola meal on iodine concentrations in blood serum and milk (μg/L)[1]

	CONCENTRATION OF IODINE IN THE DIET, MG/KG DM					
	0.5			2.0		
Canola meal, % of DM	0	3.9	13.9	0	3.9	13.9
Blood serum iodine, μg/L	99	142	148	175	251	320
Milk iodine, μg/L	358	289	169	733	524	408

[1]Weiss et al., 2015

Dietary Cation Anion Difference

The dietary cation anion difference of the diet (DCAD) provides a calculation of the difference between the major anions (sulfur and chlorine) and cations (sodium and potassium) in the diet. When there are equal amounts of these on a molecular basis, then the diet is neutral.

It is desirable to have excess anions in the close up dry period, as this may be beneficial in reducing the incidence of milk fever at calving. The sudden drain on blood calcium when lactation begins must be offset by greater calcium absorption as well as mobilization of calcium from bone. Negative DCAD diets have been shown to help maintain blood calcium levels by assisting in the release of calcium from bone.

Anionic salts can be added to the diet, but these sometimes reduce palatability of the diet and reduce DM intake. Because the anions and cations in the diet originate from the feedstuffs offered as well as mineral supplements, the selection of ingredients can be beneficial in attaining the desired balance, and reduce the need for added anionic salts. Ingredients that contribute large amounts of cations to the diet increase the need for larger quantities of anionic salts. As Table 6 shows, canola meal is an ideal choice, as the DCAD value for this ingredient is already negative and will help to reduce the need for anionic salts to be added.

Table 6. Comparison of cation (potassium and sodium), anion (chlorine and sulfur) and DCAD (mEq/kg of dry matter) for some common feed ingredients [1]

	K	Na	Cl	S	DCAD
Corn grain	+107	+9	-23	-63	31
Corn distillers' grains	+281	+130	-28	-275	109
Soybean meal	+775	+13	-155	-244	389
Canola meal	+361	+30	-11	-456	-76
Corn silage	+307	+4	-82	-88	142
Alfalfa haylage	+775	+13	-155	-188	445
Grass silage	+795	+22	-181	-131	505
Barley silage	+621	+57	-106	-106	369

[1]Erdman and Iwaniuk, 2017

Feeding Solvent Extracted Canola Meal to Lactating Cows

Meta Analyses of Feeding Value

Since 2011, there has been four meta-analyses conducted comparing canola meal with other vegetable proteins in diets for lactating dairy cows. These studies support the fact that the RUP value of the meal is high, and that canola meal has a unique amino acid profile that efficiently supports milk protein production.

Huhtanen et al. (2011) evaluated results from 122 studies where supplemental protein was supplied by either soybean meal or canola meal. In all cases, the added protein replaced grain and the forages were kept constant. The analysis revealed that for each kg increase in crude protein consumed, milk production increased by 3.4 kg with canola meal and 2.1 kg with soybean meal. The researchers concluded that canola meal was generally undervalued when compared to soybean meal.

Using somewhat different data selection criteria, Martineau et al. (2013) compared the effects of replacing vegetable proteins in the diet with the same amount of protein from canola meal. At the average inclusion level (2.3 kg per day) of canola meal, milk yield increased by 1.4 kg across the 49 studies used in the analysis. In an additional evaluation, Martineau et al. (2014) compared the response in plasma amino acids to changes in the protein source in the diet. Essential amino acids were higher and milk urea nitrogen was lower when cows received canola meal compared to all other sources of protein. These differences indeed reflect the importance of the amino acid profile of canola meal as it relates to the needs of the lactating dairy cow.

To incorporate the most recent research findings, Martineau et al. (2019) conducted a final meta-analysis to compare feeding results from studies limited to those in which canola meal was compared to another protein in full and in part. Several research studies have shown that mixing other vegetable proteins with canola meal enhances the value of the non-canola protein source, but it was not clear if the non-canola proteins enhanced the value of canola meal. This comprehensive study indicates that blending other vegetable proteins with canola meal will not improve milk production. The study also showed that canola meal can be provided in diets up to 19% of the DM with no losses in milk production, and no negative effect upon intake (Figure 1).

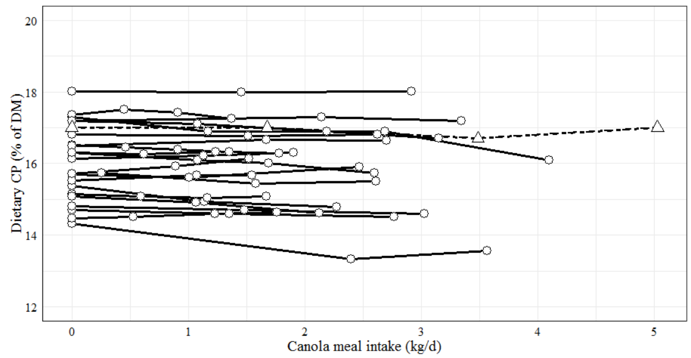


Figure 1. Effects of increasing canola meal in the diet on DMI as determined in numerous studies (Martineau et al, 2019). Higher intakes of canola meal do not reduce DM intake.

Individual Feeding Trials

Table 7 shows the results of head-to-head studies that have been published in recent times comparing canola meal to other common vegetable protein sources. As the table illustrates, canola meal performed as well or better than the alternative meals evaluated for milk production potential in most published studies.

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.

Table 7. Comparison of milk production (Kg) by cows given diets where the major supplemental protein source was supplied by solvent extracted canola meal or another vegetable protein

REFERENCE	CANOLA MEAL	ALTERNATIVE	DIFFERENCE
		SOYBEAN MEAL	
Brito and Broderick, 2007	41.1	40.0	+1.1
Broderick et al., 2012	40.7	39.7	+1.0
Broderick et al, 2015	39.5	38.5	+1.0
Broderick and Faciola, 2014	38.8	38.2	+0.6
Christen et al., 2010	31.7	31.7	0
Faciola and Broderick, 2013	37.3	36.4	+0.9
Galindo et al., 2017	46.0	43.7	+2.3
Gidlund et al, 2015	30.2	29.5	+0.7
Maxin et al. 2013a	30.9	31.9	-1.0
Moore and Kalscheur, 2016	55.7	51.2	+4.5
Paula et al., 2015	40.3	39.4	+0.9
Paula et al., 2018	44.1	42.9	+1.2
Weiss et al., 2015	39.4	37.6	+1.8
		COTTONSEED MEAL	
Brito and Broderick, 2007	41.1	40.5	+0.6
Maesoomi et al., 2006	28.0	27.0	+1.0
White et al, 2000	22.3	21.8	+0.5
		CORN DDDGS	
Acharya et al., 2015	34.9	35.5	-0.6
Christen et al., 2010	31.7	31.2	+0.5
Maxin et al., 2013a	30.9	32.2	-1.3
Mulrooney et al., 2009	35.2	34.3	+0.9
Swanepoel et al., 2014	47.9	44.9	+3.0

Table 7 (continued)

		WHEAT DDDGS	
Abeysekara and Mutsvangua, 2016	40.4	40.2	+0.2
Chibisa et al., 2012	45.0	45.0	0
Maxin et al., 2013a	30.9	30.8	+0.1
Mutsvangwa et al., 2016	43.4	42.4	+1.0
		SUNFLOWER MEAL	
Beauchemin et al., 2009	27.0	26.7	+0.3
Vincent et al., 1990	26.7	25.1	+1.6
		FLAX MEAL	
Beauchemin et al., 2009	27.0	26.8	0.2
		BREWERY GAINS	
Moate et al., 2011	23.4	22.3	+1.1
		RAPESEED MEAL	
Hristov et al., 2011	47.1	45.0	+2.1

Table 8. Trials conducted in China 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)	-0.2 L
Farm 2	325 cows; switchback study; straight substitution of soybean meal by canola meal (1.0 kg/cow/day)	+0.6 L
Farm 3	320 cows; switchback study; straight substitution of soybean meal by canola meal (0.7 kg/cow/day)	+0.3 L
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)	+1.0 L
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] (Wang, 2013)

Feeding Expeller Canola Meal to Lactating Cows

As would be expected, the nutritional value of canola expeller meal is similar to that of solvent-extracted meal except for its higher energy values due to the greater fat content, as well as potentially higher RUP value due to the processing methods. Theodoridou and Yu (2013), using molecular spectroscopy, determined that expeller canola meal proteins were altered to a greater extent by heat than solvent extracted canola meal, and therefore the RUP value is slightly greater for the expeller meal. As well Heim and Krebs (2018) determined that RUP was greater for moist heat-treated expeller meal than for cold pressed and increased linearly with the duration of the moist heat pressure treatment.

Because less expeller meal is produced, and because it is highly sought after for use in non-ruminant diets, less research support is available for this ingredient than for solvent extracted canola meal. Like solvent extracted canola meal, expeller canola meal is a suitable ingredient for cattle feeding. Table 9 compares the effects on milk production of feeding canola meal, expeller canola meal or heated expeller canola meal. Expeller canola meal and its effect on milk production in lactating dairy cows was studied at the University of Saskatchewan (Beaulieu et al., 1990; Jones et al., 2001), and more recently at Pennsylvania State University (Hristov et al, 2011). Results indicate that the inclusion of expeller canola meal in diets for lactating dairy cows result in milk yields that were as good as or even numerically higher than those obtained with solvent extracted canola meal.

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

Table 9. Milk production from dairy cows fed diets containing canola meal, expeller canola meal or heat-treated expeller canola meal

REFERENCE	PARITY	STAGE OF LACTATION	TREATMENT	MILK, KG
Beaulieu et al., 1990	Mixed	Mid	Solvent Canola meal	28.0
			Expeller Canola meal	28.0
Hristov et al., 2011	Multiparous	Early lactation	Solvent Canola meal	41.7
			Expeller Canola meal	41.7
Jones et al., 2001	Multiparous	Past peak	Solvent canola meal	28.6
			Expeller canola meal	30.0
			Heated expeller meal	30.0
Jones et al., 2001	Primiparous	Past peak	Solvent canola meal	23.6
			Expeller canola meal	24.0
			Heated expeller meal	25.2

While there are fewer studies that have been conducted to evaluate Canadian expeller canola meal, there are a number of experiments that have been completed in Europe, using double zero rapeseed. Rinne et al (2015) compared expeller soybean and expeller rapeseed meal added in increments to cows receiving a clover grass silage diet. Energy corrected milk increased by a larger amount at each increment of addition with the expeller rapeseed meal as compared to the expeller soybean meal. Gidlund et al., (2017) determined that the inclusion of expeller rapeseed meal in lactation diets resulted in reduced methane emissions. In another study (Puhakka et al., 2016) it was determined that replacing fava beans with expeller rapeseed meal resulted in reduced intakes and lost milk production.

Feeding Canola Seed and Canola Oil to Dairy Cows

Generally speaking very little seed and oil are used in diets for dairy cows. In the past, there has been interest in feeding rumen-protected canola oil and canola seed for 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 expeller-pressed canola 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.

More recently, fatty acids have been investigated to assess their influence on health and reproduction. Canola seed in prepartum diets has been evaluated in an unsuccessful attempt to improve calf health at birth, cow health and reproductive traits (Salehi et al., 2016a, 2016b). Cows were given control diets, or diets with canola seed (a source of C18:1 oleic acid) or sunflower seed (a source of C18:2 linoleic acid) during the dry period, and all cows received the same lactation diet after calving. Calf birth weights were greater with either oilseed as compared to the control. Adding oilseeds to the diet prepartum tended to increase reproductive disorders. Colostrum quality was improved when cows were given sunflower seed prepartum but not canola seed.

Methane is a greenhouse gas produced by rumen microbes that represents a loss in energy to the cow. Beauchemin et al. (2009) investigated the effects of long chain fatty acids on rumen methane production by incorporating crushed flax, sunflower or canola seed in lactation diets. Flax and sunflower seed are sources of polyunsaturated fatty acids, while canola is a source of monounsaturated fatty acids. All of the fatty acid sources reduced methane relative to the control. Dry matter digestibility was depressed with the flax and sunflower seed diets, but not with the diet containing canola seed. Cows were past lactation peak at the start of the study, and there were no differences in milk yield between treatments.

Canola Products in Rations for Beef Cattle

Canola meal has been demonstrated as a suitable protein source for beef cattle, capable of replacing several other vegetable protein products. As noted previously, canola meal has an energy value that is similar to barley (Nair et al., 2015, 2016) and has been shown to be a valuable source of energy for backgrounding and finishing cattle (Damiran and McKinnon, 2018).

In an early study, 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 these levels of inclusion. There were no differences in average daily gain. Diets with the highest level of canola meal increased DMI and reduced feed efficiency relative to the lower level and the barley control diet. Damiran and McKinnon (2018) replaced 10% and 20% of the barley in a balanced finishing diet with canola meal, and found no differences in performance from the control diet. 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 partially replaced wheat in the feed supplement. This was confirmed in a later study (Damiran et al., 2016).

In a heifer growth study, Llewellyn et al. (2015) supplemented a forage-based diet with farm processed canola meal, farm processed camelina meal or soybean meal. Average daily gains were 0.5, 0.34 and 0.42kg/day for the canola, camelina and soybean meal diets, respectively.

In addition to canola meal, wheat DDGS (wDDGS) is readily available in Western Canada. Li et al. (2014) supplemented diets for backgrounded heifers with canola meal, wDDGS, corn DDGS or high-protein corn DDGS with urea. All protein supplements improved performance and increased DMI relative to a low protein control. Total tract digestibility was highest with canola meal, and total protein entering the duodenum was highest for the high-protein corn DDGS plus urea diet. Good et al. (2017) compared 4 protein sources: canola meal, soybean meal, 50% canola meal and 50% wDDGS and finally 50% soybean meal and 50% wDDGS in diets for growing/finishing cattle. There were no differences in body weight gain or feed to gain ratio between the diets containing canola meal, soybean meal or canola meal plus wDDGS. However, the mixture of soybean meal with wDDGS had a negative effect on fattening and grade. Yang et al. (2013) found that 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 wDDGS.

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 revealed an improved fatty acid profile in beef in association with the lipid fraction of the meal.

Canola Products in Rations for Calves

There are only a few publications reviewing the use of canola meal in diets for calves before weaning. 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. Hadam et al. (2016) provided preweaned calves with diets that contained 24% soybean meal, 12.5% soybean meal plus 16.5% canola meal or 35% canola meal. There were 12 calves per treatment. No statistically significant differences were found in starter intakes for the first 35 days of life. However, intakes were numerically lower with the two diets containing canola meal. While again not statistically significant, feed efficiency favored the soybean meal diet. The researchers suggested that a flavour agent might have improved intakes with the very high canola meal diet.

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 after weaning. Corn DDGS could only partially be used to replace canola meal in diets for growing heifers from 12 months of age (Suarez-Mena et al., 2015) before digestibility and nitrogen retention declined.

Unlike canola meal, soybean meal contains high concentrations of phytoestrogens. Phytoestrogens can mimic the action of estrogen, and alter hormonal cycles (Woclawek-Potocka et al., 2005; Cools et al., 2014). 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. Proteins with low levels of phytoestrogens, such as canola meal, might provide an alternative if breeding difficulties arise.

Using Canola Meal for Small Ruminants

Canola meal is an ideal supplement for the production of wool and mohair, due to the high-sulfur 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. Asadollahi et al (2017) determined that a diet with 7% roasted canola seeds improved growth rates, intramuscular fat, loin eye area, and sensory characteristics of lambs as compared to a standard diet. 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 oil (Karami et al., 2013).

Canola meal can likewise be utilized in lactation diets of small ruminants. Andrade and Schmidely (2006) provided lactating goats with diets containing 0 or 20% rolled canola seed. Milk production was increased with the canola seed. Because the amino acid composition of goat milk is similar to cow milk, canola meal should be well suited for lactation.

Practical Inclusion levels of canola meal in ruminant diets

DIET TYPE	INCLUSION LEVEL
Preweaning calves	Up to 35%. Flavoring agent may be helpful
Growing calves, lambs and goats	No limit
Lactating cows and goats	No Limit
Backgrounding beef	No Limit
Finishing beef	No Limit

CH. 4 - THE VALUE OF CANOLA MEAL IN SWINE DIETS

Canola meal is well accepted by swine, and with improvements in diet formulation, it can be included at increasingly high levels in the diet during all phases of growth and reproduction. The widespread adoption of more accurate feed evaluation systems for energy and amino acids, along with greater knowledge of the nutritional composition of canola meal insure accurate feeding results.

Palatability and Feed Intake

The effect of a feed ingredient on feed intake in pigs is difficult to objectively evaluate, given the many factors involved. Variables such as basic palatability of the ingredient, dietary inclusion level, other ingredients in the feed mix, feed energy, 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 Chapter 2 of this guide. Certainly, glucosinolates represent a major negative influence on feed intake in pigs. Glucosinolates have a bitter taste that can result in the meal being objectionable to many animals. Canola meal produced in Canada, with its very low levels of glucosinolates (3.57μmol/g), has a very neutral taste. As mentioned in Chapter 2, traditional rapeseed meal can have glucosinolate levels of over 100μmol/g. Levels this high result in meal that can only be used in minimal amounts so as to avoid issues with feed intake.

Heyer et al.(2018) replaced 20% of the soybean meal in the control diet with solvent extracted canola meal, or canola meal that had been subjected to low, medium or high extruder intensity. Although the extrusion further reduced the glucosinolates content of the meal, there were no differences in feed intake by weaned pigs. Feed intake, weight gain and feed to gain ratio did not differ for any of the treatments, including the control. This study showed that further reduction of glucosinolates in canola meal would not benefit feed intake and that weaned pigs fed canola meal ate as much as pigs fed soybean meal.

Landero et al. (2018) 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.

Restrictions for inclusion levels of canola meal may remain in practice, but are being continually challenged and disproven by researchers. Improper feed quality evaluation information for digestible nutrients in canola meal has resulted in some problems with poorer pig performance in the past. 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. Ultimately, the relationship between ingredient cost and nutrient content will determine the appropriate level of inclusion of canola meal in well-formulated diets.

Energy for Swine

Canola meal is a coproduct that contains a relatively large amount of fibre and a complex carbohydrate matrix with limited digestibility. Diet formulation based on NE allows for the proper inclusion of canola meal in swine diets so as to not impact performance.

Table 1. Energy values for solvent extracted canola meal, as fed basis, Kcal/kg

REFERENCE	DIGESTIBLE ENERGY	METABOLIZABLE ENERGY	NET ENERGY
Berrocoso et al., 2015	3,084	2,922	1,928[1]
Heo et al., 2014	2,901	2,692	1,850
Kim et al., 2018	3,180	2,925	2,099
Le et al., 2017	2,605	2,409	1,765
Liu et al., 2014	2,883	2,681	1,769
Liu et al., 2016	2,630	2,303	1,520[1]
Liu et al., 2014	2,972	2,724	1,798[1]
NRC, 2012	3,154	2,903	1,821

[1]Calculated as ME x 0.66 (Kil et al, 2013)

Energy values published by the National Research Council (NRC, 2012) are given in Table 1 and are based on historical information, and more currently determined values have been added. While there appears to be a range in determined values, Kim et al (2018) recently reviewed the methods available for calculating NE and found that the results ranged from 1,960 to 2,233 kcal/kg as fed for canola meal.

lIt is therefore likely that the various methods in use add to the variability of published values.

The energy value of expeller and cold pressed canola meal vary with the amount of ether extract in the meal. Woyengo et al. (2016) provided the equation below to allow the adjustment of net energy values:

NE,kcal/kg = 0.700 × DE + 1.61 × EE + 0.48 × starch – 0.91 × CP – 0.87 × ADF, where NE = net energy, DE = digestible energy, EE= ether extract, CP = crude protein and ADF= acid detergent fiber.

Enzymes to improve energy

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. More recently, Velayudhan et al. (2018) noted numeric increases in ATTD for DM (3.6%) and gross energy (3.3%) when a multi-carbohydrase enzyme was included in canola meal diets for lactating sows. Sows lost less weight (5.3 vs. 3.3 kg) with no increase in intake with the enzyme supplemented diet.

The improvements in the above studies applied to the entire diet, and might be expected to vary depending upon how much canola meal was included in the diet. In vitro analyses are useful in that they permit the ingredient to be analyzed free of the remainder of the diet. In vitro dry matter digestion of both solvent extracted and expeller canola meal were improved by 8.7 and 9.2% respectively (Lee et al, 2018) with enzyme supplementation.

Amino Acids for Swine

Amino Acid digestibility

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 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. This is reviewed further in the section below titled Canola Meal in Starter Diets.

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 feed ingredient. Table 2a provides results from recent studies conducted to determine the standardized ileal digestibility of amino acids for solvent extracted canola meal and Table 2b shows results for expeller canola meal. While some of the references have imposed a variety of treatments, the values provided in Table 2a and 2b are for Brassica napus canola meal as would be available from Canadian processing plants.

Table 2a. Standardized ileal digestibility (SID) of amino acids in solvent extracted canola meal for growing pigs[1]

AMINO ACID	AVERAGE, %[2]	STANDARD DEVIATION
INDISPENSABLE		
Arginine	87.19	2.92
Histidine	77.46	9.11
Isoleucine	78.55	3.83
Leucine	81.20	2.96
Lysine	77.23	3.71
Methionine	85.44	3.18
Phenylalanine	80.48	5.61
Threonine	74.59	4.52
Tryptophan	82.93	4.08
Valine	76.46	3.95
DISPENSABLE		
Alanine	78.72	3.68
Aspartate + Asparagine	74.76	4.42
Cysteine	73.16	6.67
Glutamate + Glutamine	85.23	2.32
Glycine	77.63	6.77
Proline	82.83	8.51
Serine	77.25	4.44
Tyrosine	78.47	4.75

[1]Adewole et al., 2017; Almeida et al, 2014; Berrocoso et al., 2015; Flavero et al., 2014; le et al., 2017; Maison and Stein, 2014; Mejicanos and Nyachoti, 2018; Sanjayan et al., 2014; Trindade Neto et al., 2012

[2]Average of 29 values

Table 2b. Standardized ileal digestibility (SID) of amino acids in solvent extracted canola meal for growing pigs[1]

AMINO ACID	AVERAGE, %[2]	STANDARD DEVIATION
INDISPENSABLE		
Arginine	85.83	4.70
Histidine	83.77	2.32
Isoleucine	78.77	2.27
Leucine	77.13	7.21
Lysine	77.63	2.40
Methionine	83.73	4.55
Phenylalanine	78.77	4.89
Threonine	71.50	3.98
Tryptophan	84.30	2.40
Valine	74.07	6.53
DISPENSABLE		
Alanine	76.63	5.89
Aspartate + Asparagine	73.50	5.82
Cysteine	72.43	5.15
Glutamate + Glutamine	81.73	5.99
Glycine	68.40	13.50
Proline	90.80	-
Serine	74.80	4.01
Tyrosine	76.33	3.72

[1]Seneviratne et al., 2011; Grageola et al., 2013; Woyengo et al., 2016

[2]Average of 3 values

Amino Acid Profile

The amino acid profile of canola meal has been demonstrated to meet the amino acid needs of swine in a very efficient manner, with lysine being the first limiting amino acid. Because synthetic lysine is readily available, the addition of lysine to canola meal based diets results in a protein that will readily meet the needs of swine.

The convention used to evaluate amino acid profiles of ingredients is to determine the percentages of each essential amino acid relative to lysine. Interestingly, whether using the NRC (2012) or the European Institut National de la Recherche Agronomique (INRA) model (van Milgen and Dourmad, 2015) to assess amino acid requirements, canola meal stacks up almost perfectly (Table 3), particularly if lysine, the first limiting amino acid, is augmented. This means that pigs can use canola amino acids efficiently to support tissue gain.

Table 3. Ideal amino acid profile based on two models, and values for canola meal (% of Lysine)

AMINO ACID(S)	MODEL VALUES		CANOLA MEAL	
	INRA	NRC	AS IS	ADDED LYSINE[1]
Methionine	30	29	33	30
Methionine +Cysteine	60	56	63	58
Threonine	65	61	74	67
Valine	70	65	73	67
Isoleucine	55	52	59	54
Leucine	100	101	123	113
Phenylalanine	50	60	69	63
Phenylalanine + Tyrosine	95	94	109	100
Histidine	32	34	56	51
Arginine	42	46	108	99

[1]Lysine content of canola meal increased by 9% (lysine x 1.09)

Ether Extract

The lipid portion of canola meal has been shown to be highly digestible by swine. Seneviratne et al. (2011) found that the lipid component of expeller canola meal was 93.6% digested. Because canola oil is largely composed of monounsaturated fatty acids and low in saturated fatty acids, the digestibility is high.

Minerals and Vitamins

The mineral and vitamin profile of canola meal has been provided in detail in Chapter 2. In addition, there have been some revealing studies conducted specifically in swine with regards to calcium and phosphorus.

Canola meal is a rich source of phosphorus. Like many oilseed meals, a large portion of the phosphorus in canola meal is bound by phytic acid. It is common practice to add phytase enzyme to improve the digestibility of phosphorus and reduce the need for addition of this nutrient to the diet. Results from three studies (Akinmusire and Adeola, 2009; Flavelo et al., 2014; Adhekari et al., 2016) demonstrated that phosphorus digestibility can be increased in canola meal with the use of phytase from an average of 34 to 61%. Recently, Maison et al. (2015) analyzed five samples of canola meal and determined a greater digestibility value for phosphorus of 45%, a value that is higher than determined from older studies. Phytase supplementation still increased phosphorus digestibility to 64%, similar to the previous findings.

An added benefit of phytase supplementation is the improvement in calcium digestibility. González-Vega, et al. (2013) demonstrated that the addition of phytase enzyme increased the availability of calcium in canola meal from 47 to 70%. Similarly Adhikari et al. (2016) saw an improvement in calcium digestibility from 58% to 75%.

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 could tolerate in the diet was defined by several researchers. Bell (1993) proposed a maximum level in pig diets of 2.0 to 2.5μmol of glucosinolates/g of diet. Two subsequent studies supported this recommendation (Schöne et al., 1997a, 1997b). In the first of these two studies, 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 concentration greater than 2.4μmol/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 2.0μmol/g of diet (Schöne et al., 1997b). Given that Canadian canola meal contains, on average, 3.6μmol/g of glucosinolates, this would correspond to a maximum canola meal inclusion level of 55 to 69% 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), and starter pigs perform well with diets containing 40% canola meal (Parr et al., 2015). The maximum tolerable concentration of glucosinolates in swine diets remains of interest, but current levels of glucosinolates are demonstrating no limitations for canola meal inclusion in grower-finisher diets.

Feeding Solvent Extracted Canola Meal

Canola meal in starter diets

Historical feeding guidelines suggested that performance would suffer when young pigs were provided with diets in which canola meal comprised greater than 5% of the total (Bourdon and Aumaître, 1990; Lee and Hill, 1983). However, new research has brought to light a very different story on canola meal inclusion in starter pigs.

Landero et al.(2011) fed canola meal to weaned pigs with an average initial weight of 8.1 kg at inclusion levels of up to 200 g/kg without negatively impacting performance. This was demonstrated again in 2014 by Sanjayan et al., in a study where canola meal was included at 25% of the diet for weaned pigs (initial body weight of 7.26 kg), with highly acceptable performance results after the first week of the trial. To determine if the grain source included in the canola meal diet might make a difference, Mejicanos et al. (2017) provided diets to piglets (starting weight 6.7 kg on average) with 20% soybean meal compared to 20% canola meal and either wheat or corn as the primary grain. Performance of pigs with canola meal diets equaled that of soybean meal diets. The main difference in these three studies, compared to the earlier work, is that researchers formulated diets based on NE and SID amino acids.

Wang et al. (2017) fed newly weaned pigs with diets containing 20% canola meal. The 4 sources of canola meal tested were selected to show differences in quality characteristics as might occur with differing extremes in growing season. There were differences in apparent total tract digestibility between the soybean meal and canola meal diets, but no differences in digestibility between the 4 canola meal diets.

In another study, Parr et al, (2015) provided piglets with diets containing 10, 20, 30 or 40% canola meal, replacing soybean meal in the diets. There was a linear increase in gain to feed ratio as the canola meal inclusion increased. This important study shows that, with correct diet formulation, up to 40% canola meal can be included in starter diets for piglets.

Table 4 provides comparisons between canola meal and soybean meal as determined in recent studies for solvent extracted meal. In general, there were few statistically significant treatment effects on average daily gain (ADG) and gain per unit of feed.

Table 4. Studies evaluating solvent extracted canola meal in starter diets as compared to soybean meal control diets.

REFERENCE		CANOLA MEAL	CONTROL	P VALUE
Landero et al., 2011	Inclusion %	20	20	
	ADG, g	493	488	0.592
	Gain/feed	0.70	0.73	0.087
Mejicanos et al., 2017	Inclusion %	20	20	
	ADG, g	408	408	0.459
	Gain/feed	0.61	0.59	0.024
Parr et al., 2015	Inclusion %	40	28	0.951
	ADG, kg	0.57	0.56	0.001
	Gain/feed	0.68	0.59	
Sanjayan et al., 2015	Inclusion %	15	20	
	ADG, g	453	452	0.979
	Gain/feed	0.60	0.60	0.714
Seneviratne et al., 2011	Inclusion %	15	15	
	ADG, g	445	469	0.870
	Gain/feed	0.71	0.71	0.323
Wang et al., 2017	Inclusion %	20	20	
	ADG, g	664	660	0.457
	Gain/feed	0.66	0.65	0.047

Canola meal in growing finishing diets

Table 5 shows results from three recent growing-finishing studies. There were no differences in performance in the two studies in which canola meal was compared to solvent extracted soybean meal. Recently Smit et al. (2018) compared solvent extracted canola meal to expeller soybean meal and saw greater rates of gain and gain to feed ratio with the expeller soybean meal diet. The authors noted that the grower diet, containing 25% canola meal was abruptly introduced to the pigs, and they suffered reduced feed intakes for a short period afterwards. Feed intake did rebound, however gains and feed to gain ratio remained significantly different. If pigs are to be changed to very high levels of canola meal, it might be necessary to make the changes in stages.

Table 5. Studies evaluating solvent extracted canola meal in grow-finish diets as compared to soybean meal control diets.

REFERENCE		CANOLA MEAL	CONTROL	P VALUE
Kim et al, 2015	Inclusion %	11.3	27.3	
	ADG, g	700	725	0.102
	Gain/feed	0.46	0.44	0.196
Little et al., 2015	Inclusion %	27.3/23.2	21.0/18.0	
	ADG, kg	0.94	0.93	0.700
	Gain/feed	0.36	0.37	0.020
Smit et al., 2018[1]	Inclusion %	25/20	15/12.5	
	ADG, g	0.988	1.025	0.001
	Gain/feed	0.361	0.373	0.001

[1]The control diet was based on expeller soybean meal

Mexican feeding trials

Three feeding trials were conducted in three Mexican states — Nuevo León, Sonora and Michoacán (Hickling, 1996). The objective was to replicate the performance found in previously conducted Canadian feeding trials (Table 6), 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 low 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 7.

As with the temperate climate 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.

Table 6. Original Canadian 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]

	GROWER			FINISHER		
INGREDIENTS	SBM	LOW CM	HIGH CM	SBM	LOW 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	0.06	0.12	0.12	0.15
Minerals/vitamins	4	4	4	4	4	4
PERFORMANCE						
Average daily feed, kg	1.91	1.93	1.89	3.06	3.11	3.08
Average daily gain, kg	0.76	0.76	0.77	0.84	0.83	0.82
Feed/gain	2.52	2.52	2.46	3.64	3.75	3.75
NET PERFORMANCE						
DIET	SBM		HIGH CM		HIGH CM	
Average daily feed, kg	2.46		2.50		2.47	
Average daily gain, kg	0.80		0.80		0.80	
Feed/gain	3.08		3.13		3.10	
Dressing , %	78		78		78	
Backfat index	107		107		107	

[1]Hickling, 1994

Table 7. 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]

	GROWER			FINISHER		
INGREDIENTS	SBM	LOW CM	HIGH CM	SBM	LOW CM	HIGH CM
Sorghum or corn	72	68	67	76	72	70
Soybean meal	24	19	16	20	13	10
Canola meal	-	8	12	-	10	15
Tallow	-	1	2	-	1	2
L-Lysine	-	0.33	0.47	-	0.5	0.7
Minerals/vitamins	4	4	4	4	4	4
PERFORMANCE						
Average daily feed, kg	2.17	2.23	2.18	3.22	3.21	3.12
Average daily gain, kg	0.78	0.77	0.76	0.85	0.83	0.82
Feed/gain	2.78	2.87	2.86	3.79	3.85	3.79

NET PERFORMANCE			
DIET	SBM	HIGH CM	HIGH CM
Average daily feed, kg	2.72	2.74	2.67
Average daily gain, kg	0.82	0.81	0.80
Feed/gain	3.32	3.39	3.35
Meat yield , %	48.6	48.8	49.3
Backfat, cm	2.38	2.33	2.15

[1]Hickling, 1996

Canola meal in gestation and lactation diets

Early studies showed that canola meal is readily accepted in diets for sows and gilts. 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. Other studies indicated that levels of 20% canola meal did not affect performance of lactating sows (King et al., 2001). These results suggest that canola meal may represent the main supplemental protein source in gilt and sow diets.

More recently, Velayudhan and Nyachoti (2017) provided sows with diets containing 0, 15 or 30% canola meal from the time they were moved to the farrowing room until weaning at 21 days of lactation. The researchers determined that there were no effects of treatment on body weight change or change in backfat thickness, and that both piglet growth and milk composition were not influenced by the diets. There were likewise no differences in the weaning to estrus interval. The researchers concluded that up to 30% canola meal can be included in diets for sows with no loss in performance by sows or their litters. A follow up study (Velayudhan et al., 2018) confirmed that sow performance was optimal when up to 30% canola meal was included in the diet.

In another recent study (Liu et al., 2018) sows were allocated diets that replaced 0, 50 or 100% of soybean meal in the diet starting from day 7 of gestation through to weaning. The highest level of canola meal was 23.3% of the gestation diet, and 35.1% in the lactation diet. Piglet survival was significantly greater with the diets containing canola meal, but the weaning to estrus interval was slightly higher with the highest canola meal diet than with the control diet (Table 8).

Table 8. Sow and litter performance[1]

PARAMETER	DIET			P VALUE
	SOYBEAN MEAL	SOY/CANOLA MEAL	CANOLA MEAL	
Number of sows	40	37	37	
Average parity	2.33	2.32	2.33	
Overall body weight loss, kg	28.2	27.2	32.8	0.22
Pigs born alive/litter	12.5	11.9	12.2	0.76
Litter birth weight, kg	18.7	19.1	19.2	0.65
Piglet survival, %	80.2	87.0	87.0	<0.05
Weaning to estrus, days	5.42	5.22	5.80	<0.05

[1]Liu et al., 2018

Feeding Expeller Meal

As would be expected, there is no loss in performance when pigs receive expeller canola meal. Seneviratne et al. (2011) provided weanling pigs with diets enriched with 15% canola meal in exchange for 15% soybean meal (Table 9). There were no differences in ADG or gain to feed ratio in that study. Landero et al., 2012 feed diets containing 5, 10, 15 and 20% canola meal, substituted for soybean meal to pigs, starting at 26 days of age and continuing until 54 days of age. There were no differences in performance for any of the treatments. Diets were formulated to the same NE and SID levels. Apparent total tract digestibility of protein and energy declined linearly as the inclusion level of the canola meal increased.

Table 9. Studies evaluating expeller canola meal in starter diets as compared to soybean meal control diets.

REFERENCE		CANOLA MEAL	CONTROL	P VALUE
Landero et al., 2015	Inclusion %	20	20	
	ADG, g	455	454	0.933
	Gain/feed	0.71	0.72	0.757
Seneviratne et al., 2011	Inclusion %	15	15	
	ADG, g	445	469	0.870
	Gain/feed	0.72	0.71	0.323

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.

Practical Inclusion levels of canola meal in swine diets

DIET TYPE	INCLUSION LEVEL	REASON
Piglet starter diets	40%	High performance reported up to 40%
Hog grower finisher diets	25%	No practical data available beyond 25%
Sow gestation	25%	No practical data available beyond 25%
Sow lactation	35%	High performance reported up to 35%

CH. 5 - THE VALUE OF CANOLA MEAL IN DIETS FOR POULTRY

Canola meal is fed to all types of poultry throughout the world. The meal provides an excellent amino acid profile and is an alternative to, or complement to other protein ingredients such as soybean meal. Canola meal provides excellent value in diets where the greatest emphasis in formulation is placed on amino acid balance. Canola meal can also be a cost effective alternative to other proteins in high energy broiler diets. Care must be taken to formulate diets on a digestible amino acid basis to ensure performance is optimal when canola meal is included in diets for poultry.

Palatability and Feed Intake

In general, poultry animals will maintain appropriate feed intake levels when given diets high in canola meal that are formulated for available amino acids. However, studies in raising poultry suggest that canola meal might need to be restricted during the starter period to 20% for broilers and turkeys, and 10% for more exotic ducks, geese and quail. Concentrations of 30% to 40% of the diet are readily tolerated at later stages of growth. Oryschak and Beltranena (2013) and Rogiewicz et al. (2015) demonstrated that proper diet formulation can allow for canola meal to be included at 20% of the diet with no effect on feed intake in the diet of laying hens. 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 given diets with up to 30% canola meal (Newkirk and Classen, 2002; Ramesh et al., 2006).

Energy for Poultry

Canola meal has a lower energy value for poultry compared with the most common vegetable protein source, soybean meal. In certain diets, such as for broilers, the greater emphasis placed on the value of energy may 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/kg greater than previously published.

Enzymes to increase energy

The use of dietary enzymes is common in poultry feeds, especially those containing barley and wheat, and these have been demonstrated to improve carbohydrate digestibility. Canola meal contains a significant portion of cell wall components that are undigested by poultry. A number of researchers have fed dietary enzymes in an attempt to increase 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 polysaccharide (NSP) degrading enzymes to improve canola meal digestibility have 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 digestibility values 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, and found a 6% increase in AMEn. Gallardo et al. (2017) calculated an 8% improvement in the energy value of canola meal. However, increases in AMEn of only 2.5% and 2.9% with the use of multi-carbohydrase enzymes were witnessed by Rad-Spice (2017) and Jayaraman et al. (2016). Although the data is not completely conclusive, moderate enhancement of canola meal digestion may occur, and the enzymes may likewise improve the digestibility of other dietary ingredients.

Table 1. Energy values of Canola meal for Poultry (AMEn, Kcal/kg)

REFERENCE	SPECIES	12% MOISTURE BASIS	DRY MATTER BASIS
Adewole et al., 2017	Broilers	1777	2019
Chen et al., 2015	Broilers	1983	2254
Gallardo et al., 2017	Broilers	1822	2071
Gorski et al., 2017	Broilers	1851	2217
Jayaraman et al., 2016	Broilers	2144	2437
Jia et al., 2012	Broilers	1810	2057
Rad-Spice, 2017	Broilers	1834	2084
Rahmani et al., 2017	Broilers	1789	2032
Jia et al., 2012	Laying hens	1936	2200
Jia et al., 2012	Turkeys	1766	2007
Kozlowski et al., 2018	Turkeys	1886	2143
Wickramasuriya et al., 2015	Ducks	1885	2142
Mandal et al., 2005	Quail	1852	2105

Amino Acids for Poultry

The key to feeding high inclusion levels of canola meal in diets for poultry is to balance the diets on an available amino acid basis. Extensive research has been conducted in recent times to determine the standardized ileal digestibility (SID) of amino acids from Canola meal. Results for broilers are provided in Table 2.

Table 2. Standardized ileal digestibility (SID) of amino acids in solvent extracted canola meal for growing broilers[1]

AMINO ACID	AVERAGE, %[2]	STANDARD DEVIATION
Indispensable		
Arginine	87.26	2.64
Histidine	71.21	13.86
Isoleucine	81.08	2.99
Leucine	83.96	2.32
Lysine	78.77	2.17
Methionine	88.88	2.59
Phenylalanine	84.00	2.02
Threonine	76.21	3.25
Tryptophan	90.68	5.83
Valine	78.60	1.93
Dispensable		
Alanine	82.34	2.42
Aspartate + Asparagine	78.59	3.35
Cysteine	75.69	4.97
Glutamate + Glutamine	87.84	3.39
Glycine	79.71	3.13
Proline	78.17	3.23
Serine	77.95	2.50
Tyrosine	85.15	5.90

[1]Adewole et al., 2017, Chen et al., 2015, Gallardo et al., 2017,Kim et al., 2012, Kong and Adeola, 2013

[2]Average of 24 values

Fewer values are available for other classes of poultry (Table 3). It may be possible to use the SID values from broilers for species where data have not been determined. Huang et al. (2006) found that there were no differences in apparent ileal digestibility of amino acids between broiler chicks, laying hens and adult roosters , which is not the case for all feed ingredients (Adedokun et al, 2009; Huang et al., 2006).

Table 3. Standardized ileal digestibility (SID) of amino acids in solvent extracted canola meal for poultry

AMINO ACID	LAYERS[1]	TURKEYS[2]	DUCKS[3]
Indispensable			
Arginine	88.0	88.0	86.1
Histidine	83.0	73.5	81.0
Isoleucine	77.5	71.5	81.0
Leucine	80.5	75.0	86.5
Lysine	81.0	77.5	75.8
Methionine	88.5	79.0	86.5
Phenylalanine	81.0	85.0	85.6
Threonine	71.5	74.5	75.9
Tryptophan	77.5	-	87.4
Valine	78.0	70.5	79.0
Dispensable			
Alanine	79.0	78.0	81.3
Aspartate + Asparagine	76.0	80.0	75.8
Cysteine	79.0	69.5	-
Glutamate + Glutamine	87.0	84.0	87.4
Glycine	76.0	84.0	76.1
Proline	-	72.0	85.5
Serine	72.0	81.5	86.6
Tyrosine	78.0	73.0	81.3

[1]Saki et al., 2017b; Huang et al., 2006

[2]Koslowski et al., 2011; Koslowski et al., 2018; Huang et al., 2006

[3]Kong and Adeola, 2013

Minerals and Vitamins

The complete mineral and vitamin profile from canola meal is provided in Chapter 2. These values can be used as guidelines in formulations.

Phosphorus

Canola meal is notably a rich source of phosphorus, which is a critical nutrient for all classes of poultry. In the past, only the non-phytate portion of the phosphorus in canola meal was assumed to be available, which is approximately 35% of the total phosphorus of the meal. However, using the ileal digestibility technique, Mutucumarana et al. (2014) calculated that 47% of the phosphorus in canola meal was digestible, and that a portion of the phytate phosphorus was digested by birds. Phytase enzymes may be added to the feed, but results with phytase in poultry have largely been disappointing (Slominski, 2011; Kong and Adeola, 2011). In contrast, phytase has been shown to be effective in improving phosphorus bioavailability in rapeseed meal varieties (Czerwiński et al., 2012).

Cation-anion balance

It is common practice to formulate diets based on cation-anion balance. Canola meal is high in sulfur, which can interfere 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. Adding potassium bicarbonate to diets is a better alternative, as this corrects the problem at its source. Canola meal contains less potassium (1.2%) than soybean meal (1.9%), so the electrolyte balance is lower in a diet based on canola meal than a soybean meal based diet.

Broiler Chickens

Unlike rapeseed meal, canola meal does not need to be restricted on the basis of the glucosinolate contribution to the diet. The very low levels of glucosinolates that are present in Canadian canola meal have eliminated concerns for this anti-nutrient in practical feeding situations.

Recent improvements in understanding requirements of broilers have led to the development of routine formulation procedures that have permitted greater amounts of canola meal to be included in today's diets for broilers. As noted, it is now common practice to formulate diets based on cation-anion balance. Feed intake in broilers has been correlated with the cation-anion balance of the diet based on some pioneering investigations into feeding canola meal to poultry (Summers and Bedford, 1994).

In addition, formulating diets on the basis of SID has resulted in weight gains that are nearly identical to those found with other protein ingredients, particularly during the grower period. Recent research suggests that up to 30% canola meal can be used in broiler diets. Gorski et al (2017) provided starter diets (1-21 days of age) to broilers that contained 0, 10, 20, 30 and 40% canola meal. Weight gains were reduced with the 30 and 40% inclusion rates, due to lower feed intakes for these diets. Grower diets, provided from 21 to 37 days of age contained 0, 10, 20 or 30% canola meal. There were no differences in average daily gain or feed intake between diets during the growing period.

Gopinger et al. (2014) formulated diets with 0, 10, 20, 30 and 40% canola meal, which was provided to the birds from 7 to 35 days of age. Growth rates were greater with the 10, 20 and 30% canola meal diets than with the soybean meal control, but declined with the 40% canola meal diet. There was no decline in growth rates from 15 to 35 days of age with the highest level of canola meal in the diet. Looking at these two studies, it would appear that canola meal inclusion levels of up to 20% for 0-7 days, 30% from 7-14 days and up to 40% beyond are possible.

In similar fashion, Ariyibi (2019) fed diets to broilers that contained 6 incremental levels of canola meal ranging from 0 to 15% from 1 through 7 days of age, 0 to 18% from 7 through 14%, 0 to 25% from 14 through 21 days of age, and 0 to 35% from 21 through 28 days of age. Increasing levels of canola meal had no effect on growth performance. These results are in agreement with older studies (Newkirk and Classen, 2002; Naseem et al., 2006) and demonstrate the versatility of canola meal for broiler chickens.

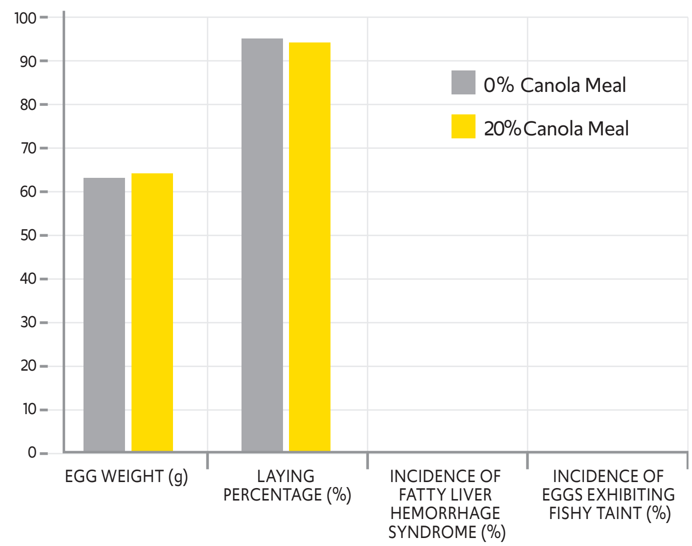
Laying Hens

Canola meal is a commonly fed and economically effective feed ingredient in commercial egg layer diets. As with broiler diet formulation, SID amino acids must be considered. Early research, where diets were formulated on a crude protein basis, showed a reduction in egg weight when canola meal was substituted for soybean meal. Diets formulation on a crude protein basis resulted in insufficient lysine content in the canola meal diet (Kaminska, 2003). Previous published research by Novak et al. (2004) supported the hypothesis that insufficient lysine can affect egg weight. These researchers increased lysine intake from 860 mg/d to 959 mg/d and observed an increase in egg weight from 59.0 g to 60.2 grams.

Traditionally, including canola meal in laying-hen diets was limited to a maximum of 10%, due to a potential association between liver hemorrhage mortality and feeding older varieties of canola meal (Butler et al., 1982; Campbell and Slominski, 1991). The authors suggested that this could have been the result of residual glucosinolate content found in these early varieties of canola (Campbell and Slominski, 1991). Plant breeding has steadily reduced the level of glucosinolates to the point where they are currently less than one-third of those found in the first canola varieties that were fed in these studies. More recent studies with laying hens have demonstrated excellent performance with high levels of canola meal inclusion in the diet.

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. As Figure 1 shows, egg weights and laying percentage were maintained for the duration of the 36 week-long study. There were also no differences in liver hemorrhage in the hens, and there was no detectible fishy odor in the eggs. Rogiewicz et al. (2015) sililarly demonstrated excellent performance of hens fed 15–20% canola meal. Gorski (2015) provided hens from 33 to 49 weeks of age with diets containing 0 (soybean meal control) 8, 16, or 24% canola meal. They found no differences between treatments in feed intake, egg production, egg weight, or change in weight of the hens over the course of the 16-week study.

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

In yet one more study (Savary et al., 2017), hens were given diets containing soybean meal as the major protein source, or 10 or 20% canola meal. The experiment was analyzed for 4 feeding periods: 30 to 41, 42 to 49, 50 to 61 and 62 to 78 weeks of age. There were no differences in egg production, feed efficiency, or mortality for any of the feeding phases. Furthermore, the researchers noted that there were no differences in egg quality or hen weights.

Based on these recent findings, canola meal can be fed effectively at elevated levels in laying hen 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. Laying hens have repeatedly demonstrated an ability to handle high levels of canola meal.

Broiler Breeders

There is limited new research on the use of canola meal in broiler breeders, likely because much of the results from laying hens are applicable to these birds. The high-protein and high-fibre content of canola meal makes it an ideal feedstuff to manage weight gain in broiler breeder birds. Older research showed that canola meal has no negative effects on egg fertility or hatchability of leghorn breeders (Kiiskinen, 1989; Nasser et al., 1985). 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. Use of canola meal for broiler breeders can be justified due to the extensive information available for laying hens and other poultry.

Turkeys

Canola meal is an excellent protein source for growing turkeys. It is common commercial practice to feed high dietary concentrations of canola meal to growing and finishing turkeys.

It has long been known that the key to using canola meal for turkeys successfully is to insure the diets are balanced for amino acids. Early on, Waibel (1992) demonstrated that 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 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.

More recently, Kozlowski et al. (2018) verified that starter and grower diets with 20% canola meal resulted in growth rates that were similar to those obtained with soybean meal. Feed to gain was found to be slightly higher in the starter phase for the canola meal diet (1.43 for canola meal as compared to 1.36 for soybean meal) but this could be reduced to 1.37 with the inclusion of multi-carbohydrase enzymes. There were no differences in average daily gain, feed intake or feed efficiency due to treatment over the length of the 8 week-long study. Similarly, Noll et al. (2017) provided starter turkeys with diets containing 0 (soybean meal control), 8, 16 or 24% canola meal. The researchers found no differences in any performance parameters measured. A follow-up shorter study, conducted during the very sensitive first 3 weeks of life noted that up to 24% canola meal could be provided to starter turkeys (Noll et al., 2017).

Commercially, 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. The dietary electrolyte balance of canola meal (Na + K–Cl) is approximately 307mEq/kg. However, canola meal contains a significant amount of sulfur, and this should also be considered: (Na + K) – (Cl + S) = 103 mEq/kg) (Khajali and Slominski, 2012).

Ducks and Geese

Ducks and geese represent the third largest source of poultry meat, and these birds are also prized for their eggs and feathers. Canola meal is commonly fed to ducks and geese, and with no reported issues resulting from the use of the meal.

Wickramasuriya et al. (2015) determined that the first limiting amino acid for ducks is methionine, and found that canola meal represented a well-balanced amino acid profile for these birds. In addition, the higher available phosphorus as compared to soybean meal is a desirable attribute. Bernadet et al. (2009) studied the effects of rapeseed meal on the growth of mule ducks and noted that inclusion level would be limiting due to glucosinolates, which were not measured in their study. They did, however, determine that concentrations of 7% rapeseed meal in the starter period, and 21% in the grow finish period allowed for excellent growth. This suggests that at least these amounts of canola meal can be included in diets for ducks.

Geese have a greater digestive capability than other types of poultry, and appear to digest canola meal efficiently (Jamroz, et al., 1992). The amino acid digestibility of canola meal in ducks is shown in Table 3. Canola meal and soybean meal have similar amino acid digestibility in ducks (Kluth and Rodehutscord, 2006).

Quail

Quail are raised for eggs as well as meat. Saki et al. (2017b) evaluated canola meal for quail hens at 10, 20 or 30% of the diet from 46 to 56 weeks of age. Production declined at the 20 and 30% level of inclusion, but there were no differences in performance at the 10% inclusion rate. The authors noted that this would allow 1/3 of the soybean meal to be replaced for canola meal. In an earlier study (Sarıçiçek et al., 2005), researchers replaced 0, 25 or 50% of the soybean meal in the diet for quail hens (0, 9.25 or 18.5% of the total diet as canola meal). In this 126 day-long study, there were no differences in hen body weight change, feed efficiency, % lay or egg mass.

Table 4. Growth of quail in a study involving canola meal as compared to soybean meal[1]

	DIET		
	CONTROL	LOW CANOLA MEAL	HIGH CANOLA MEAL
Indispensable			
Percent of protein	0	25	50
Percent of diet	0	12.15	24.3
	NO ENZYMES		
Weight gain, g	150	144	132
Feed intake	761	751	740
Feed/gain	5.06	5.22	5.59
	ENZYMES		
Weight gain, g	143	142	147
Feed intake	738	753	755
Feed/gain	5.16	5.13	5.16

[1]Sarıçiçek et al, 2005

Sarıçiçek et al. (2005) also compared canola meal to soybean meal in a quail growth study (Table 4). Again, 0, 25 or 50% of the protein from soybean meal was replaced with protein from canola meal, resulting in diets with 0, 12.15 and 24.3% total canola meal. In addition, multi-carbohydrase and phytase enzymes were tested for their ability to improve digestibility. Growth rates with the 50% canola meal were lower than the control when no enzymes were added to the diet. When the enzymes treatments were supplied, there were no differences in growth, feed intake or feed to gain for all three treatments.

Expeller Canola Meal for Poultry

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, and it can be included as the sole source of protein in the diet without additional fat. A number of recent studies have been conducted to determine the AMEn value of expeller canola meal for growing broilers (Table 5). As can be seen from the table, the oil content of expeller meal can vary with source, and the energy value increases with oil content. 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 from other sources.

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.

Table 5. Determined AMEn of expeller canola meal for broilers (Kcal/kg)

REFERENCE	OIL, % OF DM	AMEn, 12% MOISTURE BASIS	AMEn, DM BASIS
Bryan et al., 2017	10.1	2,053	2,333
Bryan et al., 2017	14.2	2,294	2,607
Kong and Adeola, 2016	13.9	2,376	2,697
Toghyani et al, 2014	8.3	1,987	2,258
Woyengo et al., 2010	12.0	2,370	2,694
Feed/gain	5.16	5.13	5.16

It should be borne in mind that the oil content of expeller meal is due to the efficiency of the type of press used, so the product should be tested and the energy value adjusted accordingly. Each percentage of fat provides approximately 80 kcal of added energy.

Table 6. Standardized ileal digestibility (SID) of amino acids in expeller canola meal for growing broilers[1]

AMINO ACID	AVERAGE[2]	STANDARD DEVIATION[3]
Indispensable		
Arginine	83.60	3.65
Histidine	71.01	12.15
Isoleucine	76.23	6.77
Leucine	78.93	2.67
Lysine	79.55	1.00
Methionine	85.18	2.91
Phenylalanine	80.38	2.03
Threonine	76.68	4.20
Tryptophan	80.00	5.77
Valine	77.33	4.43
Dispensable		
Alanine	80.40	1.76
Aspartate + Asparagine	77.80	2.91
Cysteine	75.80	2.17
Glutamate + Glutamine	84.13	6.66
Glycine	81.78	5.41
Proline	74.98	1.74
Serine	77.95	3.26
Tyrosine	74.50	6.14

[1]Woyengo et al., 2010; Toghyani et al, 2014; Toghyani et al., 2015; Bryan et al., 2017

[2]N = 16

As table 6 illustrates, the digestibility of the amino acids in expeller canola meal is similar to values obtained with solvent extracted meal, provided excess heating is not applied. Bryan et al (2017) demonstrated that subjecting the meal to high heat can result in decreasing the digestibility of the amino acids.

Canola Seed and Oil

Canola seed is rich in oil, and can be used as an energy source. Toghyani et al (2017) analyzed six samples of seed, representing the range in composition. AMEn for growing broilers ranged from 4,501 to 4,791 and averaged 4,554 kcal/kg (dry matter basis). The variation could largely be explained by the variability in oil content, which ranged from 40.8 to 47.9% of the seed. This recently determined energy value for the seed was similar to the previously determined value (Barekatain et al., 2015) of 4,691 kcal/kg of dry matter.

Canola oil is routinely fed as an energy source to broiler chickens. In addition to its energy value, it is an excellent source of unsaturated fatty acids. Kanakri et al (2018) fed broiler chickens diets containing approximately 3% added fat from beef tallow, flaxseed oil, corn oil, canola oil, macadamia oil or coconut oil. While there were no differences in growth performance between the different types of fat provided, the tissue fatty acid compositions of the birds reflected the varying fat sources provided. Muscle tissues from birds given canola oil had the lowest concentrations of saturated fatty acids, and were second only to birds fed flax oil in omega 3 fatty acid content of muscle.

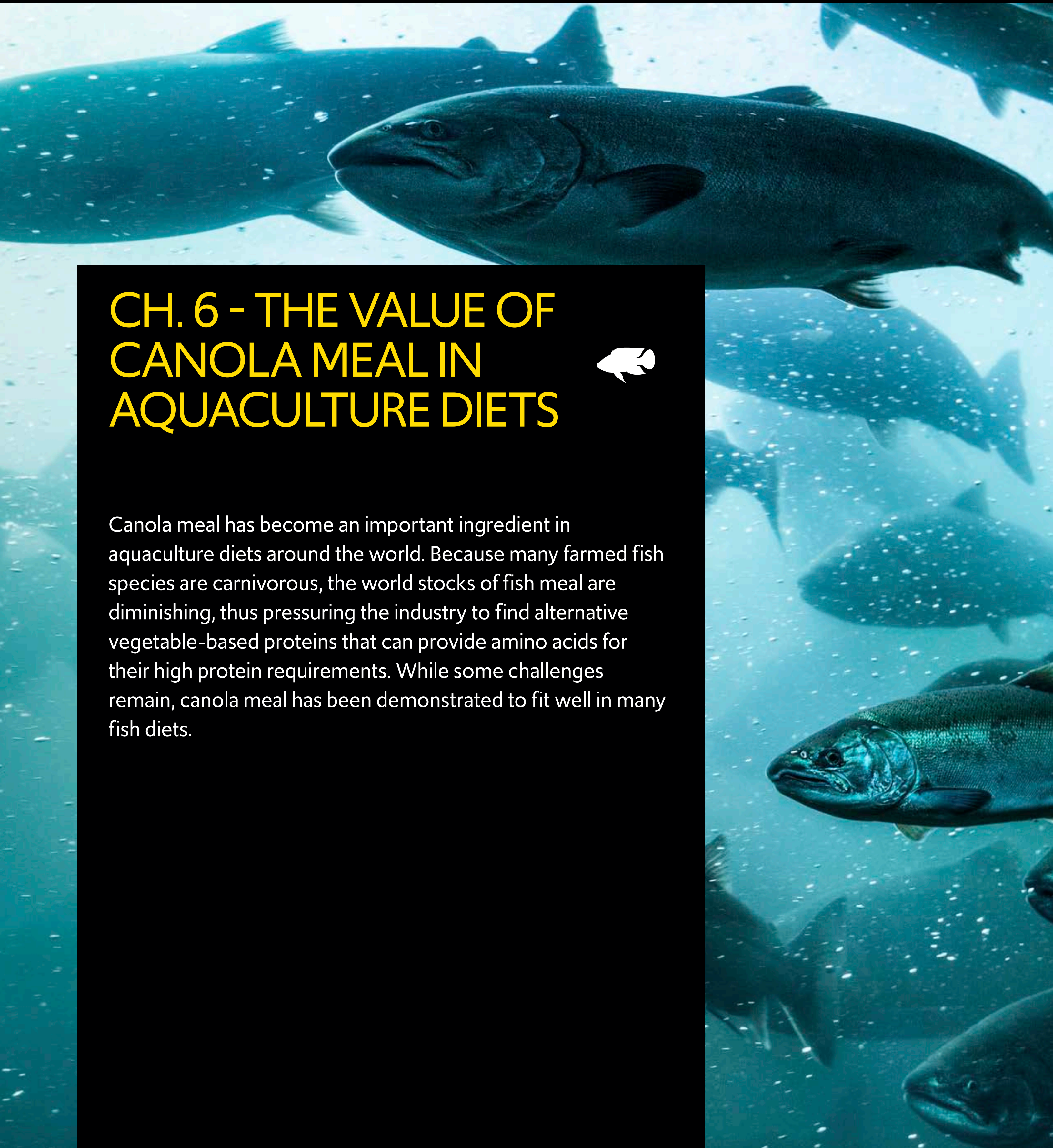
The ratio of linoleic acid (omega 6) to linolenic acid (omega 3) is approximately 2:1, as compared to 7:1 for soybean oil and 50:1 for corn oil. This is of importance, because a common desaturase enzyme is used to elongate both fatty acids. Birds have the ability to elongate linolenic acid to docosahexaenoic acid (DHA). Excess linoleic acid limits the conversion (Cachaldora et al., 2008).

With the hens' ability to synthesize DHA from linolenic acid, eggs commonly provide an important and economical dietary supply of long chain omega 3 fatty acids. The fatty acid profile of the basal diet is the key to the success of producing DHA enriched eggs when the diets are supplemented with linolenic acid from sources such as flax oil or chia oil, and canola based diets have been shown to be superior to diets where major ingredients contribute competing linoleic acid (Gonzalez-Esquerra and Leeson, 2001;

Goldberg et al., 2016). In addition, Rowghani et al. (2007) showed that adding between 3 to 5% canola oil to corn-soybean meal diets resulted in over 8 times greater concentrations of DHA in eggs than diets without oil addition.

Practical inclusion levels of canola meal in poultry diets

DIET TYPE	INCLUSION LEVEL	REASON
Chick starter	20%	Intakes may be reduced with higher inclusion
Broiler grower	30%	High performance results reported at 30% inclusion
Broiler finisher	40%	High performance results reported at 40% inclusion
Layers	24%	No data available beyond 24%
Broiler breeders	30%	Limited data available
Turkey starter	24%	No data available beyond 24%
Turkeys grower	24%	No data available beyond 24%
Ducks and Geese starter	7%	Limited data available
Ducks and Geese grower	21%	No data available beyond 21%
Quail	18.5%	Limited data available



CH. 6 - THE VALUE OF CANOLA MEAL IN AQUACULTURE DIETS

Canola meal has become an important ingredient in aquaculture diets around the world. 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.

Palatability and Feed Intake

Canola meal is a palatable source of protein for aqua diets. In some older studies as well as feeding experiments involving rapeseed meal, palatability was sometimes reduced due to the bitterness imparted by glucosinolates. As Chapter 2 shows, levels of glucosinolates in canola meal are now quite low. In clear contrast to older studies, soluble canola protein concentrate has successfully been used as an attractant for diets in which fish meal concentrations have been reduced (Hill et al., 2013). 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.

Rather than palatability, intake of canola meal is often limited by the nutrient requirements of the species for which the feeds are being formulated. For example, carnivorous fish have very high protein requirements, and a low tolerance for carbohydrates. Omnivorous species on the other hand have a greater tolerance for carbohydrate.

Table 1. Average canola meal inclusion levels in diets of carnivorous fish with no compromise in performance over the standard diet.

SPECIES	SCIENTIFIC NAME	AVERAGE INCLUSION
Carnivorous Marine		
Rainbow trout[1]	Oncorhynchus mykiss	20
Atlantic Salmon[2]	Salmo salar	10
Barramundi[3]	Lates calcarifer	30
European Sea bass[4]	Dicentrarchus labrax	25
Japanese seabass[5]	Lateolabrax japonicus	15
Carnivorous Freshwater		
Freshwater Angelfish[6]	Pterophyllum scalare	8
Piavucu[7]	Leporinus macrocephalus	38
Sunshine bass[8]	Morone chrysops	20

[1]Thiessen et al., 2003; Thiessen et al., 2004; Yigit et al., 2012; Collins et al, 2012; Collins et al., 2013. [2]Burr et al., 2013; Collins, et al., 2013. [3]Ngo et al., 2016. [4]Lanari and D'Agaro, 2005. [5]Cheng et al., 2010 [6]Erdogan and Olmez, 2009. [7]Galdioli et al., 2001; Soares et al., 2000. [8]Webster et al., 2000

As Table 1 shows, inclusion levels may be limited to 30% or less for carnivorous species, but inclusions have been demonstrated to be considerably greater for a number of commercially important omnivorous species (Table 2).

Table 2. Average canola meal inclusion levels in diets of omnivorous fish with no compromise in performance over the standard diet.

SPECIES	SCIENTIFIC NAME	AVERAGE INCLUSION
Omnivorous-Marine		
Australasian snapper[1]	Pagrus auratus	60
Omnivorous-fresh water		
Silver perch[2]	Bidyanus bidyanus	60
Streaked prochilod[3]	Prochilodus lineatus	8
Rohu (carp)[4]	Labeo rohita	20
Wuchang bream[5]	Megalobrama amblycephala	35
Nile tilapia[6]	Oreochromis niloticus	33
Black carp[7]	Mylopharvngodon piceus	11
Grass carp[8]	Ctenopharyngodon idella	37
Pacu[9]	Piaractus mesopotamicus	19
Mori[10]	Cirrhinus mrigala	24
Pangasius catfish[11]	Pangasius sutchi	30

[1]Glencross et al., 2004. [2]Booth and Allan, 2003.: [3]Galdioli et al., 2002; [4]Iqbal et al., 2015; Umer and Ali, 2009; Parveen et al., 2012; Umer et al., 2011. [5]Zhou et al., 2018. [6]Yigit and Olmez, 2009; Zhou and Yue, 2010; Luo et al, 2012; Mohammadi et al., 2016; Fangfang et al., 2014; Soares et al., 2001. [7]Huang et al., 2012. [8]Veiverberg et al., 2010; Jiang et al., 2016. [9]Viegas et al, 2008. [10]Parveen et al., 2012. [11]Van Minh et al., 2013

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 less than 40% crude protein as fed, this limits the feasible inclusion rate of canola meal to below 20% when formulating practical diets for carnivorous species like salmonids. However, in omnivorous or herbivorous fish, such as carp and tilapia, dietary crude protein requirements are considerably lower, and this limitation does not apply.

The digestibility of dry matter (Tables 3 and 4) and energy (Tables 5 and 6) in canola meal is highly variable, due to the varied digestive systems of fish species farmed around the world. As well, processing systems used in the manufacturing of vegetable protein sources influence the extent of digestibility, and these have varied widely from study to study.

As with swine and poultry, the method of formulation impacts the nutritive worth and feeding value of canola meal. 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 post-extraction 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.

Fibre is not digested in monogastric animals to any appreciable extent, and this applies to aquaculture species as well. Plant fibre can be divided into two categories: soluble fibre (oligosaccharides) that increases intestinal viscosity and insoluble fibre that increases bulk. Canola meal contains approximately half as much soluble fibre as soybean meal (Mejicanos et al., 2016). Modest amounts of insoluble fibre can improve transit time and feed intake, but large amounts result in too much bulk, depending upon the species of fish at hand. 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.

Table 3. Average apparent dry matter digestibility (%) of canola meal for carnivorous and omnivorous fish as determined in studies published since 2000.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Carnivorous-Marine		
Rainbow trout[1]	Oncorhynchus mykiss	73.4
Atlantic Salmon[2]	Salmo salar L	76.2
Arctic Char[3]	Salvelinus alpinus	46.8
Turbot[4]	Scophthalmus maximus	57.1
Barramundi[5]	Lates calcarifer	41.2
European sea bass[6]	Dicentrarchus labrax	71.2
Yellowfin sea bream[7]	Acanthopagrus (Sparus) latus	33.5
Cobia[8]	Rachycentron canadum	58.5
Atlantic cod[9]	Gadus morhua	49.6
Meagre[10]	Argyrosomus regius	44.1
Omnivorous-Marine		
Haddock[11]	Melanogrammus aeglefinus	58.9
Australasian snapper[12]	Pagrus auratus	19.6*

[1]Mwachireya et al., 2000; Burel et al., 2000; Dalsgaard et al., 2012. [2]Burel et al., 2000; Dalsgaard et al., 2012. [3]Burr et al., 2011. [4]Burel et al., 2000. [5]Ngo et al., 2015. [6]Igbal et al., 2015. [7]Wu et al., 2006. [8]Zhou et al., 2004. [9]Tibbets et al, 2006. [10]Rodrigues Olim, 2012. [11]Tibbetts et al., 2004. [12]Glencross et al., 2004a.

Table 4. Average apparent dry matter digestibility (%) of canola meal for fresh water omnivorous fish as determined in studies published since 2000.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Omnivorous-fresh water		
Silver perch[1]	Bidyanus bidyanus	51.9
Rohu (carp)[2]	Labeo rohita	51.3
Nile Tilapia[3]	Oreochromis niloticus	54.0

[1]Allan et al., 2000.
[2]Hussain et al., 2015.
[3]Borgeson et al., 2006

Table 5. Average apparent energy digestibility (%) of canola meal for carnivorous fish as determined in studies published since 2000.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Carnivorous		
Rainbow trout[1]	Oncorhynchus mykiss	78.9
Atlantic Salmon[2]	Salmo salar L	49.0
Arctic Char[3]	Salvelinus alpinus	46.8
Turbot[4]	Scophthalmus maximus	69.3
Barrimundi[5]	Lates calcarifer	47.6
Australasian snapper[6]	Pagrus auratus	19.6
European Sea bass[7]	Dicentrarchus labrax	91.7
Yellowfin seabream[8]	Acanthopagrus (Sparus) latus	56.3
Cobia[9]	Rachycentron canadum	83.1
Atlantic cod[10]	Gadus morhua	60.6
Meagre[11]	Argyrosomus regius	73.6
Omnivorous-Marine		
Haddock[12]	Melanogrammus aeglefinus	60.1
Australasian snapper[13]	Pagrus auratus	19.6

[1]Mwachireya et al., 2000; Burel et al., 2000; Thiessen et al., 2004; Cheng and Hardy, 2002. [2]Burr et al., 2011. [3]Burr et al., 2011. [4]Burel et al., 2000. [5]Ngo et al., 2015. [6]Glencross et al., 2004a. [7]Lanari and D'Agaro, 2005. [8]Wu et al., 2006. [9]Zhou et al., 2004. [10]Tibbets et al, 2006. [11]Rodrigues Olim, 2012. [12]Tibbetts et al., 2004. [13]Glencross et al., 2004a.

Table 6. Average apparent energy digestibility (%) of canola meal for omnivorous fish as determined in studies published since 2000.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Omnivorous-fresh water		
Silver perch[1]	Bidyanus bidyanus	58.1
Rohu (carp)[2]	Labeo rohita	51.3
Nile Tilapia[3]	Oreochromis niloticus	68.0

[1]Allan et al., 2000.
[2]Hussain et al., 2015.
[3]Borgeson et al., 2006

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 limits the amount that can be included in formulations. Results from studies published since 2000 are provided in Tables 7 and 8 for carnivorous and omnivorous species.

Table 7. Protein digestibility (%) of canola meal for carnivorous fish as determined in studies published since 2000.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Carnivorous-marine		
Rainbow trout[1]	Oncorhynchus mykiss	96.5
Atlantic Salmon[2]	Salmo salar L	86.2
Arctic Char[3]	Salvelinus alpinus	72.8
Turbot[4]	Scophthalmus maximus	82.9
European Sea bass[5]	Dicentrarchus labrax	89.8
Barramundi[6]	Lates calcarifer	85.4
Yellowfin seabream[7]	Acanthopagrus (Sparus) latus	84.7
Cobia[8]	Rachycentron canadum	89.0
Meagre[9]	Argyrosomus regius	93.9
Atlantic cod[10,11]	Gadus morhua	68.3
Meagre[11]	Argyrosomus regius	73.6
Carnivorous Freshwater		
Freshwater Angelfish[10]	Pterophyllum scalare	86.5

[1]Mwachireya et al., 2000; Burel et al., 2000; Dalsgaard et al., 2012; Gaylord et al., 2008; Gaylord et al., 2010; Thiessen et al., 2004; Cheng and Hardy, 2002. [2]Burr et al., 2011. [3]Burr et al., 2011. [4]Burel et al., 2000. [5]Lanari and D'Agaro, 2005. [6]Ngo et al., 2015. [7]Wu et al., 2006. [8]Zhou et al., 2004. [9]Rodrigues Olim, 2012. [10]Erdogan and Olmez, 2010. [11]Tibbets et al, 2006.

Table 8. Protein digestibility (%) of canola meal for carnivorous fish as determined in studies published since 2000.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Omnivorous-marine		
Haddock[1]	Melanogrammus aeglefinus	83.0
Australasian snapper[2]	Pagrus auratus	82.3
Omnivorous-freshwater		
Silver perch[3]	Bidyanus bidyanus	83.0
Rohu (carp)[4]	Labeo rohita	49.9
Nile Tilapia[5]	Oreochromis niloticus	82.0

[1]Tibbetts et al., 2004. [2]Glencross et al., 2004a. [3]Allan et al., 2000.[4]Hussain et al, 2015. [5]Borgeson et al., 2006

The amino acid balance of canola protein is the best of the commercial vegetable protein sources currently available. As Table 9 shows, the essential amino acid index value for canola meal is superior to that of soybean meal, and on par with fish meal (Burel and Kaushik, 2008). 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).

Table 9. Essential amino acid index (EAAI) for several protein sources used in aquaculture[1]

PROTEIN SOURCE	EAAI	MAJOR LIMITING AMINO ACID FOR CARP AND RAINBOW TROUT
Fish whole body protein	97	Threonine
Fish muscle	97	Threonine
Whole herring meal	94	Threonine
Soybean meal	91	Methionine, cysteine, threonine, lysine
Canola meal	95	Lysine
Canola protein concentrate	94	Lysine

[1]Burel and Kaushik, 2008

Minerals and Vitamins

Canola meal provides a rich source of phosphorus, although much of the phosphorus is in the form of phytic acid, which is not available to most farm reared fish. Because of this, many aqua diets are formulated to contain phytase (NRC, 2011), the enzyme necessary to cleave phosphorus from phytic acid and improve the availability of phosphorus. Research also showed that phytase increases the availability of other minerals, including calcium, magnesium and manganese (Cheng and Hardy, 2002; Vandenberg et al., 2011; Hussain et al., 2015), reducing the need for supplementation of these minerals. Recent research by Habib et al. (2018) showed that citric acid, like phytase, is beneficial in releasing minerals from phytic acid.

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 (Chapter 2). 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 (3.2 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 (40%).

Carbohydrates may be considered anti-nutritional for some species and opens the possibility of including carbohydrases in feed formulations. 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.

While the presence of anti-nutritional factors in canola requires consideration for its use in some aquaculture diets, canola protein and oil also has significant advantages over the use of fish meal and fish oil, in that canola meal is lower in polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/F) as well as dioxin-like polychlorinated biphenyls (DL-PCB). When fish meal and fish 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). According to the European Commission's Scientific Committee on Food, the recommended maximum human intake of organochlorine contaminant is 14 pg/kg body weight/ week. 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 aqua feeds by the use of canola oil and meal could significantly impact the safety of farmed fish and increase consumer acceptance of these products.

Value Add Processing

Several experiments have been conducted to evaluate canola protein concentrate. Canola meal may be converted into canola protein concentrate (CPC) by aqueous extraction of protein (Burr et al., 2013; Thiessen et al., 2004). CPC contains approximately the same crude protein concentration as fish meal, with a better amino acid profile than corn gluten meal and soybean meal. Collins et al (2012) determined that CPC had no negative effects on growth of rainbow trout when compared to fish meal.

Extrusion of diets for fish is common. Results are mixed for the effects of extrusion on the digestibility of canola meal. Burel et al. (2000) determined that extruded rapeseed meal had no effect on dry matter or protein digestibility for rainbow trout but improved digestibility of dry matter and protein for turbot, relative to solvent extracted meal. Dry matter digestibility was reduced with extrusion when fed to silver perch. Satoh et al. (1998) determined that extrusion increased digestibility for Chinook salmon. Extrusion conditions may need to be determined by species.

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 Meal for Omnivorous Fishes

Canola meal is increasingly used in aquaculture diets for species such as catfish, carp, tilapia, bass, perch, sea bream, and turbot. 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 (Cai 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.

Tilapia are commonly given diets containing canola meal. Abdul-Aziz, et al. (1999) 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 canola meal, and observed 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 canola meal, devoid of any harmful effects. Palatability may need to be taken into account when using canola meal in diets for tilapia. Yigit and Olmez (2012) found that intakes and growth rates were reduced when canola meal was substituted for more than 10% of the fish meal in the diet. Mohammadi et al (2016) likewise found that there were no differences in protein efficiency ratio (PER) and feed efficiency for diets containing up to 40% canola meal, but intakes and weight gains were reduced at both 20 and 40% inclusion levels. This suggests that the diets were nutritionally adequate, but failed to entice the fish to consume them. Feed attractants may be beneficial.

Several species of carp are reared for food throughout the world, and more information on the feeding requirements of these species is being researched. Jiang et al. (2015) determined that grass carp grew well with diets containing 30% canola meal, 20% soybean meal and 10% cottonseed meal, provided the diets were supplemented with lysine and methionine. Fish meal could be totally replaced with a combination of rapeseed meal and chlorella algae (Shi et al., 2017), suggesting that similar results might be expected with canola meal. Habib et al (2018) included phytase or citrate in canola meal diets for rohu, and determined that both options improved the digestibility of calcium, phosphorus, sodium, potassium and magnesium, allowing lower supplementation of these minerals. Rohu given canola meal as their protein source had higher growth rates than those given cottonseed meal, rapeseed meal, soybean meal or fish meal (Iqbal et al., 2015).

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 and Van Minh (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 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 alteration in performance of juvenile blue shrimp. In Malaysia, researchers found that canola meal alone could be used to replace 20% of the fish meal without altering performance. The same researchers (Bulbul et al, 2016) determined that a mixture of canola meal and soybean meal (40:60) could be used to fully replace fish meal in diets for kumura shrimp provided an attractant was applied to the meal. 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. Safari et al. (2014) found that ground canola seed was a promising ingredient for crayfish.

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 Oil

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 linoleic acid (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. Similarly, Karayücel, and Dernekbaşi (2010) found no differences in performance when 100% of the supplemental lipid was provided by canola oil in rainbow trout.

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.

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ALBERTA CANOLA

SaskCanola

Manitoba Canola Growers

Canola Council of Canada
400-167 Lombard Avenue
Winnipeg, Manitoba
Canada R3B 0T6
Phone: (204) 982-2100
admin@canolacouncil.org
www.canolacouncil.org