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FEED INDUSTRY GUIDE – 7th EDITION, 2024

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 analysis technology. Since the previous edition in 2019, 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 profiles and digestibility values for solvent extracted and expeller canola meal for all species
- Findings regarding the use of canola meal for early lactation, using canola meal to support milk production throughout the lactation cycle
- Updated information on a wider variety of aquaculture species
- Results from studies showing the ability of canola meal to support gut health
- The contribution of canola meal to sustainability

A copy of this publication can be found on the Canola Council of Canada's website 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 vegetable protein ingredient in the world. The vast, fertile fields of Western Canada are the primary canola production region. In early summer, canola fields dot the countryside with brilliant yellow flowers, yielding between 18-20 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.

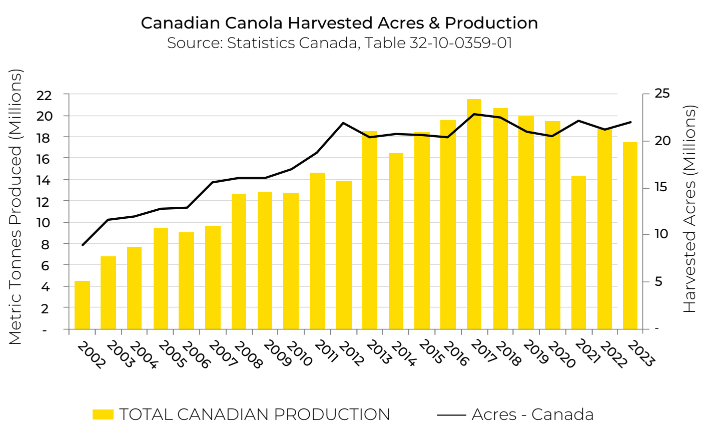
The name "canola" (Canadian oil) was coined in order to differentiate it from rapeseed. Canola is an offspring of rapeseed (Brassica napus and Brassica campestris/rapa), that was bred through traditional plant breeding techniques to have low levels of anti-nutrients, specifically erucic acid (< 2%) in the oil portion and low levels of glucosinolates (< 30 μmol/g) in the meal portion. The near removal of the glucosinolates in canola results in a meal that is 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 18-20 million metric tonnes of canola seed per year. The Canadian canola industry is targeting an increase in yield to reach 26 million metric tonnes of production per year, 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 production has risen steadily over the last two decades.

Global demand for canola oil and meal continues to grow, spurring investments in new processing capacity here in Canada. From 2021 to 2023, there were five major announcements to add 6.7 MMT of processing
capacity in the next several years – representing a 60% increase from the current capacity of 11.1 MMT. This expansion will result in additional canola meal available for export from Canada to countries such as the U.S., China, Mexico and the Indo-Pacific region. 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.

Figure 1. Total production and acres of canola from 2002 through 2023.



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].

	--------CALENDAR YEAR-------			
	2019/2020	2020/2021	2021/2022	2022/2023
Total seed production	**19,912**	**19,485**	**13,757**	**18,174**
Total seed export	**10,038**	**10,585**	**5,248**	**7,944**
China	1,926	2,714	1,265	4,608
Japan	2,140	2,323	1,383	1,101
Mexico	1,154	1,374	1,035	1,208
United Arab Emirates	989	997	307	169
Pakistan	691	660	64	267
European Union	2,177	1,751	625	215
United States	495	429	537	320
Other countries	467	337	33	56
Domestic seed processing	**10,129**	**10,425**	**8,555**	**9,961**
Domestic meal use	**737**	**625**	**649**	**528**
Total meal export	**4,904**	**5,261**	**4,516**	**5,311**
United States	3,466	3,581	2,920	3,484
China	1,417	1,577	1,587	1,819
Other Export	21	103	9	8

[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	36 minimum
Fat (oil) (typical), solvent extracted, % by mass	2 minimum	2 minimum
Fat (oil) (typical), expeller pressed, % by mass	10 minimum	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, 2020).

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):

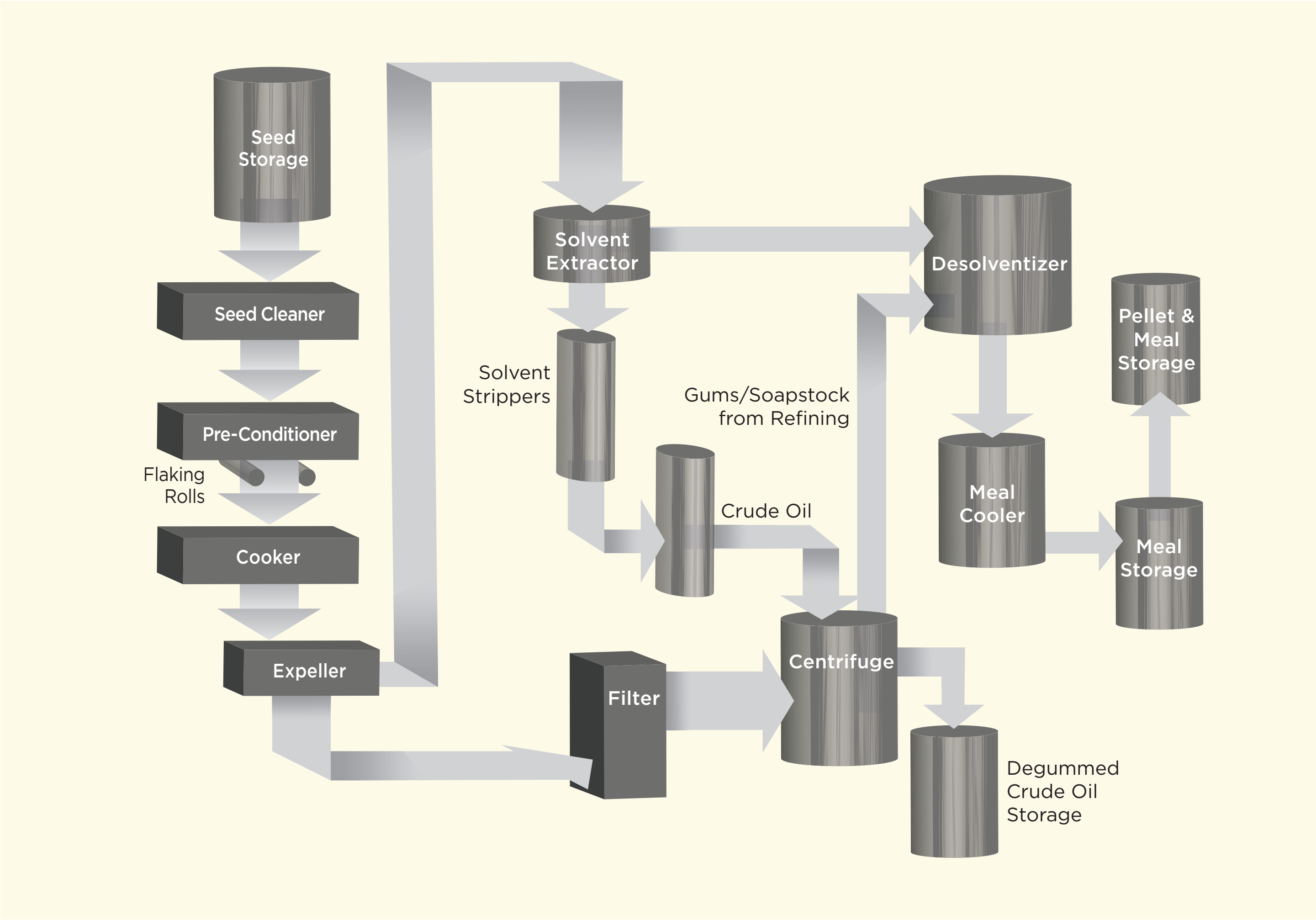
- Seed cleaning
- Seed preconditioning and flaking
- Seed cooking
- Pressing the flake to mechanically remove a portion of the oil
- Solvent extraction of the press-cake to remove the remainder of the oil
- Desolventizing and toasting of the meal
- Drying and cooling of the meal

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 the solvent extraction process



CH. 2 – NUTRIENT COMPOSITION OF CANOLA MEAL

Nutrient Composition of Solvent Extracted Meal

Origin and Chemical Analysis

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 season 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.

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

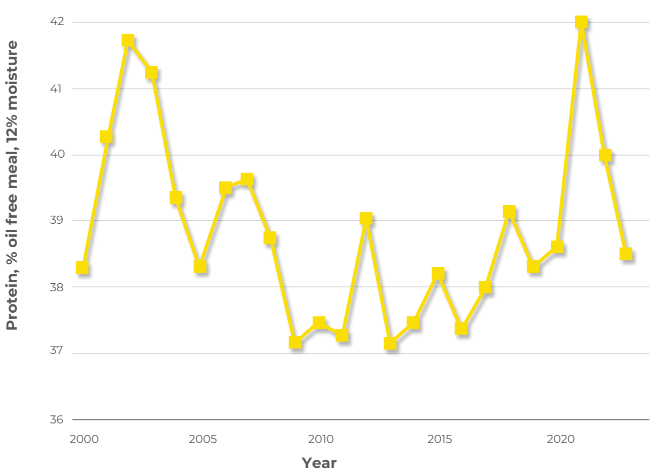
COMPONENT	12% MOISTURE BASIS	DRY MATTER BASIS
Moisture, %	12.00	0.00
Crude protein (N*6.25), %	36.90	42.00
Rumen escape protein, % of protein (NRC method)[2]	43.50	43.50
Rumen escape protein, % of protein (CNCPS method)[3]	53.00	53.00
Ether extract, %	2.81	3.20
Oleic acid, %	1.74	1.98
Linoleic acid, %	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 %	33.60	38.20
Acid detergent fibre, %	16.30	18.60
Neutral detergent fibre, %	25.50	29.00
Sinapine, %	0.88	1.00
Phytic acid, %	2.02	2.30
Glucosinolates, uMol/g	3.14	3.57

[1] Radfar et al., 2017; [2] Broderick et al., 2016; [3] Ross et al., 2013.

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 usually ranges between 37 and 40%. 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 2021 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. Protein content of canola meal from 2000 to 2023. Protein values calculated on an oil-free, 12% moisture basis (Canadian Grains commission, https://grainscanada.gc.ca/en/grain-research/grain-harvest-export-quality/canola/2023/



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 the meal is noted for having high levels of methionine and cysteine. The amino acid profile values in Table 2 were corrected to a 36% protein basis, and are 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.

Table 2. Amino acid composition of canola meal on a 36% as-fed 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 6.2, 2021.

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 the refining of 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 3. Fatty acid composition of canola oil[1].

FATTY ACID	% OF TOTAL FATTY ACIDS
C16:0 Palmitic acid	4.5
C16:1 Palmitoleic acid	0.2
C18:0 Stearic acid	2.4
C18:1 Oleic acid	64.5
C18:2 Linoleic acid (omega 6)	17.7
C18:3 Linolenic acid (omega 3)	8.6
C22:1 Erucic acid	<0.1
Total saturated	7.8
Total monounsaturated	65.4
Total polyunsaturated	26.3

[1] Ghazani and Marangoni, 2013.

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].

CARBOHYDRATE FRACTIONS	12% MOISTURE BASIS	DRY MATTER BASIS
Monosaccharides (Fructose and Glucose), %	1.55	1.76
Disaccharides (sucrose), %	5.58	6.34
Oligosaccharides, %	2.23	2.53
Starch, %	0.43	0.49
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. Like other vegetable protein sources of phosphorus, a portion of the total is in the form of phytate.

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

MINERAL	12% MOISTURE BASIS	DRY MATTER BASIS
Calcium, %	0.65	0.74
Phosphorus, %	0.99	1.13
Phytate phosphorus, %	0.64	0.73
Non-phytate phosphorus, %	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	4.70	5.30
Iron, mg/kg	162.00	184.00
Manganese, mg/kg	58.00	66.00
Molybdenum, mg/kg	1.40	1.60
Zinc, mg/kg	47.00	53.00
Selenium, mg/kg	1.10	1.30

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

Vitamins

Information on the vitamin content of canola meal is very limited and the values provided in Table 6 were averaged from four sources (Wickramasuriya et al., 2015). Canola meal is noted as rich in choline, biotin, folic acid, niacin, riboflavin and thiamine (NRC, 2012). 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.

Table 6. Vitamin content of canola meal[1].

VITAMIN	12% MOISTURE BASIS	DRY MATTER BASIS
Biotin, mg/kg	1.08	1.22
Choline, g/kg	6.7	7.6
Folic acid, mg/kg	1.55	1.76
Niacin, mg/kg	160	182
Pantothenic acid, mg/kg	9.4	10.6
Pyridoxine, mg/kg	7.10	8.10
Riboflavin, mg/kg	5.80	6.5
Thiamine, mg/kg	5.20	5.9
Vitamin E, mg/kg	18.5	21.0

[1] Wickramasuriya et al., 2015.

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 Canadian canola meal to levels that do not pose threats to performance and feeding for most species.

Glucosinolates

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. Canola glucosinolates are composed of two main types, aliphatic and indolyl (or indole) 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). The low glucosinolate content of canola, compared to previous cultivars of rapeseed, constitutes the major improvement in meal quality achieved by plant breeders.

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.

According to the most recent data provided by The Canadian Grains Commission (2023) (https://www.grainscanada.gc.ca/en/grain-research/export-quality/oilseeds/canola/2021/08-glucosinolate.html) the content of glucosinolate compounds in canola seed is low and has not changed noticeably since 2000. The level of glucosinolates in Canadian canola seed prior to processing has averages around 10 µmol/g. Glucosinolate content is then concentrated in the meal; after that, the glucosinolates are reduced during processing to values averaging 3.6 µmol/g.

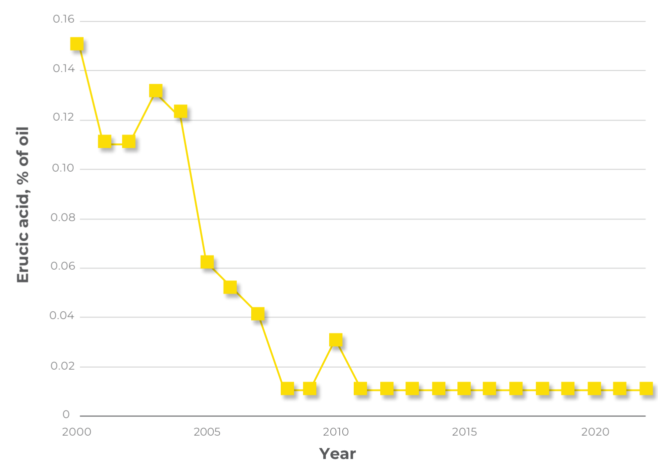
Erucic acid

Consumption of this fatty acid has been associated with myocardial lesions. However, Canadian plant breeders successfully reduced the amount of erucic acid in canola oil to very near zero levels (Figure 2). Erucic acid is no longer considered a problem for either the meal or the oil.

Tannins

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 associated with the hull and are primarily insoluble. These tannins do not appear to have the same negative effects on palatability and protein digestibility that they do in other edible plants (Khajali and Slominski, 2012).

Figure 2. Erucic acid levels in canola oil from 2000 to 2022. (https://www.grainscanada.gc.ca/en/grain-research/export-quality/oilseeds/canola/2021/10-fatty-acid-composition.html).



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 like 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 meal 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 composition of expeller canola meal[1].

COMPONENT	12% MOISTURE BASIS	DRY MATTER BASIS
Moisture (as measured), %	4.02	0.00
Crude protein (N*6.25), %	34.28	38.95
Rumen escape protein, % of protein (NRC method)[2]	48.50	48.50
Rumen escape protein, % of protein (CNCPS method)[3]	59.10	59.10
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, %	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; and 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 (12% moisture basis).

	REFERENCE			
Components	Feedipedia, 2018	Assadi et al., 2011	Montoya and Leterme, 2008	Dairy-One, 2023
Moisture, %	6.8	5.0	5.7	5.8
Crude protein, %	18.4	20.0	20.7	21.5
Ether extract,%	40.5	43.8	38.6	34.5
Linoleic acid, %	8.3	8.5	7.9	–
Linolenic acid, %	4.1	4.2	3.9	–
Ash, %	3.8	3.7	4.1	4.7
Crude fibre, %	8.9	–	–	8.9
ADF, %	12.7	–	10.6	15.9
NDF, %	17.9	16.6	12.9	22.5
Calcium, %	0.43	–	–	0.39
Phosphorus, %	0.64	–	–	0.65

CH. 3 – CANOLA MEAL FOR RUMINANTS

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.

Practical Inclusion Levels of Canola Meal in Diets for Ruminants

DIET TYPE	INCLUSION LEVELS
Starter preweaning	20% with no flavoring agent
Starter preweaning	Up to 35% with flavoring agents
Weaning transition	No Limit
Heifer development and growth	No Limit
Dairy transition	No Limit
Dairy lactation	No Limit
Beef backgrounding	No Limit
Beef finishing	No Limit
Goat lactation	No Limit
Lambs and Kids, growing	No Limit

Dairy Cattle

Canola Meal Use

In a 2021 anonymous survey conducted by the marketing agency broadhead and executed by Farm Journal on behalf of the Canola Council of Canada, the primary concern expressed by nutritionists regarding feed formulation was ensuring profitability. The second-greatest concern was environmental sustainability.

Canola meal has become a common feed ingredient for dairy cows. Nutritionists find it easy to balance diets for amino acids and to reduce protein use when canola meal is present. Recent research demonstrates that canola meal and canola oil reduce greenhouse gas (GHG) emissions when fed to dairy cows, compared to feeding other vegetable proteins.

Canola Meal and Profitability

While not frequently measured in university trials, several field trials have shown canola meal can help improve profitability. A trial conducted in Wisconsin involving 1,295 mid-lactation cows showed a significant improvement in income over feed costs (Faldet, 2018). The ration, formulated to contain 3.4 kg of dry matter from canola meal/cow/day, reduced ration costs while increasing milk production.

In an early-lactation study conducted in California involving 566 cows that were three to 23 weeks into lactation, canola meal supported greater milk yield at a lower feed cost (Swanepoel et al., 2020). In this feeding trial, the control diet contained canola, the primary vegetable protein used in California. For both of the two test diets, half of the added protein was provided by soybean meal as a replacement for canola meal. One of the soybean meal diets also contained added methionine (Table 2).

Table 1. Findings for cows involved in a Wisconsin field trial.

PARAMETER	CONTROL PERIOD	TEST PERIOD
Number of cows	1,295	1,295
Ration cost/day, $	6.25	6.22
Milk, kg	41.91	43.95
Fat %	3.86	3.92
Protein %	3.19	3.29
Fat, kg	1.67	1.79
Protein, kg	1.43	1.49
3.5% FCM, kg	46.32	49.45
ECM, kg	46.41	49.27

Table 2 shows that substituting part of the canola meal with soybean meal resulted in lost production, even with elevated levels of rumen-protected methionine. There were no differences in rate of involuntary culling or health events. The daily ration cost at the time the trial was conducted was approximately $US 0.05 and $US 0.08/cow/day less expensive for the canola meal treatment compared to the treatments containing soybean meal or soybean meal with added methionine.

Table 2. On-farm results for cows participating in a feeding trial in California.

	DIET		
Item	Canola meal	Soybean meal	Soybean meal + methionine
Canola meal, % of DM[1]	14.3	6.6	6.6
Soybean meal, % of DM[1]	0	6.6	6.6
Milk, kg	51.31	49.55	49.93
Fat, kg	1.78	1.71	1.75
Protein, kg	1.45	1.38	1.44
Dry matter intake, kg	28.5	28.2	28.3
First service conception, %	48.9	44.7	48.5
1st + 2nd service conception, %	68.9	64.2	67.4

[1] Cost for canola meal was $US 405/ton, and cost for soybean meal was $US 496/ton, equivalent to $US 440 and $US 550/metric tonne, respectively.

Using Canola Meal to Reduce Greenhouse Gas Emissions

Canola meal has been repeatedly shown to contribute to reducing methane emissions in lactating Holstein dairy cows. It can provide an economical way to lower enteric methane and nitrous oxide output, the two greenhouse gases of greatest importance in livestock production.

Enteric methane production can be expressed in several ways. The first is amount/animal/day. This is influenced by the size (Jersey vs. Holstein as an example), maturity of the animal, and the level of milk production. Another measurement used is methane/unit of feed consumed. This metric is useful for analyzing the portion of the total gross energy lost under defined conditions. It is referred to as methane yield. Methane intensity is a measure of methane output/unit of meat or milk produced.

Table 3 provides results from recent studies in which canola meal was used to replace soybean meal as a protein source in experimental rations. Only one trial was available with Jersey cows. The inclusion of 10.1% canola meal in that study did not reduce methane output, as determined using the indirect calorimetry method (Reynolds et al., 2019). The results showed that, on average, energy- corrected milk (ECM) was increased by 1.0 kg/cow/day, while methane was reduced by 5.0, 7.5 and 8.6% when expressed as grams/day, yield or intensity, respectively.

Many factors influence the extent to which enteric methane output is reduced by the inclusion of canola meal in the diet. Some examples are the forage sources and the forage-to-concentrate ratio. The level of canola meal inclusion appears to be a factor, as well. In a recent experiment (Benchaar et al., 2021), cows received 16% crude protein diets that varied from 0–24% canola meal. As Table 4 shows, methane output was reduced as the level of inclusion increased.

Less information is available for dry cows and heifers, but some inferences can be gathered from studies with beef cattle as well as in-vitro trials. Substitution of canola meal for soybean meal in one growth study reduced methane yield by 27% (Elshareef et al., 2020). Likewise, in-vitro fermentation results have demonstrated reduced methane production under a variety of feeding situations (Paula, et al., 2017; Ramirez-Bribiesca et al., 2018; Soliva et al., 2008).

Table 3. Comparison of methane output for diets in which canola meal replaced soybean meal as the primary source of protein.

	MEAL[1]			METHANE OUTPUT		
Ref[2]	SRC	% Of DM	ECM, kg[3]	g/ day	g/kg DMI	g/kg ECM[3]
1	SBM	17.0	44.0	489	19.0	11.1
	CM	24.0	46.2	461	16.6	10.0
2	SBM	15.0	29.4	461	24.1	17.8
	CM	20.8	30.7	456	22.5	15.8
3	SBM	10.2	32.0	442	17.6	13.8
	CM	13.0	33.1	404	15.7	12.2
4	SBM	13.6	40.3	414	17.0	10.4
	CM	17.1	41.1	396	15.0	9.5
5	SBM	14.5	55.4	538	20.3	9.7
	CM	19.4	55.4	466	18.0	8.4
6	SBM	13.7	31.0	335	19.1	10.8
	CM	10.1	31.7	360	20.5	11.4

[1] SBM = solvent-extracted soybean meal. CM = solvent-extracted canola meal; [2] 1-Benchaar et al., 2021; 2-Gidlund et al., 2015; 3-Holtshausen et al., 2021; 4-Lage et al., 2021; 5-Moore et al., 2016; 6-Reynolds et al., 2019
[3] ECM = energy-corrected milk.

Table 4. Relationship between the level of inclusion of canola meal in the diet and methane output as determined in one study[1].

	CANOLA MEAL INCLUSION LEVEL, % OF DM			
Variable	0	8	16	24
Production				
Dry matter intake (DMI), kg	25.8	26.9	27.3	27.7
Energy corrected milk (ECM), kg	44.0	45.0	45.6	46.2
Methane				
g/day	489	475	463	461
g/kg DMI	18.9	17.8	17.1	16.8
g/kg ECM	12.5	12.0	11.6	11.3

[1] Benchaar et al., 2021.

Part of the methane reduction value of canola meal can be associated with the lipid profile, which is rich in the mono-unsaturated fatty acid oleic acid. Lipids can reduce enteric methane in three ways: by directly targeting methanogens and protozoa, by acting as a reservoir for H+, and by providing a concentrated source of energy. Unsaturated fatty acids can bind to protozoa cell membranes and inhibit the transport of H+ by protozoa to methanogens (Kobayashi, 2010). The biohydrogenation of unsaturated fatty acids likewise provides a hydrogen sink, resulting in less H+ available in the rumen to produce methane. A meta-analysis (Eugene et al., 2008) revealed that methane was reduced by 2.2% for each 1% addition of lipid to the diet of dairy cows. Similarly, Beauchemin, et al. (2008) found that dietary lipids reduced methane by 5.6% for each 1% lipid added to diets for beef cattle.

The reduction in methane that occurs with the feeding of canola meal is only partially related to the contribution of the lipid fraction. Beauchemin et al. (2009) determined that when canola oil, flax oil or sunflower oil were added to diets already containing canola meal, all supported reduced methane output, demonstrating additivity between the meal and oil fractions. Furthermore, Ramirez-Bribiesca et al. (2018) found that the fermentation of canola meal increases propionate, resulting in one less carbon moiety available to contribute to gas production. These researchers were able to identify a high negative correlation between the slowly degraded protein fraction of CM (-0.99) and methane. They additionally correlated reduced methane with fat content of the meal (-0.80). Williams et al. (2020) determined that tannins can likewise reduce methane, with the effect being additive to the effects of fat. The seed hull of canola is a notable source of tannins.

Canola meal additionally has been shown to reduce nitrous oxide. Many research papers, as described in two recent meta-analyses (Martineau et al., 2013; Martineau et al., 2019), have shown that the efficient use of absorbed protein from canola results in lower blood urea nitrogen when compared to other vegetable protein meals. Excreted urea nitrogen is rapidly converted to ammonia gas, which can thereby indirectly contribute to atmospheric nitrous oxide. As Table 5 illustrates, urine nitrogen excretion is reduced, and milk nitrogen (protein) is elevated as canola meal in the diet is increased. Hristov et al. (2011) found that modifying the level of canola oil in diets containing canola meal did not alter nitrous oxide production.

Table 5. Effect of increasing canola meal on the diet on urinary nitrogen excretion[1].

	CANOLA MEAL INCLUSION LEVEL, % OF DM			
	0	8	16	24
Nitrogen intake, g/day	679	700	707	718
Milk nitrogen, g/day	210	213	218	222
Urine nitrogen, g/day	35.1	33.4	31.7	31.4
Urine nitrogen, % of total intake	5.1	4.8	4.5	4.3

[1] Hassanat et al., 2020.

Canola Meal Palatability

Canola meal is a highly palatable ingredient for adult ruminant animals. Many recent studies have revealed that intakes in dairy cows can be maintained or enhanced when canola meal replaces soybean meal or distillers' grains. In a Latin Square designed study, Benchaar et al. (2021) provided dairy cows with diets containing 0, 8, 16 or 24% canola meal, replacing soybean meal. Dry-matter intakes increased linearly with canola meal inclusion, contributing to greater milk yield (Table 6). 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 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. Three early-lactation trials (Moore and Kalscheur, 2016; Gauthier et al., 2019; Kuehnl and Kalscheur, 2021) noted a 1-kilogram increase in intake when canola meal replaced soybean meal in the diet. Heim and Krebs (2020) suggested that solvent-extracted canola meal may be more palatable than expeller canola meal. Solvent-extracted meal is more readily available on the North American market.

Table 6. Effect of increasing dietary canola meal on dry matter intake[1].

	DIET			
Canola meal inclusion, %	0	7.89	15.8	23.7
Soybean meal inclusion, %	17.0	11.3	5.65	0
Dry matter intake, kg/day	25.8	26.9	27.3	27.7
Energy corrected milk, kg/day	44.0	45.0	45.6	46.2

[1] Benchaar et al., 2021.

Growing cattle likewise have been shown to find canola meal to be a palatable feed ingredient. Nair et al. (2014) found that when barley grain was replaced by 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.

Using Canola Meal as a Protein Source

Amino acid composition

Canola meal has been recognized as the star of all vegetable proteins due to the meal's superior amino acid profile. A quarter century ago, Shingoethe (1996) demonstrated that the amino acid profile of canola meal matched the needs of dairy cows for milk yield (Table 7), and complemented rumen microbial protein to a greater degree than other vegetable proteins. This was recently underscored by Kuehnl and Kalscheur (2022), who continue to examine the effect of amino acids in early lactation, and showed that the efficiency of amino acid utilization was superior for canola meal.

The determined amino acid composition of the intact meal and the rumen undegraded protein (RUP) fraction of the meal are provided in Table 8. These values were determined by Ross (2015), based on the RUP method developed by Cornell University (Ross et al., 2013). The samples were a subset of a survey of samples obtained from 2011 through 2014 from processing plants across Canada.

Table 7. Milk protein score system used to compare proteins (1.00 = perfect)[1].

		LIMITING AMINO ACID		
Protein	Score	1st	2nd	3rd
Rumen microbial protein	0.78	Histidine	Leucine	Valine
Fish meal	0.75	Leucine	Tryptophan	Isoleucine
Canola meal	0.68	Isoleucine	Leucine	Lysine
Cottonseed meal	0.46	Methionine	Isoleucine	Lysine
Soybean meal	0.46	Methionine	Valine	Isoleucine
Sunflower meal	0.46	Lysine	Leucine	Methionine
Meat and bone meal	0.43	Tryptophan	Isoleucine	Methionine
Brewers' grains	0.40	Lysine	Methionine	Histidine
Corn distillers' grains	0.32	Lysine	Tryptophan	Methionine
Corn gluten meal	0.21	Lysine	Tryptophan	Isoleucine
Feather meal	0.19	Histidine	Methionine	Lysine

[1] Shingoethe, 1996.

The determined amino acid composition of the intact meal and the rumen undegraded protein (RUP) fraction of the meal are provided in Table 8. These values were determined by Ross (2015), based on the RUP method developed by Cornell University (Ross et al., 2013). The samples were a subset of a survey of samples obtained from 2011 through 2014 from processing plants across Canada.

Table 8. Essential amino acid composition of canola meal and canola meal RUP fraction, as determined by Cornell University using the Ross method[1].

		LIMITING AMINO ACID		
Protein	Score	1st	2nd	3rd
Arginine	2.17	2.23	6.03	6.19
Histidine	0.93	0.91	2.56	2.53
Isoleucine	1.24	1.28	3.44	3.56
Leucine	2.52	2.68	7.00	7.44
Lysine	1.84	1.76	5.11	4.89
Methionine	1.27	1.55	3.53	4.31
Phenylalanine	1.44	1.49	4.00	4.14
Threonine	1.47	1.51	4.09	4.19
Tryptophan	0.48	0.51	1.33	1.42
Valine	1.44	1.54	4.00	4.28

[1] Ross et al., 2015 Rumen undegraded protein in canola meal.

Rumen undegraded protein in canola meal

While the amino acid profile contributes greatly to the importance of canola meal in ruminant feeds systems, equally so does the RUP component of the meal. Approximately half of the protein in canola meal is in the form of RUP (Table 9). The RUP, expressed as a percentage of total protein, has consistently been demonstrated to be greater than that found for solvent extracted soybean meal.

Many feed libraries have incorrect values for the RUP content of canola meal. In the past, the in-situ nylon bag method has been used to partition feed protein into RUP and rumen degraded protein (RDP) fractions. The error in this method resides in the fact that soluble protein and protein that becomes soluble and leaves the porous bags are assumed to be degraded by the microbes in the rumen, and, therefore, unavailable as an amino acid source for the host animal. Indeed, so entrenched is the notion that solubility and degradation are equal, that the recently released NASEM (2021) did not update the acceptance of this notion since the last publication (NRC, 2001). Errors in estimating how feed proteins are partitioned have hampered the ability of feed formulators to support optimum rumen microbial growth, as well as the calculation of the amounts of amino acids entering the intestine from microbial and feed ingredient sources.

Table 9. The RUP value for canola meal and soybean meal, as determined by several newer methods of analysis (% of total protein).

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., 2013	52.5	41.5	1.27
Ross, 2015	53.2	45.2	1.18
Tylutki et al., 2008	41.8	38.3	1.09

The actual rumen degradability of soluble protein is variable and has long been known to be variable. The breakdown of protein results in the release of ammonia nitrogen in the rumen. Broderick et al. (1991) evaluated the amount of ammonia generated under in vitro conditions, and clearly indicate that peptides and amino acids can accumulate. The authors stated *"a portion of the soluble protein may require some disruption of secondary and tertiary structure for proteolysis to proceed. Proteins with extensive disulfide bonding, such as albumins or immunoglobulins, or those containing artificial cross-links caused by chemical treatment, are more slowly degraded than less ordered proteins."*

Proteins that are rich in disulfide bonds are soluble, but resistant to degradation in the rumen (Wallace, 1983; McNabb et al., 1994). The two major storage proteins in canola meal are napin, an albumin protein, and cruciferin, a globulin protein (Perera et al., 2016). Under a range of conditions, both proteins can become soluble (Chmielewska et al., 2020), with napin highly likely to become soluble in the rumen environment. In the case of canola meal, with napin rich in disulfide bonds, the degradability of soluble protein is less than some other common vegetable proteins.

Table 10 provides an example of true degradation rates for the soluble fraction of proteins (Hedqvist and Udén, 2008). The soluble protein in canola meal is broken down much more slowly than the soluble protein in soybean meal or wheat distillers' grains. This means that there is considerable opportunity for the soluble fraction from canola meal to reach the intestine. Add to that the fact that soluble protein will exit the rumen with the liquid outflow, which is at least twice as fast as the solid turnover rate (Seo et al., 2006). This would likewise apply to the misrepresented portion of protein that becomes solubilized while suspended in the rumen during the in-situ analyses.

Table 10. Rates of digestion of the soluble fraction of protein in the rumen for selected ingredients[1].

VEGETABLE PROTEIN	SOLUBLE PROTEIN,	SOYBEAN MEAL
Canola meal (rapeseed meal)	20.4	19
Flax (linseed meal)	58.6	18
Lupins	80.2	34
Peas	77.8	39
Soybean meal	16.9	46
Wheat distillers' grains	24.3	62

[1] Hedqvist and Udén, 2008.

Rumen microbial protein production

Studies have confirmed that diets containing canola meal support similar levels of microbial production when compared to soybean meal. Using the direct measurement abomasal nitrogen flow, Brito et al. (2007) and Paula et al. (2018) both determined that there were no differences in microbial protein yield when canola meal was used to replace soybean meal as a source of protein. Results from two feeding trials (Lage et al., 2021; Pereira et al., 2020) using urinary purine derivatives to estimate microbial protein yield found no differences in the two sources of protein, while Swanepoel et al. (2021) using the same methodology found that the canola meal diet promoted rumen conditions to improve microbial growth. Paula et al. (2017) determined that there were no differences in microbial protein yield for soybean meal or canola meal diets in a dual flow fermentation study.

In a different experimental model in which canola meal was substituted for barley, rumen microbial growth was decreased with higher levels of canola meal. 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.

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 fiber (NDF) approach 65%, with the potentially available NDF estimated at 35%. Depending on rate of passage, the actual amount digested would be even less. Using 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. The recently released NASEM (2021) system, which uses a 48-hour NDF digestibility determination, is more accurate and provides a more realistic energy value.

Based on the results of a 4-year survey of 12 processing plants (144 samples), Paula et al. (2017) 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%. In a follow-up to this, Arce-Cordero et al. (2021) found that the calculated net energy of lactation (NE-L) at 3 times maintenance intake would be 1.87 Mcal/kg.

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 11.

Table 11. Average energy values for solvent extracted and expeller canola meal.

	CANOLA MEAL PROCESSING METHOD	
	Soluble protein	Soybean meal
Total digestible nutrients (TDN), %	68.2	74.6
Digestible energy (DE), Mcal/kg	3.35	3.70
Metabolizable energy (ME), Mcal/kg	2.70	3.01
Net energy of lactation (NEL-3M)	1.78	2.01
Net energy maintenance (NEM)	1.92	2.16
Net energy of gain (NEG)	1.27	1.47

Canola Fatty Acids

Solvent extracted canola meal tends to contain somewhat higher fat than many other oilseed meals, and this fat contributes to the energy value of the meal. This highly unsaturated source of fatty acids is made up largely of the mono-unsaturated fatty acid oleic acid (C18:1).

Unsaturated fatty acids in the rumen have the potential to allow the accumulation of biohydrogenation intermediates that can interfere with milk fat synthesis and result in milk fat depression. Oleic acid is less likely to produce the fatty acid intermediates that contribute to milk fat depression than the fatty acids with 2 or more unsaturated bonds. In a meta-analysis, Dorea and Armentano (2017) determined that feed ingredients with oils containing predominately linoleic acid (C18:2) were twice as likely to reduce milk fat as those containing mainly C18:1 or linolenic acid (C18:3). Lopes et al. (2017) concluded that oilseeds with higher C18:1 concentrations are likely to increase milk fat concentration and yield as well as the C18:1 content of milk in dairy cows, compared with oils containing C18:2.

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 linoleic 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 experimental 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, indicating that the diet with greater levels of C18:1 did not impact milk fat yield.

Furthermore, the common unsaturated fatty acids (acids (C18:1, C18:2 and C18:3) can interfere with microbial metabolism by destabilizing the cell membrane, increasing the permeability of the membrane (Yoon et al., 2018). This effect is greatest as the number of double bonds increases (C18:3> C18:2>C18:1).

In contrast, some studies have indicated that rumen digestibility increases with C18:1. Chilikani et al (2004) added approximately 6.5% canola oil (62% C18:1) into diets for late-lactation cows and evaluated ruminal digestibility. As Table 12 shows, rumen digestibility values were greater for the diet to which the canola oil had been added. Prom and Lock (2021) found that added C18:1 improved rumen DM and NDF digestibility.

Table 12. Rumen digestibility of nutrients by cows receiving supplemental canola oil[1].

	TREATMENT	
Nutrient	Control	Canola oil
Dry matter intake, kg/day	14.0	14.5
Total fatty acid intake, g/day	244	1,154
Nutrient	Rumen digestibility, %	
Dry matter	42.3	45.1
Organic matter	45.5	48.5
Crude protein	24.1	37.1
Neutral detergent fiber	43.3	50.6
Acid detergent fiber	34.7	44.2

[1] Chilikani et al., 2004.

The rate of biohydrogenation of C18:1 has been shown to be lower than the more saturated fatty acids (Baldin et al., 2018). This means that more can escape the rumen, and enter the intestines, where it has additional benefits. Unlike other C18 fatty acids, C18:1 has been shown to act as an amphiphilic agent and improve nutrient digestibility (Prom et al., 2021). In a trial (Lopes et al., 2017) that compared diets containing conventional (high C18:2) soybean meal to a genetically modified high C18:1 soybean meal variety, it was found that total tract digestibility was greater with the high C18:1 meal. The importance of this finding is that the only difference in the diets was the composition of the fatty acids. In another study (Prom et al., 2018), infusing C18:1 into the abomasum improved fatty acid digestibility.

Micronutrients in Canola Meal

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 infectious organisms that cause maladies such as hoof rot and mastitis. However, increasing ration iodine generally results in greater concentrations entering the milk, with high milk iodine 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 (Flachowsky et al., 2014). Even though levels of glucosinolates are extremely low in current-day canola 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). The Troan et al. (2018) study provided cows with diets containing 0, 6, 14 or 20% expeller rapeseed meal, which contained a total of 1.07 µmol/g of glucosinolates. It was 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 13), and this would permit the benefits of higher iodine inclusion to be manifested, without producing unacceptable levels of iodine in milk.

Table 13. Effects of feeding canola meal on iodine concentrations in blood serum and milk (ug/L)[1].

	CONCENTRATION OF IODINE IN THE DIET, MG/KG DM					
Item	0.5			2.0		
Canola meal, % of DM	0	3.9	13.9	0	3.9	13.9
Blood serum iodine, ug/L	99	142	148	175	251	320
Milk iodine, ug/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 (Wu et al., 2008; Zimpel et al., 2021).

Table 14. Comparison of cations (potassium and sodium) anions (chlorine and sulfur) and DCAD (mEq/kg of dry matter) for some common feed ingredients[1].

	CATIONS		ANIONS		
Ingredient	K	Na	Cl	S	DCAD
Canola meal	361	30	-11	-456	-76
Corn grain	107	9	-23	-63	31
Corn distillers' grains	281	130	-28	-275	109
Soybean meal	775	13	-155	-244	389
Alfalfa silage	775	13	-155	-188	445
Barley silage	621	58	106	106	369
Corn silage	307	4	-82	-88	142
Grass silage	795	22	-181	-131	505

[1] Erdman and Iwaniuk, 2015.

Anionic salts can be added to the diet, but these sometimes reduce palatability and 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 14 below 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.

Antioxidants

Oxidative stress in a common occurrence in the transition period, and during heat stress. Canola meal contains a variety of antioxidants, including phenolic compounds (Vuorela et al., 2004; Wanasundara et al., 1995), vitamin E and carotenoids (Loganes et al., 2016). These contribute to the reduction of free radical compounds and concomitant cellular damage produced by them.

Feeding Solvent Extracted Canola Meal to Lactating Cows

Meta-analyses of feeding value

There have been five in-depth meta-analyses conducted since 2011 in which canola meal was compared to other vegetable proteins in diets for lactating dairy cows. While each had slightly different objectives and therefore different data-extraction methodology, all these investigations support the fact that canola meal is a high RUP meal with an exceptional amino acid profile.

Huhtanen et al. (2011) evaluated results from 122 studies in which 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 undervalued when compared to soybean meal. Table 15 summarizes the data from this report.

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. Results from 27 published studies, evaluating 88 treatments, were included in the analysis. At the average inclusion level (2.3 kg per day) of canola meal, milk yield was 1.4 kg greater when cows were given canola meal across the 49 studies used in the analysis.

Table 15. Summary of the meta-analysis of Huhtanen et al. (2011).

VARIABLE	CANOLA MEAL	SOYBEAN MEAL
Dry matter intake, kg/d	19.4	16.8
Milk yield, kg/d	27.2	23.6
Energy corrected milk yield, kg/d	28.6	23.6

In a continuation of the previous meta-analysis, Martineau et al. (2014) compared the response in plasma amino acids to changes in the protein source in the diet. Results from 10 feeding experiments and 21 treatment comparisons were available for this analysis. Plasma essential amino acid concentrations 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. The conclusion from this report was that canola meal increased the availability of essential amino acids.

Moura et al. (2018) collected data from 37 peer-reviewed manuscripts evaluating the use of canola meal to replace other vegetable protein sources. In this study, mean treatment differences were compared. A summary of the results is provided in Table 16. Differences were statistically significant for all values shown.

Table 16. Summary of the meta-analyses of Moura et al. (2018).

VARIABLE	OBSERVATIONS	RAW MEAN DIFFERENCE
Dry matter intake, kg/d	79	0.22
Milk yield, kg/d	88	0.69
Milk protein yield, kg/d	60	0.02
Milk urea N, mg/dL	22	-0.98
Milk N to N intake	34	0.22

To include 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 with 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, the highest level tested at the time data were collated, with no losses in milk production and no negative effect upon intake.

Canola meal in early lactation

Only recently have trials been conducted to evaluate canola meal for cows in early lactation. Since 2016, there have been four research studies that support the utilization of canola meal in diets for dairy cows in early lactation (Table 17). All trials showed that cows given canola meal in early lactation produced greater quantities of milk. Feed efficiency values were similar for both protein sources, with one exception (Moore and Kalscheur, 2016) where there was a significant advantage for the canola meal diet.

Although there were no differences in feed efficiency in the experiments conducted by Gauthier et al. (2019) and Swanepoel et al. (2020), both showed less loss in body condition when cows received the diets containing canola meal. Both were large herd studies conducted under actual farm conditions.

Table 17. Performance of cows receiving canola meal or soybean meal in early lactation.

		INCLUSION, % OF DM		MILK YIELD, KG		ECM/DMI[1]	
Trial[2]	Length, weeks	Canola meal	Soy-bean meal	Canola meal	Soy-bean meal	Canola meal	Soy-bean meal
1	16	19.4	14.5	56.5	52.3	2.31	2.17
1	16	11.9	8.9	54.8	50.1	2.22	2.16
2	22	13.0	7.0	44.5	42.3	1.53	1.50
3[3]	22	14.3	6.3	51.3	49.6	1.79	1.73
3	22	14.3	6.3	51.3	49.9	1.79	1.77
4	16	16.5	12.1	52.8	50.9	2.18	2.13

[1] Energy corrected milk/dry matter intake; [2] 1: Moore and Kalscheur, 2016; 2: Gauthier et al., 2019; 3: Swanepoel et al., 2020; 4: Kuehnl and Kalscheur, 2021; [3] Both soybean meal diets contained 6.5% canola meal. The 2nd soybean meal diet provided additional methionine.

Mid lactation feeding trials

Tables 18 and 19 show the milk yield results for head-to-head studies that have been published in recent times comparing canola meal to other common vegetable protein sources. Most of the trials involved comparing canola meal to soybean meal (Table 20), although there have been trials involving other proteins (Table 21). As the tables illustrate, canola meal performed as well or better than the alternative meals evaluated for milk production potential in most published studies.

Table 18. Comparison of milk production (kg) by cows in which the major supplemental protein was provided by canola meal or soybean meal.

	PROTEIN SOURCE		
Reference	Canola meal	Soybean meal	Difference
Benchaar et al., 2021	42.2	40.4	1.8
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
Galindo et al., 2017	46.0	43.7	2.3
Gauthier et al., 2019	44.5	42.3	2.2
Gauthier et al., 2019	44.5	44.8	-0.3
Gidlund et al., 2015	30.2	29.5	0.7
Holtshausen et al., 2021	34.2	35.0	-0.8
Kuehnl and Kalscheur, 2021	52.8	50.9	1.9
Kuehnl and Kalscheur, 2022	44.3	41.4	2.9
Lage et al., 2021	43.8	41.1	2.7
Maxin et al., 2013	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
Paula et al., 2020	37.2	36.4	0.8
Sanchez-Duarte et al., 2019	38.2	37.5	0.7
Swanepoel et al., 2020	51.3	49.6	1.7
Swanepoel et al., 2020	51.3	49.9	1.4
Weiss et al., 2015	39.4	37.6	1.8

Table 19. Comparison of milk production (kg) by cows in which the major supplemental protein was provided by canola meal or another vegetable protein.

	PROTEIN SOURCE		
Reference	Canola meal	Cottonseed meal	Difference
Brito and Broderick, 2007	41.1	40.5	0.6
Maesoomi et al., 2006	28.0	27.0	1.0
	Canola meal	Corn DDGS	
Acharya et al., 2015	34.9	35.5	-0.6
Christen et al., 2010	31.7	31.2	0.5
Maxin et al., 2013	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
	Canola meal	Wheat DDGS	
Abeysekara and Mutsvangua, 2016	40.4	40.2	0.2
Chibisa et al., 2012	45.0	45.0	0
Maxin et al., 2013	30.9	30.8	0.1
Mutsvangwa et al., 2016	43.4	42.4	1.0
	Canola meal	Sunflower meal	
Beauchemin et al., 2009	27.0	26.7	0.3
Vincent et al., 1990	26.7	25.1	1.6
	Canola meal	Brewery grains	
Moate et al., 2011	23.4	22.3	1.1
	Canola meal	Flax meal	
Beauchemin et al., 2009	27.0	26.8	0.2
	Canola meal	Rapeseed meal	
Hristov et al., 2011	47.1	45.0	2.1
	Canola meal	Expeller SBM	
Lage et al., 2021	43.8	42.6	1.2

Canola Meal for Growth

Canola meal for calves preweaning

Although well suited on a nutritional basis, canola meal is less likely to be included in diets for calves, based on older studies in which high glucosinolate levels impaired intake of the meal. Ravichandiran 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. It should be noted that canola meal from Canada contains 3.57 μmol/g on a dry matter basis.

Age of the calves may be a factor that influences acceptance. Two similar experiments were conducted with calves during the preweaning (Table 20) and post weaning periods (Table 21). Both noted a tendency for reduced intakes preweaning (Table 20), but not immediately after weaning (Table 21). Miller-Cushon et al. (2014) recommended pelleting of the starter ration to overcome sorting by young calves.

Table 20. Use of canola meal by calves preweaning.

	DIET		
Claypool et al., 1985	Canola meal	Cottonseed meal	Soybean meal
Meal % of dry matter	17.6	14.1	11.1
Intake/day preweaning,[1] g	368	479	439
Average daily gains, g/day	580	620	620
Hadam et al., 2016	Canola meal	Canola/Soy	Soybean meal
Meal % of dry matter	5.0	16.5	24.0
Intake/day preweaning,[2] g	269	250	315
Average daily gains, g/day	587	636	684

[1] Calves were weaned at 8 weeks of age; [2] Calves were weaned between 5 and 7 weeks of age. Data shown are for the first 5 weeks.

Table 21. Use of canola meal post weaning.

	DIET		
Claypool et al., 1985	Canola meal	Cottonseed meal	Soybean meal
Meal % of dry matter	17.6	14.1	11.1
Intake/day postweaning,[1] g	ND	ND	ND
Average daily gain [2], g/day	890	890	910
Hadam et al., 2016	Canola meal	Canola/Soy	Soybean meal
Meal % of dry matter	35.0	16.5/12.5	24.0
Intake/day post weaning,[2] g	2,001	1,964	2,003
Average daily gains, g/day	734	745	798

[1] Not determined (ND). Calves were weaned at 8 weeks of age, and the trial ended at 16 weeks of age. Calves were group-fed, and intakes were not recorded.
[2] Calves were weaned between 5 and 7 weeks of age. Data shown are for weeks 5–8.

Gora and Penner (2020) reviewed a series of studies in which the inclusion of sweeteners (glycerol or molasses) had a positive effect on intake of starter feeds containing canola meal. The same researchers suggested limiting inclusion of canola meal to less than 20% of the diet for young calves. In a follow-up study in which 0, 15, 30, 45 or 60% of the soybean meal was replaced by canola meal (Burakowska et al., 2021), it was determined that there were no differences in average daily gain or feed efficiency that could be related to treatment. The highest canola meal inclusion level was 20.7%. The authors stated that canola meal was a suitable replacement for up to 60% of the soybean meal in the diet.

Canola meal does support optimal growth in calves preweaning provided there are no limitations due to palatability. Recent research at the University of Saskatchewan revealed that any distaste for canola meal can be overcome by masking the taste with a sweetener or other flavor agent (Gorka and Penner, 2020), or by limiting the level of inclusion to 20% of the diet dry matter. Burkakowska et al. (2020) showed that intakes of starter diets containing 34% canola meal increased from 243 to 338 g/day when 5% glycerol was included in the diet. Pelleting the diet may also improve the acceptance of canola meal when it's used as the primary source of protein for calves (Burakowska et al., 2021b). When included in a sweetened diet at 35% of the dry matter from day 8 to day 42, there was no decrease in intake (Burakowska et. al., 2017). One study (Burakowska et al., 2021a) revealed no differences in growth rate, gain/feed, rumen production, and blood glucose and insulin levels between diets containing zero to 20.7% canola meal in unsweetened diets (Table 22).

Table 22. Evaluation of canola meal in diets of calves from day 8 to day 62 of life (Burakowska et al., 2021a).

	TREATMENT (% SOYBEAN MEAL REPLACEMENT)				
Variable	0	15	30	45	60
Canola meal, % of DM	0	5.2	10.4	15.7	20.7
Soybean meal, % of DM	28.4	24.1	19.8	15.7	11.4
Average daily gain, kg	0.91	0.93	0.90	0.87	0.86
Gain/feed	0.54	0.54	0.53	0.53	0.55
Rumen VFA concentration, mM	118	133	111	132	128
Rumen ammonia, mg/dL	4.0	3.0	3.4	5.0	3.4
Blood glucose, mg/dL	62.7	61.1	61.8	58.8	61.8
Blood insulin, ug/L	0.62	0.54	0.44	0.41	0.68

Melendez et al. (2020) compared expeller canola meal and expeller linseed meal in calf starter diets with the protein sources included at 25% of the dry matter. There were no differences in performance from birth to 60 days of age with intake averages of 0.5 kg/calf/day.

Canola meal for calves during weaning transition

Although only three studies were found for calves during weaning transition, results suggest that there is little concern with inclusion levels at that time. Table 23 provides a summary of these results.

Canola meal effects on gut health and development

In a study involving 104 dairy farms from 13 US states, Urie et al. (2018) determined morbidity and mortality rates to be 33.9 and 5%, respectively. Approximately half of the morbidity was associated with digestive problems. Canola meal can be instrumental in helping to improve gut health in dairy calves.

Table 23. Evaluation of canola meal in diets for calves during weaning transition.

REFERENCE	VARIABLE	SOYBEAN MEAL	CANOLA MEAL
Claypool et al., 1985	Inclusion, % of DM	11.1	17.6
	Dry matter intake, g/day	-	-
	Average gain, g/day	910	890
Hadam et al., 2016	Inclusion, % of DM	24.0	35.0
	Dry matter intake, g/day	2,003	2,001
	Average gain, g/day	796	734
Burakowska et al., 2021	Inclusion, % of DM	24.0	35.0
	Dry matter intake, g/day	1,581	1,628
	Average gain, g/day	783	671

In an elaborate University of Saskatchewan feeding trial (Burakowska et al., 2021b), calves were given isonitrogenous diets that provided either 24% soybean meal or 35% canola meal. Calves were weaned at 52 days of age and slaughtered at 72 days of age. There were no differences in rumen development. However, the damage index (a measure of sloughing and tissue separation) was lower for the calves that had received the canola meal starter feed. Canola meal in the starter mixture increased abomasal and jejunal tissue weights. There were no differences in brush border enzyme activities between the two starter feeding programs.

In a follow-up study, calves received diets with graded levels of canola meal, ranging from 0 to 20.7% of the dry matter. There was a tendency for rumen acetic acid levels to decline, and rumen propionic acid concentrations to increase as canola meal in the diet increased.

Incidence of diarrhea was 25% for expeller canola meal and 45% for expeller linseed meal (Melendez et al., 2020). Plasma haptoglobin — an acute phase protein — levels were also lower for the group of calves receiving the canola meal diet.

Canola meal for growing heifers

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 dairy calf study, Terre 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 flavoring 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.

Chinese Feeding Trials

The dairy industry in China has been steadily growing and innovating, and with it, the need for reliable protein ingredients.

In recognition of this need, the Canola Council of Canada supported several feed- demonstration trials in China in 2011. All the studies involved well-managed herds. Production averaged 35 L in all but one study, in which it was 25 L. Results from the demonstration trials are provided in Table 24. Even at fairly low inclusion rates, when canola meal replaced high-priced protein ingredients, milk production was maintained or increased.

Table 24. Trials conducted in China in which canola meal was substituted for other protein sources.

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

Feeding Expeller Canola Meal to Lactating Cows

Due to the desirability of expeller canola meal for non-ruminants, less of this product is available for use by the ruminant feed industry. Less research is available for this ingredient than for solvent extracted meal. The feeding value of expeller canola meal is like that of solvent-extracted canola meal, except for the dilution effect of the higher fat content, which increases the energy value.

Expeller meal tends to have a greater RUP as a portion of the total protein. 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 expeller meal and increased linearly with the duration of the moist heat pressure treatment.

Table 25 provides results from studies comparing the effects on milk production of feeding canola meal, expeller canola meal or heated expeller canola meal. The older studies were conducted at the University of Saskatchewan (Beaulieu et al., 1990; Jones et al., 2001), and the most recent study was conducted at Pennsylvania State University (Hristov et al., 2011). Results indicate that the inclusion of expeller canola meal in diets for lactating dairy cows resulted 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 designated 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 25. Milk production from dairy cows fed diets containing canola meal, expeller canola meal or heat-treated expeller canola meal.

REFERENCE	TREATMENT	MILK YIELD, KG
Beaulieu et al., 1990	Solvent canola meal	28.0
	Expeller canola meal	28.0
Hristov et al., 2011	Solvent canola meal	41.7
	Expeller canola meal	41.7
Jones et al., 20011	Solvent canola meal	28.6
	Expeller canola meal	30.0
	Heated expeller canola meal	30.0
Jones et al., 20012	Solvent canola meal	23.6
	Expeller canola meal	24.0
	Heated expeller canola meal	25.2

[1] Multiparous cows; [2] Primiparous cows.

While there are few 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 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 Chichlolowski 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.

Ahsani et al. (2019) supplied dairy cows with diets to which 9% of DM as either canola seed or soybean seed was added to diets. Additionally, 2% added fat, in the form of a commercial prilled supplement, was provided, resulting in diets with 8% fat. Both resulted in similar milk fat depressions, while production was greater for the canola seed diet (38.4 kg vs. 41.9 kg/cow/day for the soybean meal as compared to canola meal diet). Unsaturated fatty acid content of the milk was similar for both diets.

There is a significant volume of evidence to support the benefits of specific fatty acids for cow health and reproduction. Canola seed in prepartum diets has been evaluated to determine impacts on 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.

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 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.

Beef Cattle

Canola meal has been demonstrated to be a valuable feed ingredient 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 and protein for backgrounding and finishing cattle as well as winter grazing.

Results are available from feeding trials that support the use of supplemental canola meal for grazing 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. In a follow-up research paper, the researchers determined that inclusion of canola meal in a well-formulated, partial mixed ration stimulated forage dry matter intake and energy corrected milk in early, but not late lactation. Damiran et al. (2016) evaluated canola meal as a replacement for wheat distillers' grains. Cows receiving the wheat distillers' grains lost 7.8 kg of body weight, as compared to 2.5 for those receiving the canola meal supplement. There were no differences between treatments for calf birth weight or calf weaning weight.

Grazing calves have likewise benefited from canola meal supplementation. Lynch et al. (2021) evaluated the growth of weaned calves (5–6 months of age), grazing poor quality forage, that were provided canola meal at rates equal to 0.5, 1.0, 1.5 or 2.0% of liveweight. There was a linear increase in average daily gain and dry matter intake up to the provision of 1.5% canola meal.

Protein supplementation has been shown to benefit backgrounding cattle. Yang et al. (2013) found that supplementation with canola meal improved intake and weight gain in backgrounded steers. In addition to canola meal, wheat distillers' grains are readily available in Western Canada. Li et al. (2014) supplemented diets for backgrounded heifers with canola meal, wheat distillers' grains and high protein corn distillers' grains 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. Two backgrounding experiments were conducted in Saskatchewan by Good (2018). Both trials compared isonitrogenous diets based on either canola meal or soybean meal, with and without the partial substitution of these meals with wheat distillers' grains. Weight gains were lowest for the soybean meal plus wheat distillers' grain diet in the first trial, with no treatment differences in the second trial.

Prado and Martins (1999) provided finishing heifers with sorghum silage-based diets containing either 19.7% canola meal, or 19.5% cottonseed meal for the duration of a 98-day feeding period. The heifers receiving the diet with canola meal gained 1.05 kg/day, as compared to 0.87 kg/day when cottonseed meal was used as the protein source. 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. In a finishing trial, Good (2018) compared 4 protein sources: canola meal, soybean meal, 50% canola meal and 50% wheat distillers' grains, and finally, 50% soybean meal and 50% wheat distillers' grains in diets for growing/finishing cattle. There were no differences in body weight gain or feed to gain between the diets containing canola meal, soybean meal or canola meal plus wheat distillers' grains. However, the mixture of soybean meal with wheat distillers' grains had a negative effect on fattening and yield grade.

Small Ruminants

Canola meal is an ideal supplement to produce wool and mohair because of the high-sulfur amino acid requirement of these animals (White et al., 2000; Easton et al., 1998). In addition, canola meal has been shown to support weight gain in these meat animals as well as milk production.

Sheep

Several past feeding trials have shown that canola meal can readily be used without restrictions to support growth and production in sheep. Furthermore, canola meal has been demonstrated to improve feed intake (Hentz et al., 2012). Mandiki et al. (1999) fed lambs diets containing up to 30% canola-quality rapeseed meal (6.3 µmols/g of glucosinolates in the concentrate or 21 µmols/g of glucosinolates in the meal). There were no effects on weight gain or feed intake, although 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.

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.

Most recently, Sekali et al. (2020) provided growing lambs with isonitrogenous diets in which canola meal or heat-treated canola meal replaced soybean meal. The researchers determined that canola meal can readily replace soybean meal, and heat treatment does not provide an added benefit. There were no treatment effects on growth performance, carcass characteristics or meat quality. Canola meal was also noted to be more environmentally sustainable.

Goats

As the amino acid composition of goat milk is similar to cow milk, canola meal should be well suited for lactation. Tajaddini et al. (2021) found that the inclusion of canola meal in diets for goats increased milk production and dry matter intake. The researchers found that formaldehyde treatment can be applied to increase the RUP content of the meal, allowing reduced usage rates.

Andrade and Schmidely (2006) provided lactating goats with diets containing 0 or 20% rolled canola seed. Milk production was increased with the canola seed. In a follow-up study (Schmidely and Andrade, 2011) compared extruded soybeans to rolled canola seed in low and high concentrate diets. There were no differences in milk yield or milk composition for the length of the 8-week trial.

Canola meal can likewise be used for growth in goats. Most studies report the use of whole seed to allow the oil to elevate the energy content of the diet. In a study by Grande et al. (2014) a diet with canola seed outperformed soybean meal, flaxseed and sunflower seed with respect to feed conversion. Average daily gains were similar for all treatments. The incorporation of canola oil into diets for growing goats increase muscle omega-3 fatty acids, lowered organ fat and improved the oxidative stability of meal when compared to palm oil (Karami et al., 2013).

CH. 4 – CANOLA MEAL FOR SWINE

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.

Practical Inclusion Levels of Canola Meal in Diets for Swine

DIET TYPE	INCLUSION LEVELS
Piglets post weaning	High performance at all practical inclusion levels. Test diets up to 40 % inclusion
Growing pigs	High performance up to 25%. No practical data beyond 25%
Gestating sows	High performance up to 25%. No practical data beyond 25%
Lactating sows	High performance up to 25%. No practical data beyond 25%

Canola Meal and Profitability

In a meta-analysis testing the manipulation of diet to improve profitability, Wang et al. (2020) determined that the greatest capture of cost savings was accomplished by reducing dietary protein. Canola meal has an amino acid profile that is very close to ideal (Table 1) and may be used more efficiently than some other vegetable protein sources, allowing diets to be formulated with minimal protein overage. Going forward, trends in swine feeding are expected to consider not just nutrient digestibility, but also ingredient effects on factors beyond production such as manure output, greenhouse gaseous production and gut health and immunity. It is likely that canola meal will provide intrinsic benefits beyond its nutrient profile.

Sustainability

Canola meal is a valuable co-product that may not increase emissions when used in diets for pigs relative to other vegetable proteins. With respect to the swine feeding industry, the major source of greenhouse gas results from manure. Trabue et al. (2021) evaluated gaseous emissions from pigs given corn-based diets in which the supplemental protein was supplied by soybean meal, corn gluten meal, canola meal or poultry meal. There were no treatment differences in average daily gain or gain to feed. Likewise manure output was similar for all treatments. There were no differences in total methane or carbon dioxide production for any of the diets. Ammonia levels were lowest with the canola meal diets, followed by the poultry meal diet, and significantly less than occurred with the soybean meal and corn gluten meal diets.

An additional concern to the environment is phosphorus. It is common to add phytase to diets when either canola meal or soybean meal are used. Veum and Liu (2018) determined that no added inorganic phosphorus was required when growing and finishing swine received a canola meal-sorghum diet with added phytase. The authors concluded that this approach enhances the sustainability of the swine industry.

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, fiber content (bulk density), and feed mineral balance will influence feed intake. For canola meal, there are several factors with the potential to reduce feed intake, such as glucosinolates, tannins, sinapine, fiber and mineral balance, which are explained in more detail in Chapter 2 of this guide. Glucosinolates, with their bitter taste, can have a major negative influence on feed intake in pigs, as indeed they can in many animal species.

Canola meal as produced in Canada, has very low levels of glucosinolates (3.57µmol/g) and has a neutral taste. Traditional rapeseed meal can have glucosinolate levels of over 100μmol/g (see Chapter 2). Levels this high result in meal that can only be used in minimal amounts to avoid issues with feed intake. To avoid decreased feed intake, meal with such high levels needs to be used sparingly. Heyer et al. (2018) replaced 20% of the soybean meal in the control diet with solvent extracted canola meal, or the same solvent extracted canola meal that had been subjected to low, medium or high extruder intensity. Although the extrusion further reduced the glucosinolate 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 properly formulated diets containing canola meal support high levels of efficient growth performance. The nutritional value of canola meal for swine is being understood increasingly well. 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.

Protein and Amino Acids for Swine

Amino acid profile

The amino acid profile of canola meal efficiently meets the amino acid requirement of swine. Lysine is the first limiting amino acid; but, as synthetic lysine is readily available, the addition of lysine to canola meal-based diets makes them easily meet the needs of swine.

Amino acid profiles of ingredients are generally expressed as percent of lysine, with requirements expressed in the same manner. Using the recommendations of either the NRC (2012) or Institut National de la Recherche Agronomique (INRA) model (van Milgen and Dourmad, 2015), canola meal stacks up almost perfectly, and is slightly over requirements for most amino acids (Table 1, “as is” column). With lysine supplementation, the profile meets requirements with less overage (Table 1, added lysine). This shows that pigs can use amino acids from canola meal with a high efficiency.

Table 1. Ideal amino acid profile based on two models, and values for canola meal (% of Lysine).

	MODEL VALUES, % OF LYSINE		CANOLA MEAL, % OF LYSINE	
Amino acid	INRA	NRC	As Is	+ 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 corrected by 9% (lysine *1.09).

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 that 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 2 provides results from recent studies conducted to determine the standardized ileal digestibility of amino acids for solvent extracted canola meal and Table 3 shows results for expeller canola meal. While some of the references have imposed a variety of treatments, the values provided in Tables 2 and 3 are for Brassica napus canola meal as they would be available from Canadian processing plants.

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

AMINO ACIDS	AVERAGE, %[2]	STANDARD DEVIATION
Indispensable		
Arginine	88.05	3.08
Histidine	80.99	9.73
Isoleucine	80.18	4.52
Leucine	82.73	3.94
Lysine	79.54	5.18
Methionine	86.87	3.79
Phenylalanine	82.00	5.59
Threonine	76.84	5.57
Tryptophan	86.10	5.03
Valine	78.22	4.85
Dispensable		
Alanine	80.64	4.62
Aspartic acid	77.09	5.55
Cysteine	75.80	7.34
Glutamic acid	86.13	2.62
Glycine	80.03	7.38
Proline	85.74	9.27
Serine	79.56	5.46
Tyrosine	80.50	5.43

[1] Adewole et al., 2017; Almeida et al, 2014; Berrocoso et al., 2015; Favero et al., 2014; Le et al., 2017; Kim et al., 2015; Le Thanh et al., 2019; Maison and Stein, 2014; Mejicanos and Nyachoti, 2018; Park et al., 2019; Sanjayan et al., 2014; Trindade Neto et al., 2012, Velayudhan et al., 2019

[2] Average of 43 values.

Table 3. Standardized ileal digestibility (SID) of amino acids in expeller canola meal for growing pigs[1].

AMINO ACIDS	AVERAGE, %[2]	STANDARD DEVIATION
Indispensable		
Arginine	86.38	3.99
Histidine	84.55	2.46
Isoleucine	79.15	2.01
Leucine	78.63	6.60
Lysine	78.00	2.09
Methionine	84.60	4.10
Phenylalanine	79.85	4.54
Threonine	73.33	4.89
Tryptophan	85.97	3.35
Valine	75.05	5.68
Dispensable		
Alanine	78.00	5.53
Aspartic acid	75.18	5.82
Cysteine	74.55	5.97
Glutamic acid	83.45	5.98
Glycine	71.48	12.62
Proline	85.60	7.35
Serine	77.90	7.01
Tyrosine	77.50	3.83

[1] Seneviratne et al., 2011; Grageola et al., 2013; Park et al., 2019; Woyengo et al., 2016; [2] Average of 3 values.

Energy For Swine

Determined energy values

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

Energy values published by the National Research Council (NRC, 2012) are given in Table 4 and are based on historical information, and therefore more currently determined values have been added. While there appears to be a range in determined values, this may in part be related to the method of analysis. Kim et al (2018) reviewed the methods available for calculating NE and found that the results from the samples set that was tested ranged from 1,960 to 2,233 kcal/kg as fed for canola meal.

The energy value of expeller and cold pressed canola meal will 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.

Table 4. Energy values for solvent extracted canola meal, as fed basis, Kcal/kg.

REFERENCE	DIGESTIBLE ENERGY	METABOLIZABLE ENERGY	NET ENERGY
NRC, 2012	3154	2903	1821
Berrocoso et al., 2015	3084	2922	1928 [1]
Heo et al., 2014	2901	2692	1850
Kim et al., 2018	3180	2925	2099
Le et al., 2017	2605	2409	1765
Le Thanh et al., 2019	3273	3012	1834
Liu et al., 2014	2883	2681	1769
Liu et al., 2016	2630	2303	1520 [1]
Liu et al., 2018	2972	2724	1789 [1]
Sanchez-Zannatta et al., 2022	2843	2615	1524
Woyengo and Zijlstra, 2021	2880	2600	1720
Zhong and Adeola, 2019	2798	2601	1718 [1]

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

Fiber and digestion

According to Kerr and Shurson (2013) fiber is a catch-all term given to the complex carbohydrates in plant material, the composition of which can change with the method of analysis. The digestibility of fiber, often assumed to be negligible, is actually quite variable, with much of the digestion occurring in the gut. The volatile fatty acids that are generated can be used to support the needs of the gut tissue. Fiber digestion per se is not often determined in swine feeding studies. However, in a recent review (Lannuzel et al., 2022), it was estimated that approximately two-thirds of the non-starch polysaccharide from canola meal was digested. While it was previously believed that increasing the fiber content of the diet reduced the proportion of the fiber digested in the hindgut, this theory was proven false (Navarro et al., 2018). Canola meal is never the sole source of fiber in diets, and the sources of fiber and their interactions need to be taken into account.

Enzymes to improve energy availability

Enzyme addition can increase the available energy in diets that include canola meal. Multi-carbohydrase enzymes have been developed and employed 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.

Lee et al (2018) evaluated an enzyme cocktail that contained xylanase, glucanase, cellulase, mannanase, invertase, protease, and pectinase in an in vitro system. In vitro dry matter digestion of both solvent extracted and expeller canola meal were improved by 8.7 and 9.2% respectively The advantage of using the in vitro system was that the enzymes could only act on canola meal and not other ingredients in the diet. The researchers determined that the mixture increased digestibility and decreased volatile fatty acid and gas production. This indicated that more of the canola meal was digested, and less was fermented when the enzyme mixture was added to the diet.

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.

Silva et al. (2021) determined that the inclusion of 3 percent canola oil to a corn-soybean meal diet for growing-finishing pigs increased the concentration of oleic acid, and proposed that the fatty acid contribution from canola be viewed as a means of producing pork that has greater health benefits.

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; Favero et al., 2014; Adhikari 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%. Maison et al. (2015) analyzed five samples of canola meal and determined a greater digestibility value for phosphorus of 45% with no added phytase, a value that is higher than determined from older studies. Phytase supplementation still increased phosphorus digestibility to 64%, similar to the previous findings. Veum and Liu (2018) determined that no inorganic phosphorus was needed for canola meal-sorghum diets when the diets contained added phytase.

The amount of heat applied during processing may also influence phosphorus digestibility. Lee and Nyachoti (2021) found that heat processing increased phosphorus availability with both solvent extracted and expeller canola meal.

An added benefit of phytase supplementation is the improvement in calcium digestibility. Gonzalez-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%.

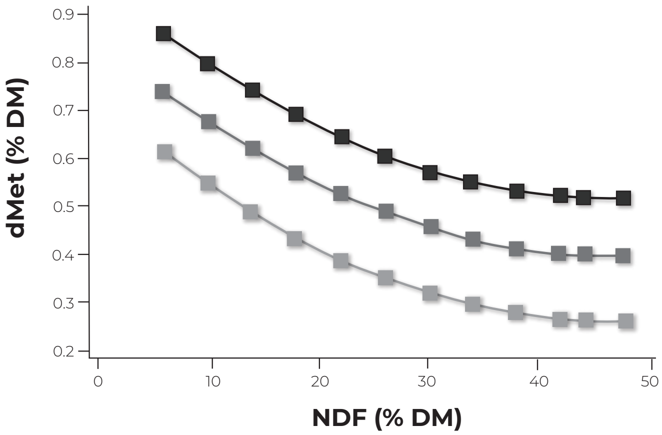
Feeding Solvent Extracted Canola Meal to Swine

Meta-analyses of feeding value

Several meta-analyses have been conducted to assess the value of canola meal in diets for swine. Hansen et al. (2020) analyzed data from 37 studies involving canola meal and 0/0 rapeseed meal to determine inclusion rate limits for the meal. For weaning pigs, results were available from studies where inclusion rates were 2 to 40 percent of the diet. Overall there was a slight reduction in dry matter intake, but this did not effect average daily gain, and resulted in a slight improvement in gain to feed ratio. The range of inclusion levels for growing-finishing swine was 3.8 to 49.0% of the diet. The authors determined that the overall average daily gain was slightly lower with canola meal, but there were no differences due to level of canola meal inclusion. The authors concluded low glucosinolate canola meal and rapeseed meal can be used without adverse effects on growth performance in well-balanced diets for weanling and growing-finishing pigs.

Messad et al (2016) used meta-analysis and meta regression analysis techniques to assess the predictability of the digestibility of amino acids in oilseed meals. The researchers found dietary neutral detergent fiber (NDF) in the diet was inversely related to amino acid digestibility by swine (figure 1).

Figure 1. Impact of dietary concentration of NDF on the digestible standardized ileal methionine (dMet) content of oilseed meals in pig feed. Black: soybean meal; dark grey: rapeseed meal; light grey cottonseed meal. DM = dry matter. From Messad et al., 2016.



Glucosinolate tolerance

Glucosinolates are a main anti-nutritional factor found in canola meal for swine. Pigs are considered to be highly susceptible to glucosinolates, and this applies most to younger pigs (Bischoff, 2019). 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 (Schone 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 to 19 μmol/g (Schone et al., 1997a).

A concentration greater than 2.4 μmol/g of glucosinolates in the diet had negative effects on feed intake, growth rate and thyroid function. In the second study, the maximum safe glucosinolate level was determined at 2.0 μmol/g of diet (Schone et al., 1997b). Given that Canadian canola meal contains, on average, 3.6 μmol/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 at the current levels of glucosinolates in canola meal, there are no limitations for inclusion in grower-finisher diets.

Canola meal in starter diets

Recent research has shown that canola meal can be a valuable ingredient for inclusion in diets for weanling 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 four 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 four 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, associated with no change in average daily gain, and a linear decrease in intake as canola meal levels were increased. This important study shows that, with correct diet formulation, up to 40% canola meal can be included in starter diets for piglets. Table 5 provides comparisons between canola meal and soybean meal as determined in recent studies. In general, there were few statistically significant treatment effects on average daily gain (ADG) and gain per unit of feed.

Some of the differences in performance might be attributed to lower energy content in the canola meal diets. Kim et al. (2020) determined that pigs less than 20 kg are unable to adjust feed intake in response to dietary net energy density regardless of diet composition.

Table 5. Studies evaluating canola meal in starter diets as compared to soybean meal control diets.

REFERENCE	INCLUSION, %	VARIABLE	CANOLA MEAL	SOYBEAN MEAL	P VALUE
Do et al., 2017	8	ADG, g	142	165	0.280
		Gain/feed	0.54	0.50	0.162
Hong et al., 2020	10	ADG, g	359	323	<0.05
		Gain/feed	0.62	0.50	<0.05
	20	ADG, g	378	323	
		Gain/feed	0.66	0.50	
	30	ADG, g	352	323	
		Gain/feed	0.64	0.50	
	40	ADG, g	325	323	
		Gain/feed	0.56	0.5	
Landero et al., 2011	20	ADG, g	493	488	0.592
		Gain/feed	0.7	0.73	0.087
Mejicanos et al., 2017	20	ADG, g	408	408	0.459
		Gain/feed	0.61	0.59	0.024

REFERENCE	INCLUSION, %	VARIABLE	CANOLA MEAL	SOYBEAN MEAL	P VALUE
Parr et al., 2015	10	ADG, g	590	560	0.108
		Gain/feed	0.6	0.59	0.001
	20	ADG, g	610	560	
		Gain/feed	0.65	0.59	
	30	ADG, g	580	560	
		Gain/feed	0.65	0.59	
	40	ADG, g	570	560	
		Gain/feed	0.68	0.59	
Sanjayan et al., 2014	5	ADG, g	472	452	0.979
		Gain/feed	0.6	0.60	0.714
	10	ADG, g	468	452	
		Gain/feed	0.59	0.60	
	15	ADG, g	453	452	
		Gain/feed	0.6	0.60	
Seneviratne et al., 2011	15	ADG, g	445	469	0.87
		Gain/feed	0.71	0.71	0.323
Wang et al., 2017	20	ADG, g	664	660	0.487
		Gain/feed	0.66	0.65	0.047

Canola meal in growing finishing diets

Table 6 shows results from three growing-finishing studies. There were no differences in performance in the two studies in which canola meal was compared to 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 receive an abrupt change in diet to very high levels of canola meal, it might be necessary to make the changes in stages.

Table 6. Studies evaluating canola meal in grow-finish diets as compared to soybean meal control diets.

REFERENCE	INCLUSION, %	VARIABLE	CANOLA MEAL	SOYBEAN MEAL	P VALUE
Kim et al., 2015	11.3	ADG, g	700	725	0.102
		Gain/feed	0.46	0.44	0.196
Little et al., 2015	27.3/23.2	ADG, g	940	930	0.700
		Gain/feed	0.36	0.37	0.200
Smit et al., 2018[1]	25/20	ADG, g	988	1025	0.001
		Gain/feed	0.36	0.37	0.001

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

Tropical climate grow-finish feeding trials

Three feeding trials were conducted in three Mexican states — Nuevo Leon, Sonora and Michoacan (Hickling, 1996). The objective was to replicate the performance found in previously conducted Canadian feeding trials (Tables 7 and 8), 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 by growing phase are shown in Table 9. As with the temperate climate results, equivalent growth, feed efficiency and carcass quality performance were observed in all three dietary treatments (Table 10). Performance between locations varied due mainly to pig genetics and seasonal effects.

Canola meal in diets for sows

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 can be the main supplemental protein source in gilt and sow diets.

Table 7. 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) or two levels of 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	0	6	10	0	8	15
Canola oil	1	1	1	1	1	1
L-Lysine	0.04	0.07	0.06	0.12	0.12	0.15
Mineral/ vitamin	4	4	4	4	4	5
Performance						
Feed intake, kg/d	1.91	1.93	1.89	3.06	3.11	3.08
Gain, kg/d	0.76	0.76	0.77	0.84	0.83	0.82
Gain/Feed	0.42	0.42	0.41	0.26	0.27	0.27

[1] Hickling, 1994.

Table 8. Canadian Feeding trial Results: Overall performance of growing-finishing pigs (20-100 kg) fed diets supplemented with soybean meal (SBM) or two levels of canola meal (CM)[1].

PERFORMANCE	SBM	LOW CM	HIGH CM
Feed intake, kg/d	2.46	2.5	2.47
Gain, kg/d	0.8	0.8	0.8
Gain/Feed	0.33	0.32	0.32
Dressing, %	78	78	78
Backfat index	107	107	107

[1] Hickling, 1994.

Table 9. Tropical feeding trial results: Average performance of growing pigs (20-60 kg) and finishing pigs (60-100 kg) fed diets supplemented with soybean meal (SBM) or two levels of 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	0	8	12	0	10	15
Tallow	0	1	2	0	1	2
L-Lysine	0	0.33	0.47	0.12	0.50	0.70
Mineral/ vitamin	4	4	4	4	4	5
Performance						
Feed intake, kg/d	2.17	2.23	2.18	3.22	3.21	3.12
Gain, kg/d	0.78	0.77	0.76	0.85	0.83	0.82
Gain/Feed	0.36	0.35	0.35	0.26	0.26	0.26

[1] Hickling, 1996.

Table 10. Tropical feeding trial results: Overall performance of growing-finishing pigs (20-100 kg) fed diets supplemented with soybean meal (SBM) or two levels of canola meal (CM)[1].

PERFORMANCE	SBM	LOW CM	HIGH CM
Feed intake, kg/d	2.72	2.74	2.67
Gain, kg/d	0.82	0.81	0.80
Gain/Feed	0.30	0.29	0.29
Meat yield, %	48.6	48.8	49.3
Backfat index	2.38	2.33	2.15

[1] Hickling, 1996

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 11).

Table 11. Evaluation of canola meal in diets for sows[1].

PARAMETER	SOYBEAN MEAL	CANOLA/ SOY	CANOLA MEAL	P VALUE
Number of sows	40	37	37	
Average parity	2.33	2.32	2.33	
Body weight loss, kg	28.2	27.2	32.8	0.22
Piglets 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	2.42	5.22	5.80	<0.05

[1] Liu et al., 2018.

Feeding Expeller Canola Meal to Swine

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 12). 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 12. Studies evaluating expeller canola meal in starter diets as compared to soybean meal control diets.

REFERENCE	INCLUSION, %	VARIABLE	CANOLA MEAL	SOYBEAN MEAL	P VALUE
Landero et al., 2011	5	ADG, g	643	661	0.420
		Gain/feed	0.71	0.71	0.758
	10	ADG, g	642	661	
		Gain/feed	0.73	0.71	
	15	ADG, g	640	661	
		Gain/feed	0.71	0.71	
	20	ADG, g	648	661	
		Gain/feed	0.72	0.71	
Landero et al., 2015	20	ADG, g	455	454	0.933
		Gain/feed	0.71	0.72	0.757
Seneviratne et al., 2010	7.5	ADG, g	906	931	0.001
		Gain/feed	0.49	0.48	0.627
	15	ADG, g	909	931	
		Gain/feed	0.49	0.48	
	22.5	ADG, g	866	931	
		Gain/feed	0.49	0.48	
Seneviratne et al., 2011	15	ADG, g	445	469	0.870
		Gain/feed	0.72	0.71	0.323

Feeding Canola Seed and Oil to Swine

Canola oil is routinely fed to pigs at all life stages. 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 when dietary inclusion levels exceeded ten percent.

Canola Meal and Gut Health

There is significant support for using canola meal to maintain gut health in swine. Portions of the fiber are selectively fermented in the gut thereby providing changes in the composition and activity of the gastrointestinal microbiota. Termed prebiotics, these components confer health benefits, and help the gut withstand pathogenic challenges. Additionally, compounds derived from the breakdown of glucosinolates can serve as antibacterial and antifungal agents (Dufour et al., 2015).

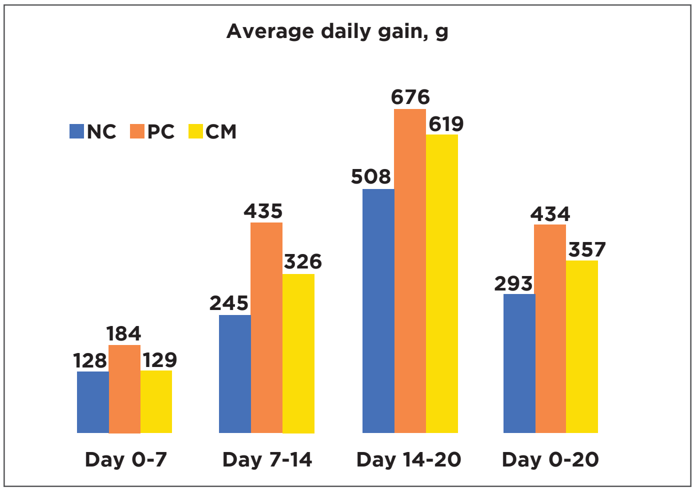
Research with lactating sows showed that gut bacteria profile was more favorable by yielding a greater proportion of lactic acid producing bacteria with a canola meal diet than a soybean meal diet (Velayudhan et al., 2018). Similarly, canola meal when used to replace soybean meal, increased the relative abundance of Lactobacillus and Enterococcus in nursery pigs (Mejicanos et al., 2017).

Since then, research conducted at North Dakota State University showed that canola meal was beneficial for weanling piglets (Hong et al., 2020). When included in the starter feed at 20% of the diet, gut microbial composition was improved, and there was a reduced inflammatory response. In a follow-up experiment, the researchers determined that piglets receiving starter feed with canola meal were better able to fight an E. coli infection than those receiving a soybean meal diet (Hong et al., 2021). The challenge was administered on day 3 of the study, and the trial was terminated on day 20. As Table 13 shows, weanling pigs receiving the soybean meal diet gained 67% as much as the pigs receiving antibiotics. In contrast, the inclusion of 20% canola meal in exchange for part of the soybean meal allowed the pigs to gain 82% of the amount gained by the antibiotic regimen. The gain resulted from greater feed intake with the canola meal diet. Figure 2 shows that the advantage provided by the canola meal was consistent for the term of the study.

Table 13. Evaluation of growth parameters in weaned piglets receiving starter feed and an E. coli challenge (Hong et al., 2021).

PARAMETER	NEGATIVE CONTROL	POSITIVE CONTROL	20% CANOLA MEAL
	Soybean meal+ challenge	Soybean meal+ challenge + antibiotic	20% canola meal+ challenge
Gain, g/day	293	434	357
Feed intake, g/day	350	513	435
Gain/feed	0.83	0.85	0.83

Figure 2. Weekly average daily gains found in the challenge study (NC= negative control, PC= positive control, CM=canola meal)



CH. 5 – CANOLA MEAL 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.

Practical Inclusion Levels of Canola Meal in Diets for Poultry

DIET TYPE	INCLUSION LEVELS
Chick starter	Intakes may be reduced with inclusion over 20%
Broiler grower	High performance reported at 30% inclusion
Broiler finisher	High performance reported at 40% inclusion
Layers	No data beyond 24%
Broiler breeders	High performance to 30%. No data beyond 30%
Turkey starter	High performance to 24%. No data beyond 24%
Turkey grower	High performance to 24%. No data beyond 24%
Turkey finisher	High performance to 24%. No data beyond 24%
Ducks starter	High performance with 10%. More data needed
Ducks grower	High performance to 21%. No data beyond 21%
Geese starter	No data found
Geese grower	High performance with 16%. No data beyond 16%
Quail grower	High performance reported at 15%
Quail egg layers	High performance with 18.5%. No data beyond 18.5%
Ostrich	High performance with 20.0%. Only one trial

Canola Meal and Profitability

The rate of production is the basis for ingredient comparison in most academic trials. However, in industry, cost/unit of gain is the integration of several factors, including ingredient cost, production, health, and survival. While feeding canola meal to poultry may not always result in the maximum rates of gain, there can be reductions in the cost/unit of production when canola meal is incorporated in diets.

Sustainability

In an elaborate study evaluating both rapidly growing and slowly growing broilers, Berger et al. (2021) showed that broiler chickens readily adapt to diets containing alternative protein sources to soybean meal and included canola meal in their evaluation. They determined that replacement may result in a slight increase in the cost of production (under 2%) due to greater feed intake but can result in major reductions in greenhouse gas emissions, often associated with the production systems used to produce and acquire soybean meal. While this may not consistently be the case, better information is being generated to allow sustainability to be predicted with greater accuracy.

Palatability and Feed Intake

Birds have been demonstrated to be averse to bitter compounds (Yoshida et al., 2022). Glucosinolates tend to impart a bitter taste and older varieties of canola meal, that contained higher concentrations of these compounds resulted in reduced intakes (Khajali and Slominski 2012).

In general, poultry maintain appropriate feed intake levels if given diets high in canola meal that are properly formulated for available amino acids. However, studies in raising poultry suggest that canola meal should be limited during the starter period to 20% for broilers and turkeys, and 10% for more less studied species such as 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 allows canola meal to be included at 20% of the diet with no negative effect on feed intake in laying hen diets. 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).

Protein and Amino Acids for Poultry

Using canola meal at high levels in poultry diets is best accomplished by balancing diets for available amino acids. Extensive research has been conducted in recent times to determine the standardized ileal digestibility (SID) of amino acids from solvent extracted canola meal. Results for broilers are provided in Table 1 and SID results for laying hens, turkeys and ducks are shown in Table 2.

Table 1. Standardized ileal digestibility (SID) of amino acids in canola meal for broiler chickens[1].

AMINO ACIDS	AVERAGE, %[2]	STANDARD DEVIATION
Indispensable		
Arginine	87.23	2.33
Histidine	76.51	11.31
Isoleucine	82.66	3.71
Leucine	83.68	2.58
Lysine	79.32	3.06
Methionine	88.93	2.10
Phenylalanine	83.89	2.21
Threonine	76.48	3.68
Tryptophan	87.15	5.18
Valine	78.85	3.94
Dispensable		
Alanine	82.96	3.04
Aspartic acid	77.59	4.17
Cysteine	76.47	3.77
Glutamic acid	89.00	3.54
Glycine	78.80	4.08
Proline	77.45	3.31
Serine	80.51	4.73
Tyrosine	82.66	5.28

[1] Adewole et al., 2017; Agyekum and Woyengo, 2022; Ariyibi, 2019; Chen et al., 2015; Gallardo et al.; 2017; Kim et al., 2012; Kong and Adeola, 2013; Osho et al., 2019; Park et al., 2019, Ross et al., 2019
[2] Average of 41 Values

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). Therefore, the values shown may be useful in extrapolating SID values for other poultry species.

Table 2. Standardized ileal digestibility (SID) of amino acids in canola meal for laying hens, turkeys and ducks[1].

AMINO ACIDS	LAYING HENS[1]	TURKEYS[2]	DUCKS[3]
Indispensable			
Arginine	88.23	88.57	85.30
Histidine	82.97	79.67	81.75
Isoleucine	77.70	76.29	78.40
Leucine	80.63	78.51	83.50
Lysine	80.60	79.86	75.50
Methionine	88.67	84.19	88.60
Phenylalanine	81.70	83.49	84.00
Threonine	73.50	75.13	74.60
Tryptophan	82.30	95.00	87.40
Valine	77.73	74.39	77.55

AMINO ACIDS	LAYING HENS[1]	TURKEYS[2]	DUCKS[3]
Dispensable			
Alanine	80.00	81.83	80.05
Aspartic acid	77.20	80.92	74.90
Cysteine	77.67	73.59	79.80
Glutamic acid	86.75	88.07	85.15
Glycine	76.70	82.01	75.55
Proline	75.70	75.68	83.10
Serine	75.60	80.04	82.05
Tyrosine	78.30	79.02	80.45

[1] Goudarzi et al., 2017; Oryschak et al., 2020. Mean of 4 values;
[2] Adedoken et al, 2008; Koslowski et al., 2011; Koslowski et al., 2018; Zhang et al, 2020. Mean of 28 values; [3] Kong and Adeola, 2013; Zhang et al, 2020. Mean of 30 values.

The SID values obtained with expeller extracted canola meal are provided in Table 3. Values are available from studies using broiler chickens only. Due to the similarities in SID values between broilers, laying hens, turkeys and ducks for solvent extracted canola meal, it is most likely that the SID values given in Table 3 can be used for all these commercial species until more information becomes available.

Table 3. Standardized ileal digestibility (SID) of amino acids in expeller extracted canola meal for broiler chickens[1].

AMINO ACIDS	AVERAGE, %[2]	STANDARD DEVIATION
Indispensable		
Arginine	85.49	4.69
Histidine	74.97	12.14
Isoleucine	80.13	7.85
Leucine	81.41	3.96
Lysine	80.79	4.46
Methionine	87.60	4.09
Phenylalanine	83.00	4.29
Threonine	77.43	4.30
Tryptophan	83.27	8.37
Valine	78.79	4.53

AMINO ACIDS	AVERAGE, %[2]	STANDARD DEVIATION
Dispensable		
Alanine	79.56	5.49
Aspartic acid	80.04	7.72
Cysteine	87.01	6.18
Glutamic acid	80.57	4.87
Glycine	76.84	3.97
Proline	79.97	3.73
Serine	77.93	6.94
Tyrosine	79.56	5.49

[1] Agyekum and Woyengo, 2022; Bryan et al., 2019; Park et al., 2019; Kong and Adeola, 2016; Toghyani et al., 2014; Woyengo et al., 2010
[2] Average of 19 samples.

Energy for Poultry

The energy value of canola meal for poultry is lower than that of soybean meal, the most common vegetable protein used in poultry diets. In certain diets, where the energy value of the diets is of great importance, such as for broilers, canola meal inclusion levels may be restricted. Egg layer diets and early-phase, high-protein turkey diets based on least cost formulation may at times restrict canola meal inclusion levels if high energy ingredients are unavailable.

The values for AMEn shown in Table 4 for solvent extracted canola meal reflect results from recent experiments, and may differ from published values where older varieties, no longer available, were tested. Some of the variability may be associated with the season and/or the location where the canola was grown. However, Georgia researchers (Veluri and Olukosi, 2020; Wu et al., 2020) revealed that the reference diet used in the determination of energy, as well as the calculation method (difference or regression) can impact the values obtained and may account for some of the variability shown. The physical form and degree of processing also impact the energy value of the meal (Khalil et al., 2021).

Table 4. Energy values of canola meal for poultry (AMEn, Kcal/kg).

REFERENCE	SPECIES	AS FED BASIS	DRY MATTER BASIS
Adewole et al, 2017	Broilers	1777	2019
Agyekum and Woyengo		1608	1909
Chen et al.,2015		1983	2254
Gallardo et al		1822	2071
Gorski et al, 2017		1851	2217
Jayaraman, 2016		2144	2437
Jia et al., 2012		1810	2057
Rad-Spice, 2018		1834	2084
Rahmani et al,		1789	2032
Wise and Adeola 2022		1763	2003
Woyengo et al., 2010		1584	1801
Zhang and Adeola, 2017		2011	2286
Zhong and Adeola, 2019		1689	1919
Jia et al., 2012	Layers	1936	2200
Oryschak et al, 2020		1928	2192
Kozlowski et al., 2018	Turkeys	1886	2143
Jia et al., 2012		1766	2007
Noll et al., 2017		2010	2284
Wickramasuriya, 2015	Ducks	1885	2142
Mandal et al., 2005	Quail	1852	2105

Table 5 provides AMEn values for expeller extracted canola meal. As the table indicates, the lipid content of the meal can be variable depending on the source, and is expected to impact the energy value of the meal.

Table 5. Energy value of expeller extracted canola meal for poultry (AMEn, Kcal/kg).

REFERENCE	SPECIES	AS FED	DRY MATTER BASIS	LIPID % OF DRY MATTER
Agyekum and Woyengo	Broilers	1994	2265	15.3
Bryan et al, 2019		2623	2997	11.4
Bryan et al., 2019		2917	3314	15.9
Sessingnong et al., 2022		2043	2322	-
Toghyani et al., 2014		2258	2566	-
Woyengo et al., 2010		2370	2694	12
Zhong and Adeola, 2019		2584	2937	18.1
Oryschak et al, 2020	Layers	2556	2904	13.2

Enzymes to increase energy

The use of dietary enzymes is common in poultry feeds, especially those containing barley and wheat. These additives have been demonstrated to improve carbohydrate digestibility. Canola meal contains a significant portion of cell wall components that are undigested by poultry. Extensive research has been conducted at the University of Manitoba to investigate cell wall composition and non-starch polysaccharide (NSP) digestion with the inclusion of NSP degrading enzymes. 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. An improvement in AMEn of 6.6% with the use of multi-carbohydrase enzymes was witnessed and reported by Rad-Spice (2018). Most recently, Niu et al. (2022) determined that the inclusion of a multi-carbohydrase enzyme cocktail increased NSP digestion from zero to 20%. Bodyweight gain by broilers in the same study was improved by 5%. Although the data are not completely conclusive, moderate enhancement of canola meal digestion may occur. The enzymes may also improve the digestibility of other dietary ingredients.

Ether Extract

The lipid content of canola meal is higher than many other vegetable protein sources, making a significant contribution to the energy value of the meal (Newkirk, 2011). A study by Barekatain et al. (2015) revealed that the digestibility of the oil in canola seed was as digestible as added canola oil is for broiler chickens.

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. Using the ileal digestibility technique, Mutucumarana et al. (2015) calculated that 47% of the phosphorus in canola meal was digestible by broilers, and that a portion of the phytate phosphorus was also digested by birds. In a more recent experiment, Munoz et al. (2018) using the precision fed rooster bioassay technique found phosphorus retention to be 44% of the total when intakes approached requirements, but declined when requirements were exceeded. The authors suggested a value of 38% based on their studies.

Phytase has been shown to be effective in improving phosphorus bioavailability in rapeseed meal varieties (Czerwiński et al., 2012) and more recently in canola meal for broilers. In an Australian study (Moss et al, 2018), the availability of phosphorus was increased from 32% to 52% with the inclusion of phytase and 69% when both phytase and xylanase were added. Phytase also improved the availability of calcium. A 40% improvement in phosphorus digestibility by broilers noted by David et al. (2021).

Cation-anion balance

It is common practice to formulate poultry diets based on cation-anion balance. Diets are generally formulated to a positive cation-anion balance. Canola meal has a negative cation-anion balance and 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.

Feeding Solvent Extracted Canola Meal to Poultry

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.

Canola meal contains less potassium and more sulfur that soybean meal (Khajali and Slominski, 2012). 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). This can be overcome by providing diets with higher levels of potassium carbonate or sodium chloride. Improvements in understanding requirements of broilers have resulted in 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.

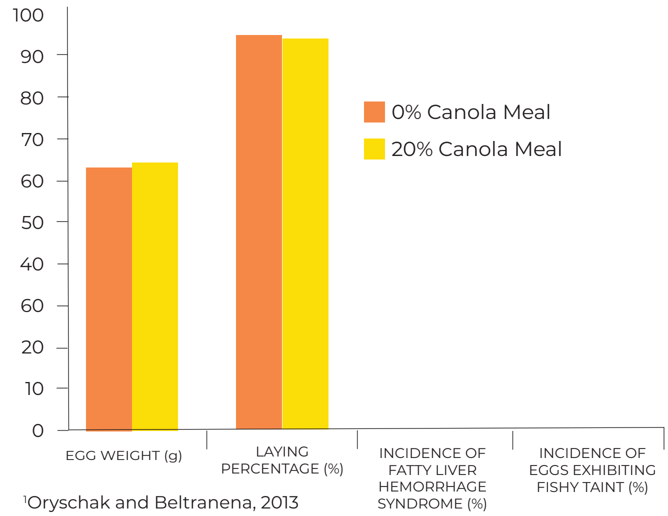
In addition, formulating diets based on SID has resulted in weight gains that are nearly identical to those found with other protein ingredients, particularly during the grower period. Recent research suggests that up to 30% canola meal can be used in broiler diets. Gorski et al. (2017) provided starter 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 to the same level as with soybean meal. 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. Looking at these three studies, canola meal inclusion levels of up to 20% for 0-7 days, 30% from 7-14 days and up to 40% at ages beyond are possible. Rad-Spice et al. (2018) concluded that canola meal can be used effectively and can replace soybean meal in diets 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. Another outdated concept suggested that feeding high levels of canola meal to brown-shelled egg layers could result in eggs with a fishy flavor. This was associated with a genetic error in the hens, and has since been resolved.

Oryschak and Beltranena (2013) demonstrated that when properly formulated, diets can include canola meal at 20% of the diet with no negative effects on egg production, hen health, 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) similarly 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 36weeks of production)[1].



[1]Oryschak and Beltranena, 2013

In an experiment conducted by Dalhousie University (Savary et al., 2017), brown-egg laying 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 statistical differences in egg production, feed efficiency, or mortality for any of the feeding phases. The researchers noted that there were no differences in egg quality or hen weights. A similarly designed follow up trial confirmed these results (Savary et al., 2019).

Most recently, a comprehensive trial conducted by Oryschak et al. (2020) clearly demonstrated that the inclusion of solvent extracted meal in the diet of brown-shelled egg layers at an inclusion level of 20* supported excellent lay performance and egg quality for a 36-week laying cycle. 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.

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-fiber 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. 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 successful use of canola meal for turkeys is to ensure that 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 not different than 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 multicarbohydrase 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. (Khajali and Slominski, 2012) recommend the equation (Na + K) – (Cl + S), which results in an electrolyte balance of approximately 100 mEq/kg.

Ducks and geese

Ducks and geese represent the third largest source of poultry meat, after chickens and turkeys. 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. The amino acid digestibility of canola meal in ducks is shown in Table 2. Canola meal and soybean meal have similar amino acid digestibility in ducks (Kluth and Rodehutscord, 2006). 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 concentrations, 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.

Zhu et al. (2019) provided starter ducks with "canola quality" rapeseed meal at levels of 0, 5, 10, 15 or 20% of the diet. The meal contained 25 umol/g of meal, a level that is approximately 5 times that of canola meal. There were no differences in growth rate for the feeding period (7 to 21 days). Feed/gain improved linearly with inclusion of the rapeseed meal, suggesting that starter feeds could contain more than the 7% proposed by Bernadet et al. (2009).

Fewer research programs are available for geese compared to other poultry species. Interestingly, geese have a greater digestive capability than other types of poultry, and appear to digest canola meal efficiently (Jamroz, et al., 1992). A dose titration study comparing graded levels of rapeseed meal to soybean meal was found (Fu et al., 2021). Isonitrogenous diets containing 0, 4, 8, 12 and 16% rapeseed meal were provided to growing geese from 35 to 70 days of age. There were no differences due to diet for growth, feed intake or feed efficiency. Dressing percentage and carcass component yields were likewise unaffected by diet. These results would suggest that 16% canola meal could be fed in the grow-finish period for geese.

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 by 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.

A growth study was described by Minisi and Mlambo (2018). In the study, 6-week old quail were given isonitrogenous diets containing 0, 2.5, 5.0, 12.5 and 17.5% canola meal, replacing soybean meal on a protein basis. There were no differences in weight gain, but feed intake was lowest for the diet containing 17.5% canola meal. Sarıcicek et al. (2005) also compared canola meal to soybean meal in a quail growth study (Table 6). 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. Dressing percentages and carcass characteristics were not different due to the diets. Combined these two trials suggest that 15% canola meal can safely be given to growing quail.

Table 6. Growth of quail in a study where canola meal partially relaced soybean meal[1].

	DIET		
	Soybean meal	Low canola meal	High canola meal
Replacement of soy protein, %	0	25	50
Canola meal in diet, %	0	12.15	24.3
	No enzymes added		
Weight gain, g	150	140	132
Feed intake, g	761	751	740
Feed/gain	5.06	5.22	5.59
	Multi-carbohydrase enzymes added		
Weight gain, g	143	142	147
Feed intake, g	738	753	755
Feed/gain	5.16	5.13	5.16

[1] Sancicek et al, 2015.

Ostriches

One novel study showed that ostriches can be grown to market weights using canola meal (Brand et al., 2020). Ostriches from 75 through 337 days of age were given diets with varying percentages of canola meal, with the canola meal replacing soybean meal and wheat grain on an amino acid basis (Table 7).

Table 7. Growth of ostriches in a study where canola meal was provided at varying levels[1].

	FEEDING PROGRAM				
	1	2	3	4	5
Starter diet (76-146 days)					
Canola, %	0	7.8	15.6	23.4	31.3
Soybean meal, %	17.9	13.4	9.0	4.5	0
Grower diet (147-230 days)					
Canola, %	0	5.0	10.0	15.0	20.0
Soybean meal, %	13.5	10.0	6.7	3.7	0
Finisher diet (231- 377 days)					
Canola, %	0	5.0	10.0	15.0	20.0
Soybean meal, %	10.4	7.9	5.2	2.6	0

[1] Brand et al., 2020.

There were no differences in intake between the diets, and there were no differences in average daily gain from the start to the completion of the trial. Average daily gains during the starter phase increased with the 15.6 and 23.4% canola meal inclusion levels, but the advantage was not maintained for the duration of the trial. There were no differences in carcass weights or dressing percentages that could be associated with the trial.

Feeding Expeller Canola Meal to Poultry

Much of the canola used for poultry is solvent extracted, but there has been growing interest in the use of expeller canola meal due to its greater energy content. One item that hinders use is oil content, which can vary with the source of the meal (Woyengo et al., 2010), making it important to know the oil content for feed formulation.

Broiler chickens

Several studies support the use of expeller canola meal for broilers. An expeller pressed yellow variety of canola was evaluated in a Dalhousie study (Bryan et al., 2019a) with and without inclusion of fiber digesting enzymes. The canola meal was substituted for soybean meal and corn with an inclusion level was 30%. Additionally, expeller meals with two levels of residual oil (10 Vs 14%) were evaluated. The energy value of the meal increased with residual oil and was further increased with the inclusion of carbohydrase enzymes.

Inglis et al. (2021) provided boilers with diets containing 20% expeller meal in the starter, grower and finisher rations. Expeller canola meal and canola oil were incorporated in the diet in exchange for soybean meal and corn to provide the birds with isoenergetic and isonitrogenous diets. The researchers found no differences in average daily gain or feed conversion for the duration of the 35- day feeding trial.

Laying hens

A feeding trial was conducted by Oryschak et al. (2020) to evaluate the effects of expeller canola meal compared to solvent extracted canola meal and soybean meal. Two varieties of meal were also included in the 36-week evaluation with a 20% level of inclusion. There were no differences in percentage lay or hen body weights with any of the diets. Egg to feed ratio decreased slightly with the expeller meal. Diets with canola meal increased the percentage of mono-unsaturated fatty acids in the eggs. These results were similar to findings of Savary et al. (2017; 2019).

Spent hens

Spent hens can play a role in food security and are often used in commercial soups and specialty dishes requiring chicken with more texture. An exploratory study was conducted by Semwogerere et al. (2019) to compare nutritional characteristics of meat obtained from spent hens from a flock receiving a soybean meal diet (40 weeks of lay), and from a flock that had been given a diet with 20% expeller canola meal (48 weeks of lay). No differences in sensory attributes were found. The hens that had received the canola meal diet had less saturated fat (34.0% as compared to 38.7% of total fatty acids for the birds given the soybean meal diet) and a greater omega-3 fatty acid (5.1 % for the canola-fed birds as compared to 3.4% for the controls).

Feeding Canola Seed and Oil to Poultry

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 can 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. 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.

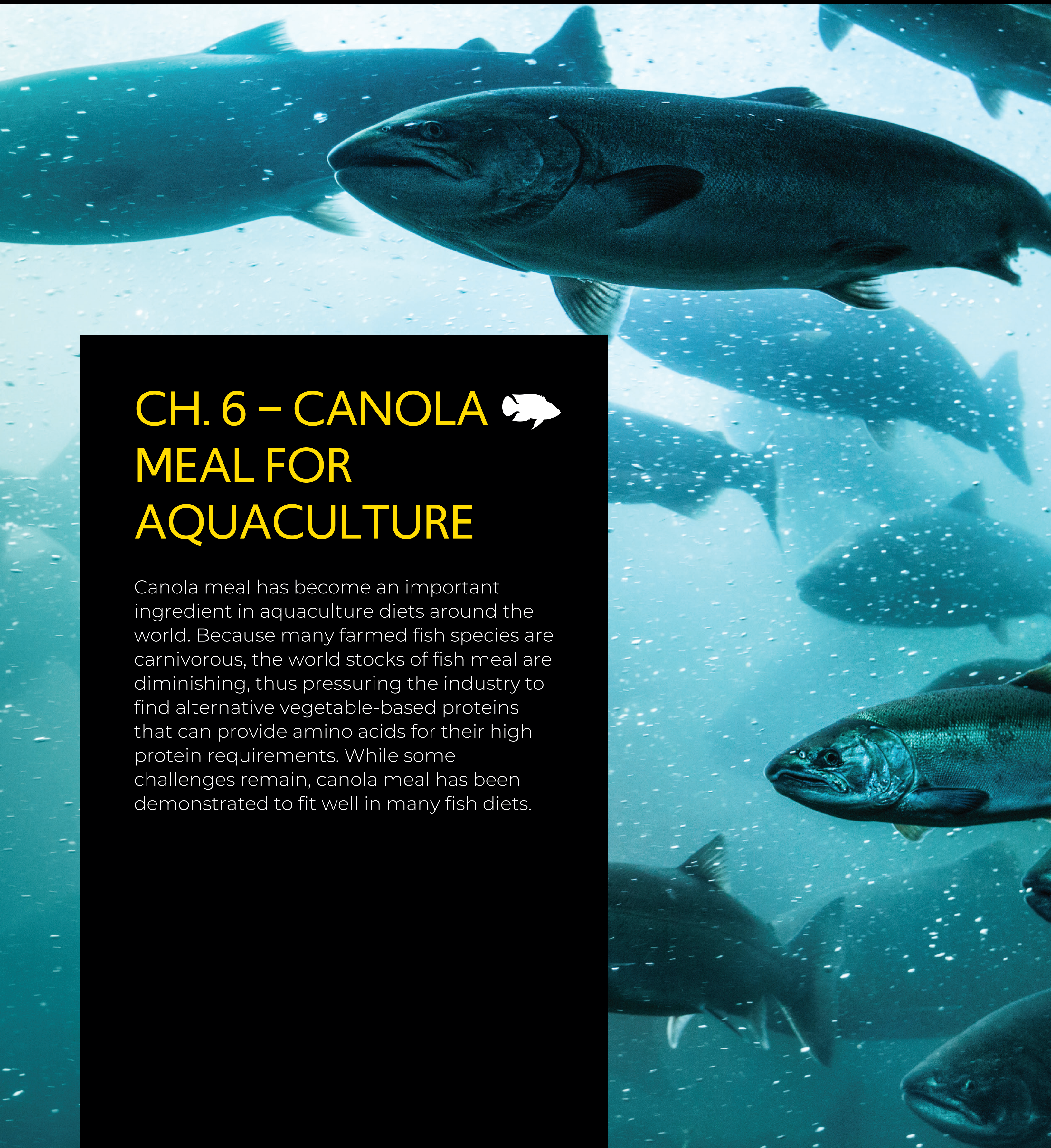
Canola Meal and Gut Health

As the use of chemical growth promoting agents continues to diminish in the poultry industry, more and more information comes to light concerning the role of ingredients and specific nutrients upon health maintenance. Canola meal has been highlighted in several feeding trials as an ingredient that may contribute to gut health and digestion.

The fiber in canola meal is partially digested in the ceca of birds, resulting in the production of volatile fatty acids (VFA). These fatty acids, and in particular butyrate, serve to inhibit pathogenic bacteria (Elnesr et al., 2020) and supply required nutrients for colonocytes in the ceca and large intestine. Kozlowski et al. (2018) found that turkeys given diets with 20% Canadian canola meal as a replacement for soybean meal experienced a shift in the proportion of butyrate as a percentage of total VFA. The amount of total VFA in the cecal contents was enhanced when multi-carbohydrase enzymes were also added to the diet. Inglis et al. (2021) reported greater fermentation in growing broilers when diets contained canola meal. These researchers also reported differences in the bacterial profile of the cecal contents.

Older studies suggested that canola meal might alter the integrity of the gut lining in poultry. Gopinger et al. (2014) provided male broiler chickens with starter and grow-finisher diets that provided 0, 10, 20, 30 and 40% canola meal. They found no loss in integrity of the mucosal lining.

Researchers at the University of Georgia recently evaluated the effects of expeller rapeseed meal, solvent extracted canola meal and a metabolite of glucosinolate degradation (allyl isothiocyanate, AITC) in two challenge studies with Eimeria maxima and Salmonella typhimurium. The same diets were used in both studies: soybean meal control, 10% expeller rapeseed meal, 30% expeller rapeseed meal, 20% solvent extracted canola meal, 500 ppm AITC and 1000 ppm AITC. The Eimeria (coccidiosis) study (Yadav et al., 2022a) revealed that there were differences in growth rates that were not related to the Eimeria challenge that was imposed. Therefore, this test was not a meaningful measure of the outcome of the two trials. However, the intestinal permeability increased to a greater extent with the soybean meal and rapeseed meal than with the canola meal diet. Furthermore, the protective ability of the canola meal was numerically improved when the diet contained 40%, as compared to 20% canola meal. The AITC was also highly effective at reducing intestinal permeability. In the second study (Yadav et al., 2022) broilers were challenged with Salmonella at hatch. Gut permeability was not elevated by exposure to Salmonella. Intestinal villus height was greatest with the 30% rapeseed meal diet, with other treatments being the same as the control. Mortality was highest with the soybean meal challenge treatment. Therefore, canola meal may provide advantages when suffering from Eimeria infections and may provide an advantage over soybean meal through lower mortality when birds are exposed to Salmonella.



CH. 6 – CANOLA MEAL FOR AQUACULTURE

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.

Practical Inclusion Levels of Canola Meal in Diets for Common Aquaculture Species with no Enzymes Added

SPECIES	SCIENTIFIC NAME	INCLUSION LEVEL
Australasian Snapper	Pagrus auratus	60
Black Carp	Mylopharyngodon piceus	11
Common Carp	Cyprinus carpio	55
Grass Carp	Ctenopharyngodon idella	37
Mori	Cirrhinus mrigala	24
Pacu	Piaractus mesopotamicus	19
Nile Tilapia	Oreochromis nioliticus	33
Pangasius Catfish	Pangasius sutchi	30
Rohu	Labeo rohita	20
Silver Perch	Bidyanus bidyanus	60
Streaked Prochilod	Prochilodus lineatus	8
Wuchang Bream	Megalobrama amblycephala	35
Atlantic salmon	Salmo salar	10
Barramundi (Asian Sea bass)	Lates calcarifer	30
Cobia	Rachycentron canadum	13
European Sea Bass	Dicentrarchus labrax	25
Japanese Sea Bass	Lateolabrax japonicus	15
Ovate Pompano	Trachinotus ovatus	16
Rainbow Trout	Oncorhynchus mykiss	20
Freshwater Angelfish	Pterophyllum scalare	8
Piavucu	Leporinus macrocephalus	38
Sunshine Bass	Morone chrysops	20
Shrimp	White Leg	15
Prawns	Macrobracium	30
Mangrove (Mud) Crabs	Scylla serrata	20

Profitability and Sustainability

As fish life continues to be depleted from the Earth's oceans, and the human population increases further, the reliance on farmed fish to supply consumers with high quality protein increases in importance. The aquaculture industry is striving to reduce its dependance on harvested fish by producing farmed fish instead. As Table 1 shows, the global aquaculture industry currently provides consumers with 30 million metric tonnes of high quality food from 15 million metric tonnes of marine fish.

Table 1. Fish in-fish-out ratios (FIFO) for select farmed species (million metric tonnes)[1].

SPECIES GROUP	FIFO	FARMED PRODUCTION, MMT	RAW MATERIALS USED, MMT
Eels	2.7	0.26	0.7
Salmonids (salmon and trout)	2.5	2.54	6.4
Marine fish	1.6	2.55	4.1
Crustaceans (marine and freshwater)	0.7	5.48	3.8
Other freshwater fish	0.3	4.05	1.2
Tilapia	0.2	3.00	0.6
Fed Carp	0.1	12.17	1.2
Overall	0.5	30.05	15.0

[1] https://www.globalseafood.org/advocate/how-much-fish-is-consumed-in-aquaculture/

Many factors relating to the environmental impact of farmed fish are related to the feed. Changes in feeding practices offer an opportunity to reduce the impact of this sector on its global warming potential (Sherry and Koester, 2020). Increasing the use of sustainable land-based ingredients and/or re-evaluating the metrics used to assess production are a few options that could accomplish this. The fastest growth rates and the highest gain-to-feed ratios may not be the best option with respect to sustainability.

Canola meal can be used to partially replace fishmeal in diets for many farmed fish species. It has an amino acid profile that matches the requirements of many species (Albrektsen et al., 2022). As Table 2 shows, the cost of production is lower for canola meal than it is for many other protein ingredients (Kaiser et al., 2022). Thus, there are opportunities to use canola meal to support a more sustainable and profitable aquaculture industry, and additional supportive information is coming to light at a rapid pace.

Table 2. Calculated production and production costs of proteins (2019 Data)[1].

PROTEIN SOURCE	GLOBAL PRODUCTION, MMT	PRODUCTION COSTS, $US/MT
Lupins	1.0	453.7
Peas	21.8	1313.4
Canola/rapeseed	70.5	406.0
Soybeans	333.7	507.6
Sunflower	56.1	583.7
Fishmeal	6.0 2	1596.0

[1] Kaiser et al., 2022; [2] Dried meal after oil extraction.

Palatability and Feed Intake

Canola meal is a palatable source of protein for use in aquaculture diets. In fact, 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) reported that the inclusion of 1% soluble canola protein concentrate in diets fed to sunshine bass significantly increased feed intake and weight gain. As described in Chapter 2, levels of glucosinolates in canola meal are now quite low, and they no longer impart a bitter taste to the meal as was found in some older studies.

The dietary inclusion level of canola meal is often limited by the nutrient requirements of some farmed fish species. 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 dietary carbohydrates. Table 3 shows that inclusion levels may be as high as 60% in the diets of some commercially important omnivorous species but is limited to 30% or less for carnivorous species (Table 4) when growth rate is used as the primary response criterion.

Table 3. Average canola meal inclusion levels in diets of omnivorous and herbivorous fish with no compromise in performance over the standard diet (studies published since 2000).

SPECIES	SCIENTIFIC NAME	INCLUSION LEVEL, %
Omnivorous Marine		
Australasian snapper[1]	Pagrus auratus	60
Omnivorous Fresh Water		
Black carp[2]	Mylopharyngodon piceus	11
Common carp[3]	Cyprinus carpio	55
Grass carp[4]	Ctenopharyngodon idella	37
Mori[5]	Cirrhinus mrigala	24
Pacu[6]	Piaractus mesopotamicus	19
Pangasius catfish7	Pangasius sutchi	30
Rohu[8]	Labeo rohita	20
Silver perch[9]	Bidyanus bidyanus	60
Streaked prochilod[10]	Prochilodus lineatus	8
Wuchang bream[11]	Megalobrama amblycephala	35
Herbivorous Fresh Water		
Nile tilapia[12]	Oreochromis niloticus	33

[1] Glencross et al, 2004a; [2] Huang et al, 2012; [3] Hussain et al., 2020; [4] Veiverberg et al., 2010; Jiang et al., 2016; [5] Parveen et al., 2012; [6] Viegas et al., 2008; [7] Van Minh et al., 2013; [8] Iqbal et al., 2015; Umer and Ali, 2009; Parveen et al., 2012; Umer et al., 2011; [9] Booth and Allen, 2003. [10] Galdioli et al, 2002. [11] Zhou et al., 2018; [12] Yigit and Olmez, 2009, Zhou and Yue, 2010; Luo et al, 2012; Mohammadi et al., 2016; Fangfang et al., 2014; Soares et al., 2001.

Table 4. Average canola meal inclusion levels in diets of carnivorous fish with no compromise in performance over the standard diet (studies published since 2000).

SPECIES	SCIENTIFIC NAME	INCLUSION LEVEL, %
Carnivorous Marine		
Atlantic salmon[1]	Salmo salar	10
Barramundi[2]	Lates calcarifer	30
Cobia[3]	Rachycentron canadum	13
European sea bass[4]	Dicentrarchus labrax	25
Japanese sea bass[5]	Lateolabrax japonicus	15
Ovate pompano[6]	Trachinotus ovatus	16
Rainbow trout[7]	Oncorhynchus mykiss	20
Carnivorous Fresh Water		
Freshwater angelfish[8]	Pterophyllum scalare	8
Piavucu[9]	Leporinus macrocephalus	38
Sunshine bass[10]	Morone chrysops	20

[1] Burr et al., 2013; Collins, et al., 2013; [2] Ngo et al., 2015; [3] Luo et al., 2012; [4] Lanari and D'Agaro, 2005; [5] Cheng et al., 2010; [6] Kou et al., 2015; [7] Thiessen et al., 2003; Thiessen et al., 2004; Yigit et al., 2012; Collins et al, 2012; Collins et al., 2013; [8] Erdogan and Olmez, 2009; [9] Galdioli et al., 2001; Soares et al., 2000 10 Webster et al., 2000.

Protein and Amino Acids for Aquaculture

The digestibility of protein from canola meal is high for most fish species. NRC (2011) does not list canola meal as an ingredient but 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 protein from soybean meal (77%) and the same as the digestibility of soy protein isolate (84%). Protein digestibility results from studies published since 2000 are provided in Tables 5 and 6 for omnivorous and carnivorous species, respectively.

Table 5. Protein digestibility (%) of canola meal for omnivorous and herbivorous fish as determined in studies published since 2000 where no enzymes were added.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Omnivorous Marine		
Australasian snapper[1]	Pagrus auratus	83.0
Haddock[2]	Melanogrammus aeglefinus	82.3
Omnivorous Fresh Water		
African catfish[3]	Clarias gariepinus	89.8
Channel catfish[4]	Ictalurus punctatus	91.4
Rohu[5]	Labeo rohita	49.9
Silver perch[6]	Bidyanus bidyanus	83.0
Herbivorous Fresh Water		
Nile tilapia[7] See Table[3]	Oreochromis niloticus	82.0

[1] Glencross et al., 2004a; [2] Tibbitts et al, 2004; [3] Elescho et al., 2021; [4] Kitagima and Fracalossi, 2011; [5] Hussain et al, 2015; [6] Allan et al, 2000; [7] Borgeson et al., 2006.

Table 6. Protein digestibility (%) of canola meal for carnivorous fish as determined in studies published since 2000 where no enzymes were added.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY, %
Carnivorous Marine		
Arctic char[1]	Salvelinus alpinus	72.8
Atlantic cod[2]	Gadus morhua	60.6
Atlantic salmon[3]	Salmo salar	86.2
Barramundi[4]	Lates calcarifer	85.4
Cobia[5]	Rachycentron canadum	89.0
European sea bass[6]	Dicentrarchus labrax	89.8
Japanese sea bass[7]	Lateolabrax japonicus	71.4
Meagre[8]	Argyrosomus regius	95.9
Rainbow trout[9]	Oncorhynchus mykiss	88.3
Striped bass[10]	Morone saxatilis	43.0
Yellowfin seabream[11]	Acanthopagrus latus	84.7
Carnivorous Fresh Water		
Freshwater angelfish[12]	Pterophyllum scalare	86.5
Piavucu[13]	Leporinus macrocephalus	78.7
Siberian sturgeon[14]	Acipenser baerii	61.0

[1] Burr et al., 2011; [2] Erdogan et al., 2010; [3] Burr et al., 2011; [4] Ngo et al., 2015; [5] Zhou et al., 2004; Luo et al., 2012; [6] Lanari and D'Agaro, 2005; [7] Cheng et al., 2010; [8] Rodrigues Olim, 2012; Olim, 2012; [9] 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; Lee et al., 2020; [10] Gaylord et al, 2004; [11] Wu et al, 2006; [12] Erdogan and Olmez., 2010; [13] Goncalves et al., 2002; Goncalves 2004; [14] Mirzakhani et al., 2020.

Energy and Fiber

Protein-to-energy ratios in fish diets are high compared to birds and mammals, and thus, aquaculture diets are typically higher in crude protein than are poultry and livestock diets. Diets for the carnivorous salmonids typically contain more than 40% crude protein. Diets for omnivorous or herbivorous fish like carp or tilapia typically contain 25 to 30% crude protein. The feasible inclusion rate of canola meal is below 20% when formulating practical diets for carnivorous species like salmonids because as fed canola meal contains less than 40% crude protein. However, in omnivorous or herbivorous fish, such as carp and tilapia, dietary crude protein requirements are considerably lower, and this limitation does not apply.

Tables 7 and 8 (dry matter digestibility) and Tables 9 and 10 (energy digestibility) illustrate the variability of these parameters when using canola meal in fish diets. This can be attributed in large part to the many varied species of fish that are farmed worldwide as well as varied processing systems used to manufacture the canola meal.

The energy value of canola meal will vary due to the amount of lipid that is present in the meal. Processing methods also affect the value of the meal. Burel et al. (2000) determined that the digestibility of rapeseed meal by rainbow trout was 69% for solvent-extracted meal and 89% with heat-processing, demonstrating the wide range in values possible.

Fiber is not digested to any large extent by aquaculture species. Plant fiber can be divided into two categories: soluble fiber, which increases intestinal viscosity, and insoluble fiber, which increases bulk. Canola meal contains approximately half as much soluble fiber as soybean meal (Mejicanos et al., 2016), which may be an advantage for some species. Modest amounts of insoluble fiber may improve transit time and feed intake, but large amounts result in excess bulk, again depending upon the species of fish. Reducing the fiber fraction of canola meal could enhance its value in nutrient-dense aqua feeds.

Table 7. Dry matter digestibility (%) of canola meal for omnivorous and herbivorous fish as determined in studies published since 2000 where no enzymes were added.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY
Omnivorous marine		
Australasian snapper[1]	Pagrus auratus	52.7
Haddock[2]	Melanogrammus aeglefinus	58.9
Omnivorous fresh water		
African catfish[3]	Clarias gariepinus	74.6
Channel catfish[4]	Ictalurus punctatus	69.4
Rohu[5]	Labeo rohita	49.9
Silver perch[6]	Bidyanus bidyanus	51.9
Herbivorous fresh water		
Nile tilapia[7]	Oreochromis niloticus	80.5

[1] Glencross et al., 2004a; [2] Tibbetts et al, 2004; [3] Elescho et al., 2021; [4] Kitagima and Fracalossi, 2011; [5] Hussain et al, 2015. [6] Allan et al, 2000; Allan et al., 2004; [7] Bibi et al., 2020; Borgeson et al., 2006 Furura et al., 2001; Pezzato et al., 2002.

Table 8. Dry matter digestibility (%) of canola meal for carnivorous fish as determined in studies published since 2000 where no enzymes were added.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY, %
Carnivorous marine		
Arctic char[1]	Salvelinus alpinus	46.8
Atlantic cod[2]	Gadus morhua	60.6
Atlantic salmon[3]	Salmo salar	76.2
Barramundi[4]	Lates calcarifer	41.2
Cobia[5]	Rachycentron canadum	48.0
European sea bass[6]	Dicentrarchus labrax	71.2
Japanese sea bass[7]	Lateolabrax japonicus	40.0
Meagre[8]	Argyrosomus regius	44.1
Rainbow trout[9]	Oncorhynchus mykiss	65.6
Yellowfin seabream[10]	Acanthopagrus latus	33.5
Carnivorous fresh water		
Freshwater angelfish[11]	Pterophyllum scalare	71.2
Piavucu[12]	Leporinus macrocephalus	63.8
Siberian sturgeon[13]	Acipenser baerii	76.4

[1] Burr et al, 2011; [2] Tibbetts et al., 2004; [3] Burel et al., 2000; Dalsgaard et al., 2012; [4] Ngo et al., 2015; [5] Luo et al., 2012; [6] Iqbal et al., 2015; [7] Cheng et al., 2010; [8] Rodrigues Olim et al., 2012; [9] Mwachireya et al., 2000; Burel et al., 2000; Dalsgaard et al., 2012; Lee et al., 2020; [10] Wu et al., 2006.; [11] Erdogan and Olmez., 2010; [12] Goncalves et al., 2002; Goncalves, 2004; [13] Mirzakhani et al., 2020.

Table 9. Energy digestibility (%) of canola meal for omnivorous fish as determined in studies published since 2000 where no enzymes were added.

SPECIES	SCIENTIFIC NAME	DIGESTIBILITY, %
Omnivorous marine		
Australasian snapper[1]	Pagrus auratus	43.9
Haddock[2]	Melanogrammus aeglefinus	60.1
Omnivorous fresh water		
African catfish[3]	Clarias gariepinus	79.9
Channel catfish[4]	Ictalurus punctatus	72.1
Rohu[5]	Labeo rohita	49.9
Silver perch[6]	Bidyanus bidyanus	58.0
Herbivorous fresh water		
Nile tilapia[7]	Oreochromis niloticus	76.9

[1] Glencross et al., 2004a; [2] Tibbitts et al, 2004; [3] Elescho et al., 2021; [4] Kitagima and Fracalossi, 2011; [5] Hussain et al, 2015; [6] Allan et al, 2000; [7] Borgeson et al., 2006; Furura et al., 2001.

Table 10. Energy digestibility (%) of canola meal for carnivorous fish as determined in studies published since 2000 where no enzymes were added.

SPECIES	SCIENTIFIC NAME	INCLUSION LEVEL, %
Carnivorous marine		
Arctic char[1]	Salvelinus alpinus	46.8
Atlantic cod[2]	Gadus morhua	60.6
Atlantic salmon[3]	Salmo salar	49.0
Barramundi[4]	Lates calcarifer	47.6
Cobia[5]	Rachycentron canadum	83.1
European sea bass[6]	Dicentrarchus labrax	91.7
Meagre[7]	Argyrosomus regius	73.6
Rainbow trout[8]	Oncorhynchus mykiss	74.1
Yellowfin seabream[9]	Acanthopagrus latus	56.3
Carnivorous fresh water		
Freshwater angelfish[10]	Pterophyllum scalare	72.3
Piavucu[11]	Leporinus macrocephalus	79.0
Siberian sturgeon[12]	Acipenser baerii	68.1

[1] Burr et al, 2011; [2] Tibbetts et al., 2006; [3] Burr et al., 2011; [4] Ngo et al., 2015 [5] Zhou et al., 2005; 6Lanari and D'Agaro, 2005.; [7] Glencross et al., 2004a; [8] Mwachireya et al., 2000; Burel et al., 2000; Thiessen et al., 2004; Cheng and Hardy, 2002; Lee et al., 2020; [9] Wu et al., 2006; [10] Erdogan and Olmez., 2010; [11] Goncalves et al., 2002; Goncalves 2004; [12] Mirzakhani et al., 2020.

Minerals and Vitamins

Canola meal is a rich source of phosphorus. Much of the phosphorus is in the form of phytic acid, which is not available to most species of farm reared fish. Because of this, many aquaculture diets are formulated to contain phytase (NRC, 2011), the enzyme necessary to cleave phosphorus from phytic acid. Research has also indicated 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, can be beneficial in releasing minerals from phytic acid.

Antinutritional Properties of Canola Meal

Like any feed ingredient, canola meal contains some molecular components that may negatively impact a variety of aquaculture species. These must be considered when formulating diets with canola meal. Canola meal contains small amounts of heat-labile (glucosinolates) and heat-stable (phytic acid, phenolic compounds, tannins, saponins and fiber) anti-nutritional factors (Chapter 2).

Glucosinolates

Glucosinolates appear to be better tolerated by many fish species (carp for example) than by swine and poultry (Bischoff, 2019; Prabu et al., 2017). Fortunately, Canadian canola meal currently contains very limited amounts of glucosinolates (3.2 µmol/g). Several publications have identified upper limits of inclusion of glucosinolates in the fish diets. The most conservative limit is set for trout, at 1.4 µmol/g of the feed (Bischoff, 2019). This would still allow for a relatively high theoretical maximum inclusion of canola meal at over 40%.

Phytic acid

Plant ingredients commonly store phosphorus in the form of phytic acid. Phytic acid added as such has been demonstrated to depress growth in many aquaculture species when total dietary levels exceed 1% of the diet. Examples are carp (Hossain and Jauncey, 1993), channel catfish (Satoh et al., 1989), rohu (Usmani and Jafri, 2002), and Atlantic salmon (Storebakken et al., 1998). Phytic acid has been found to not only reduce the availability of minerals but can likewise bind with protein and lower its digestibility.

Table 11. Evaluation of phytase inclusion in diets containing canola meal on digestibility of dry matter (DM) crude protein (CP), gross energy (E) and phosphorus (P).

			INCREASE IN DIGESTIBILITY, %			
Reference	Species	Diet canola, %	DM	CP	E	P
Xu et al., 2022	Gibel carp	18	6	4		19
Habib et al., 2018	Rohu	56				60
Hussain et al., 2017	Rohu	56		28	24	
Iqbal et al., 2021	Rohu	54	25	19	29	
Tayyab et al., 2017	Rohu	56		10	9	31
Maas et al., 2018	Nile tilapia	10	9	0	5	59
von Danwitz et al., 2016	Turbot	26	0	2		42
Fries et al., 2020	Silver catfish	30	4	13	10	29
Sajjadi and Carter, 2004	Atlantic salmon	35		0	0	18
Yigit and Keser, 2016	Rainbow trout	32	0	0		0
Cheng and Hardy, 2002	Rainbow trout	100[1]				350

[1] Calculated by regression.

The original purpose of adding phytase to diets was to enable animals to access the majority of phytate phosphorus in plants and reduce reliance on inorganic phosphate sources, thus significantly reducing phosphorus pollution. When used in diets for fish, phytase often improves the digestibility of dry matter, crude protein and energy (Table 11) in diets containing canola meal. As a result, this is an important exogenous enzyme for the aquaculture industry.

Reduced protease production

Some species of fish may experience reduced production of endogenous enzymes when plant-based ingredients are included in the diet (Santigosa, 2008; Zheng et al., 2020), which is often associated with protease inhibitors found in plant ingredients. Protease inhibitors are less common in canola than in some other ingredients, notably soybean meal (Hussain et al., 2021; Francis et al, 2001). If these ingredients are included in diets along with canola meal, then the digestion of canola meal protein can be impaired.

The addition of proteases to the diet can supplement endogenous production. Drew et al. (2005) reported 30% and 11% improvement in dry matter and protein digestibility, respectively, with the inclusion of protease in diets for rainbow trout that contained 12% canola meal. In an ingredient substitution study, Lee et al. (2020) determined that protease improved the digestibility of dry matter, crude protein, and energy from canola meal by 24, 6 and 14%, respectively, for rainbow trout. Protein efficiency ratios were improved when protease was added to diets containing 20% and 64% canola meal for prawns (Buchanan et al., 1997).

Fiber

Soluble and insoluble fibers cannot be readily digested by fish, and they are not a normal part of their diets. While these plant components can be considered simply as dilutants for some farmed species, fiber is anti-nutritional for other species. This suggests that adding carbohydrase enzymes to aquaculture feeds could be of benefit. The addition of carbohydrase enzymes has been studied in recent times, but there are limited data available regarding canola meal. In an early feeding trial, Yigit and Olmez (2010) found no advantage to the inclusion of cellulase to diets that contained 21% or 42% canola meal for tilapia. Maas et al. (2020) saw some improvement in growth performance for tilapia provided with xylanase added to a low quality diet that contained 12% rapeseed meal. Buchanan et al. (1997) revealed that the addition of a multi- carbohydrase enzyme to a diet containing canola meal increased dry matter digestibility and growth in black tiger prawns, and Ali Zamini et al. (2014) determined that salmon benefitted from a multi-carbohydrase enzyme and observed an improved growth rate, survival and feed conversion.

Feeding Canola Meal to Omnivorous and Herbivorous Fish Species

Canola meal is increasingly used in aquaculture diets for species such as catfish, carp, tilapia, bass, perch, sea bream, and turbot, which all thrive on lower protein diets. While there is still much to be learned, significant inroads have been made, particularly for some species.

Tilapia

Canola meal included in diets for herbivorous tilapia, is used to partially replace fishmeal, soybean meal or both. Soares et al. (2001) provided juvenile tilapia with diets containing 0, 25, 50 or 75% canola meal, replacing protein from soybean meal. Feed to gain and protein to gain ratios did not differ between treatments. Weight gains did not decline until the 75% canola meal inclusion level was reached. Yigit and Olmez (2009) replaced up to 50% of the protein from fishmeal with protein from canola meal in 10% increments in their study. The feed conversion ratio increased with the inclusion of canola meal, and gain declined linearly at levels above 10%. There were no differences in final body composition of the fish due to the canola feeding level. All diets contained 26% soybean meal, and this level of soybean meal may have contributed to an amino acid imbalance as canola meal levels increased and fishmeal levels were reduced. In a similar study, Luo et al. (2012) replaced up to 75% of the protein from fishmeal with canola meal (up to 55% canola meal) with no decline in survival, growth rate or feed efficiency. The diets evaluated in this study contained only 12% soybean meal. There were no differences in muscle composition of the fish in this trial.

While growth rate is often the measurement used to assign value to alternative feed ingredients, replacing fishmeal with plant protein can provide significant economic advantages at suboptimal rates of gain. Recently, Kirimi et al (2020) determined that diets for tilapia in which 1/3 of the dietary protein was provided by canola meal, sunflower meal or soybean meal resulted in diets with protein scores of 76-78%, as compared to 97% for fishmeal. However, usage of the alternative proteins reduced production costs. Iqbal et al (2021b) determined that canola meal provided the best economic returns when used at 50% of the dietary protein, replacing both fishmeal and soybean meal.

Carp

At least 8 species of carp are reared for food throughout the world (Table 12). Interest in canola meal for these species is growing due to the unique amino acid profile of this ingredient (Kaiser et al., 2022).

An older study by Abbas et al. (2008) showed that canola meal could easily replace a portion of the fishmeal in the diet of three of these species without injury to the fish, but with some reduction in weight gain (Table 13). Jiang et al. (2016) determined that grass carp grew optimally with diets containing 34% canola meal, 20% soybean meal and 10% cottonseed meal and no fishmeal, provided the diets were supplemented with lysine and methionine. Digestive enzyme production was reduced when the free amino acids were omitted from the diet. Fishmeal could also 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 found 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 primary protein source had higher growth rates than those given cottonseed meal, rapeseed meal, soybean meal or fishmeal (Iqbal et al., 2015).

Table 12. Major farmed carp species.

SPECIES	COMMON NAMES	ORIGIN
Cyprinus caprio	Common carp, European carp	Asia and Europe
Ctenopharyngodon Idella	Grass carp, White amur	Vietnam, Siberia, China
Hypophthalmichthys nobilis	Bighead carp	East Asia, China
Mylopharyngodon piceus	Black carp, Black Chinese roach, Snail carp, Black amur	East Asia, China, Vietnam
Hypophthalmichthys molitrix	Silver carp, Flying carp	Siberia, China
Catla catla	Katla, Katol, Chepti, Baudhekra, Bacha, Karakatla, Tambra	India, Nepal, Pakistan, Myanmar, Bangladesh,
Cirrhinus mrigala	Morakhi, Moree, White carp, Mrigal carp	Southwest Asia, India
Labeo rohita	Rohu, Rohita, Roho	India, Nepal, Bangladesh, Pakistan and Myanmar

Table 13. Evaluation of canola meal as a partial replacement for fishmeal by three carp species[1].

DIET	SPECIES	SUR-VIVAL, %	INITIAL WEIGHT, G	FINIAL WEIGHT, G	WEIGHT GAIN, G
Fishmeal control	Labeo rohita	100	123.0	356.6	233.6
	Cirrhinus mrigala	100	118.0	332.6	214.6
	Catla catla	100	123.0	362.4	239.4
Canola replacing 20% fishmeal	Labeo rohita	100	122.7	420.4	197.7
	Cirrhinus mrigala	100	118.7	305.6	186.9
	Catla catla	100	123.5	337.1	213.6
Canola replacing 40% fishmeal	Labeo rohita	100	122.5	284.6	162.1
	Cirrhinus mrigala	100	118.1	282.2	164.1
	Catla catla	100	123.7	305.1	181.4

[1] Abbas et al., 2008.

Canola meal is an attractive alternative to fishmeal for common carp (Hussain et al. (2020). Typically, it is included in diets for these fish at levels equal to 50-55% of the diet. The researchers further noted that common carp are often reared in areas where there is some water pollution and can benefit from the polyphenolic compounds in canola meal. They determined that maintaining Brassica polyphenols at levels between 200-500 mg/kg of feed improved feed intake, diet digestibility and growth. Canola meal (Brassica napus) is rich in polyphenols such as sinapine, sinapic acid and canolol (Nandasiri et al, 2019) which have antioxidative and antibacterial properties. Thus, canola meal may provide additional advantage under suboptimal rearing conditions.

Catfish

Catfish are easily farmed in channels or ponds, and many species of catfish are used for this purpose. The most widely farmed species fall under three genera, characterized by their origin. These are shown in Table 14.

Table 14. Major farmed genera of catfish.

GENUS	COMMON NAMES	ORIGIN
Pangasiidae	Striped catfish, basa fish, Pangasius catfish, shark catfish	Southern Asia
Icaluridae	Channel catfish	North America
Claridae	North African Catfish, air breathing catfish	North Africa, Southern Asia

Perhaps due to the ease of rearing catfish, there are surprisingly few published studies regarding the effects of diet on performance parameters. In an early trial Webster et al (1997) substituted canola meal for corn and soybean meal in diets for channel catfish. As Table 15 shows, partial replacement of soybean meal by canola meal (diets 3, 4 and 5) improved performance over soybean meal alone (diet 2) for diets with up to 36% canola meal inclusion. None of the diets performed as well as the higher fishmeal diet (diet 1).

Table 15. Evaluation of mixtures of canola meal and soybean meal in diets for channel catfish[1].

	DIET					
Ingredients	1	2	3	4	5	6
Fishmeal, %	8	4	4	4	4	4
Soybean meal, %	51	57	47	37	27	17
Canola meal, %	0	0	12	24	36	48
Measurements						
Weight gain, %	743	379	599	542	608	442
Protein efficiency ratio	1.96	1.36	1.78	1.73	1.68	1.45
Survival, %	100	98	100	100	100	100

[1] Webster et al., 1997.

Zhang et al. (2020) evaluated rapeseed meal as a replacement for fishmeal in diets for Asian red-tailed catfish. The meal was included at 0, 12, 24, 36 and 48% of the total diet. Final weights and weight gains did not differ from the control when up to 36% rapeseed meal was included in the diet. When all treatments were considered, there was a trend for gains to decline and intakes to increase as the levels of rapeseed meal increased. There were no differences in survival for any of the treatments. Digestive enzyme activity (pepsin, trypsin, lipase and amylase) declined with all inclusion levels of rapeseed meal.

Feeding Solvent Extracted Canola Meal to Carnivorous Fish Species

According to Oliva-Teles et al. (2015), it is relatively easy to replace up to half of the fishmeal in diets for carnivorous fishes with alternative proteins. Using plant-based proteins to replace more than 50% of the dietary fishmeal poses problems because the digestive tracts of carnivorous species are suited to the digestion of animal proteins. Furthermore, these species have very high protein and amino acid requirements (Araujo et al., 2021), which are difficult to fulfill without the use of protein concentrates, some of which may not be well balanced for all essential amino acids. The amino acid balance of protein from canola meal is closer to fishmeal than any other vegetable protein source, and the best source to serve as a replacement for fishmeal (Enami, 2011; Kaiser et al., 2022). In that context, canola meal is suited to replace a portion of the protein in these diets, albeit a smaller portion than may be used for omnivorous fish.

Trout

The amino acid profile of canola meal/rapeseed meal has been demonstrated to be ideal as a replacement for fishmeal for rainbow trout (Slawski et al 2013) and with protein digestibility (90.9%) that is like that of fishmeal (89.2% Burel et al., 2000).

In addition to digestibility determination, a few trials have reported encouraging results concerning the use of canola meal. In one feeding trial (Shafaeipour et al., 2008) canola meal plus DL-methionine was replaced from 10 to 57% of the protein from fishmeal (5% to 30% of the feed) in diets for trout. At the end of the 16-week long feeding period, the researchers determined that there were no adverse effects of diet on growth and that canola meal had the potential to replace substantial levels of fish meal in trout diets.

Yigit et al. (2012) provided rainbow trout fry (initial weight 1.5g) with isonitrogenous diets that contained 0, 8, 16, 24 or 32% solvent extracted canola meal for 12 weeks. The canola meal replaced fishmeal and corn flour in the diets. Growth rates declined slightly with each incremental increase in canola meal but were deemed acceptable, and there were no adverse effects of canola meal on feed intake. Performance parameters obtained with the 8% and 16% inclusion levels were not statistically different from those obtained when the trout received the diet with 0% canola meal, although the values were numerically lower for weight gain and specific growth rate. The results are displayed in Table 16.

Table 16. Performance of rainbow trout fry with diets containing various levels of canola meal[1].

	CANOLA MEAL INCLUSION LEVEL, %				
Measurement	0	8	16	24	32
Starting weight, g	1.55	1.57	1.56	1.57	1.58
Final weight, g	14.21	13.06	12.82	11.79	10.48
Weight gain, g	12.65	11.51	11.24	10.20	8.88
Specific growth rate, %/day	2.45	2.36	2.30	2.24	2.10
Feed intake, g	12.80	12.77	12.55	12.35	11.49
Gain/feed	1.04	1.10	1.09	1.19	1.30
Survival, %	98.3	98.3	98.3	98.3	96.6

[1] Yigit et al., 2012.

In a similar experiment, Collins et al. (2012) provided rainbow trout with diets in which canola meal was included at 0, 7.5, 15, 22.5 and 30%. Much like the study by Yigit et al. (2012), there were linear declines in specific growth rate as the canola meal inclusion increased. The researchers suggested limiting the canola meal inclusion level to 15%.

Canola from brown or yellow seeded canola was included in diets for rainbow tout with an initial weight of 2.5 grams and at an inclusion level of 15% (Anderson et al., 2018). Final body weight was slightly lower with the brown seeded canola but not with the yellow seeded canola relative to the control. There were no significant differences in specific growth rate or feed efficiency for any of the treatments.

Diets incorporating up to 32% canola meal have been shown to have no detrimental effects on growth when the diets are supplemented with cellulase, phytase and pectinase (Yigit and Keser, 2016). Further studies are needed on the use of enzymes along with canola meal.

These results demonstrate that practical diets can be formulated using up to 15% canola meal to reduce the use of fishmeal in diets for rainbow trout. Higher levels might be possible with enzyme supplementation. While not a full replacement for fishmeal, inclusion of canola meal at this level would be beneficial in further improving the sustainability of these fish.

Salmon

Salmon, more so than trout, have a low tolerance for plant carbohydrates. There have been many studies investigating plant protein sources, and this has largely been conducted with soybean meal and soy protein concentrate, but there have been a few recent studies evaluating canola meal.

Drew (2004) demonstrated canola meal is a superior protein source to soybean meal for salmon as it has fewer antigenic properties and therefore less likely to cause hypersensitivity. Soybean meal and soy protein concentrates can be problematic for salmon, causing allergic reactions in the gut (Kaiser et al., 2022). Furthermore, the protein in canola meal has a higher biological value than does soybean meal (Enami, 2011).

The common safe recommendation for canola meal inclusion level is 10% (Burr et al, 2013; Collins et al, 2013), due to the fiber content of the meal. However, there are indications that greater levels may be used. In a Tasmanian feeding trial in which Australian canola meal was employed (Sajjadi and Carter, 2004) diets containing 35% canola meal were evaluated. Survival was 100% with these levels and protein, and the digestibility of the diets exceeded 90%.

Feeding Solvent Extracted Canola Meal to Crustaceans

Shrimp

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. (1997) found that 15% canola meal in shrimp diets resulted in no significant performance differences relative to the control diet, but 30% and 45% inclusion levels resulted in lower growth rates and feed intake. 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 (Bulbul et al., 2014), 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 that an attractant was also added to the meal.

Escobar et al. (2022) provided shrimp with either a commercial fishmeal-based control diet, or diets containing a mixture (50:50) of canola meal and soybean meal (plant-protein based diets) included as 46% of the diet that was offered as is, or processed by fermentation. The protein digestibility of the diet containing the fermented protein mixture was 93.0%, comparable to the control diet (94.7%) and higher than the diet with the unfermented protein source (83.7%). Average gains were greatest for the diet containing the unfermented plant protein (1.1, 1.0 and 0.9 g/week for unfermented soy/canola, fermented soy/canola, and fishmeal, respectively), although survival rates were improved when the soy/canola mix was fermented.

Prawns

Like shrimp, prawns can grow normally with diets containing vegetable protein, provided the diets are palatable. 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. Suarez et al. (2009) determined that growth rate and survival rate in prawns given diets that included 18% canola meal remained equivalent to the reference diet. Six percent fishmeal was included in the test diet. Glencross et al. (2018) published digestibility values for 29 ingredients of potential use in diets for black tiger prawns, Penaeus monodon. Values for canola meal are provided in Table 17. Digestibility values for three fish meal sources are provided for comparison.

Table 17. Digestibility (%) of canola meal and three sources of fish meal for shrimp.

DIGESTIBILITY	CANOLA MEAL	ANCHOVIES	MACKEREL	TUNA
Dry matter	34.5	58.7	48.6	35.5
Crude protein	75.0	83.7	81.5	73.5
Ether extract	71.6	67.3	100	95.2
Energy	26.5	65.1	53.0	52.1

Biabani et al. (2016) provided prawns with a control diet that was based on fishmeal and 4 test diets, in which protein from canola meal replaced 25, 50, 75 and 100% of the protein from fishmeal. Growth rates were superior to that found for the control diet when the prawns were given diets with 25 or 50% of the protein from canola meal. Growth rates for the diets with 75 or 100% fishmeal replacement were equivalent to the control diet. The researchers concluded that up to 50% of the fishmeal protein could safely be replaced by canola meal.

Other crustaceans

Mud crabs appear to be able to readily digest canola meal. Thuong et al. (2008) determined that the dry matter and protein digestibility of canola meal were 83.5% and 87.6%, respectively, by mud crabs. This compares favorably to fishmeal (85.4% and 88.3% digestibility for dry matter and protein). Chinese mitten crabs can be given diets in which up to 40% of the fishmeal is replaced by a 50:50 mixture of canola meal and soybean meal with no loss in growth. Ren et al. (2018) notes that pectin acted as an antinutritional factor for rapeseed and canola meal, suggesting that the inclusion of a pectinase might improve the utility of canola meal in diets for the Chinese mitten crab.

Safari et al. (2014) conducted a survey of ingredients that might be included in diets for narrow clawed crayfish. The study revealed that ground canola seed was a promising ingredient for crayfish.

Processed Canola Meal

Canola meal can be used to produce canola protein concentrate (CPC) by the aqueous extraction of protein (Burr et al., 2013; Thiessen et al., 2004). This results in removal of antinutritional factors (mainly fiber), and produces a product with a higher protein content than canola meal, making it easier to use in formulations for species with high protein requirements. CPC contains approximately the same crude protein concentration as fishmeal with a better amino acid profile than corn gluten meal and soy protein concentrate. The ability to use CPC or rapeseed protein concentrate (RPC) to fully replace fishmeal varies with the species of fish and is possibly associated with organoleptic properties of the diets used in the studies conducted to date.

Collins et al (2012) determined that CPC had no negative effects on the growth of rainbow trout when compared to fish meal. Similarly, Slawski et al. (2012) determined that RPC could be used to fully replace fishmeal rainbow trout diets. The latter trial was repeated using CPC (Slawski et al., 2013). Canola meal replaced 0, 25, 50, 75 and 100% of the fishmeal. At the 75% replacement level, weight gain was greater than for the fishmeal control diet. However, Burr et al. (2013) determined that salmon provided with a basal diet high in plant protein ingredients could tolerate only 10% CPC as a replacement for fish meal. Twenty percent was not acceptable and resulted in lower growth rates. It is possible that attractants might be needed for some species of fish.

Using Canola Oil in Aquaculture

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 negative impact on growth performance of fish (Glencross and Turchini, 2011). Canola oil is unique in that the oil contains a high proportion of the monounsaturated fatty acid oleic acid.

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 linoleic acid (omega 6), which helps to maintain an omega 3 to omega 6 ratio naturally found in fish. Salini et al. (2015) also found that saturated and monounsaturated fatty acids are preferentially oxidized for energy, thereby sparing long-chain polyunsaturated fatty acids from oxidation. 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 to omega 6 ratio in fillets. Similarly, Karayucel, 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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