canola council OF CANADA

CANOLA MEAL DAIRY FEEDING GUIDE

7th EDITION, 2024
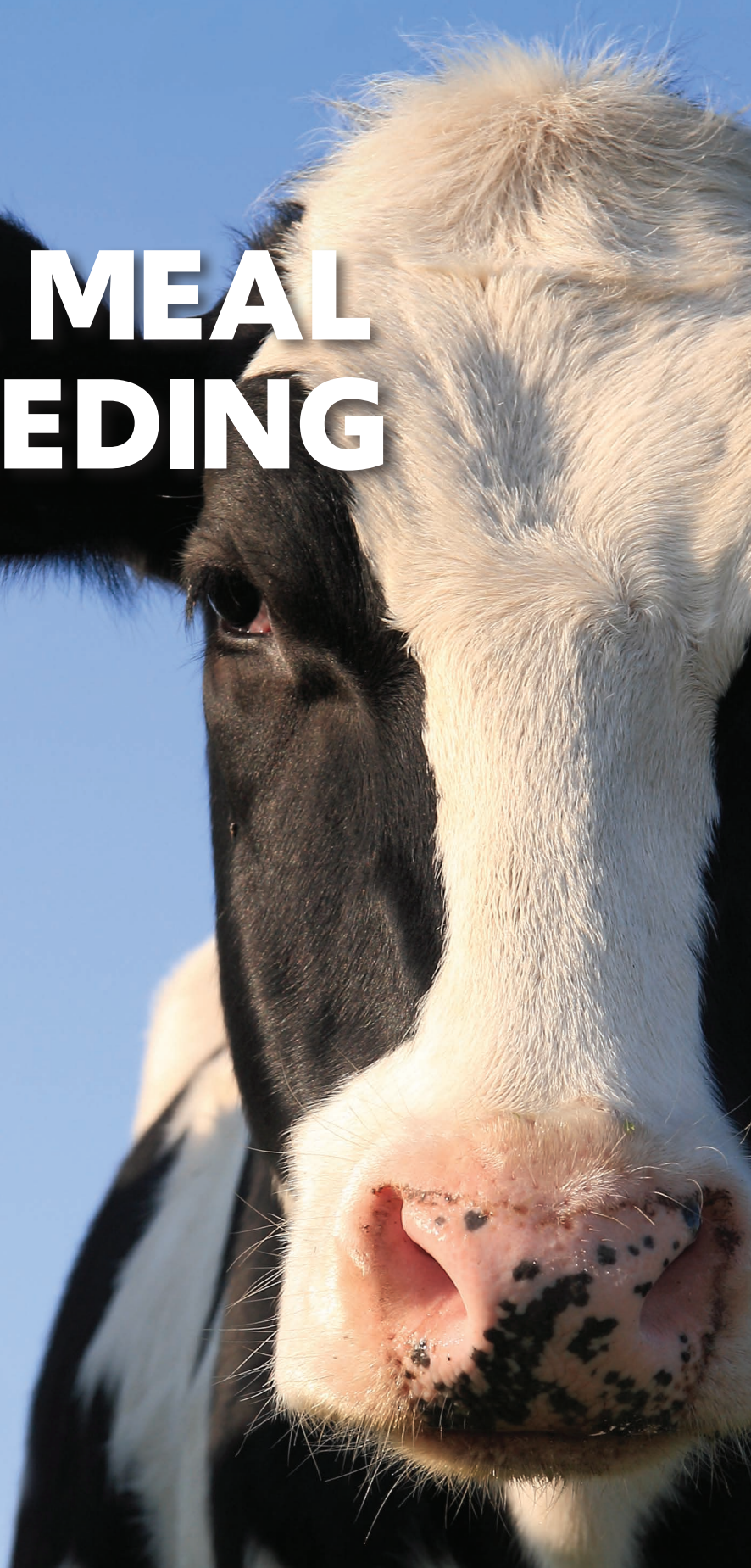
CANOLA MEAL

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 Harvested Acres & Production
Source: Statistics Canada, Table 32-10-0359-01
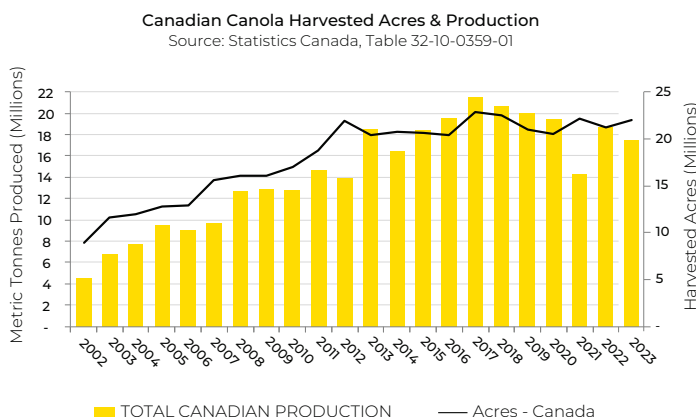
Canadian canola meal is traded under the rules outlined in Table 2. Canola and rapeseed meals are commonly used in animal feeds around the world. Together, they are the second most widely traded protein ingredients after soybean meal. The major producers of canola and rapeseed meal are Canada, Australia, 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):
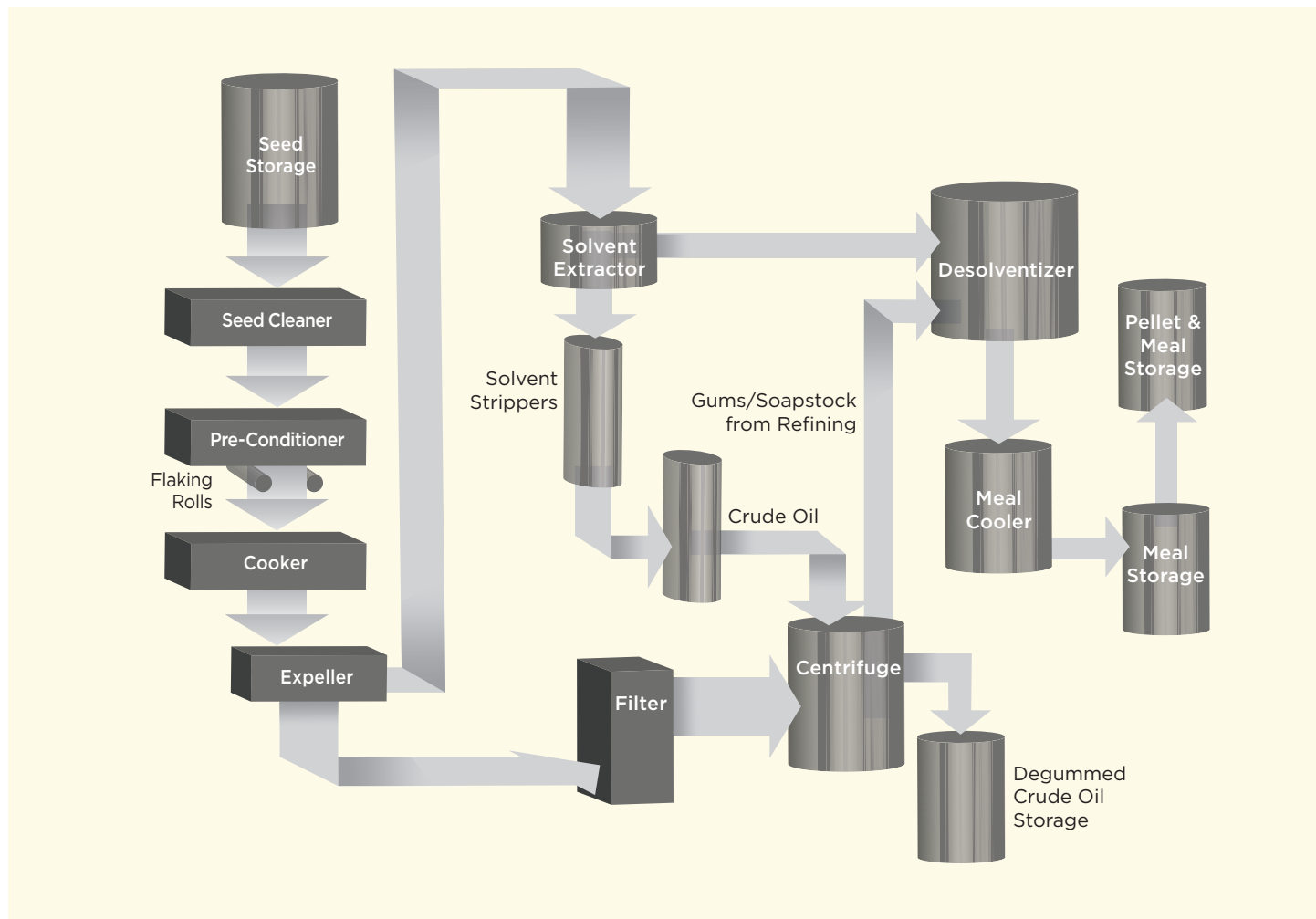
- Seed cleaning
- Seed preconditioning and flaking
- Seed cooking
- Pressing the flake to mechanically remove a portion of the oil
- Solvent extraction of the press-cake to remove the remainder of the oil
- Desolventizing and toasting of the meal
- Drying and cooling of the meal

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

Seed Storage

Seed Cleaner

Pre-Conditioner

Flaking Rolls

Cooker

Expeller

Solvent Extractor

Solvent Strippers

Crude Oil

Gums/Soapstock from Refining

Filter

Centrifuge

Degummed Crude Oil Storage

Desolventizer

Meal Cooler

Pellet & Meal Storage

Meal Storage

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/
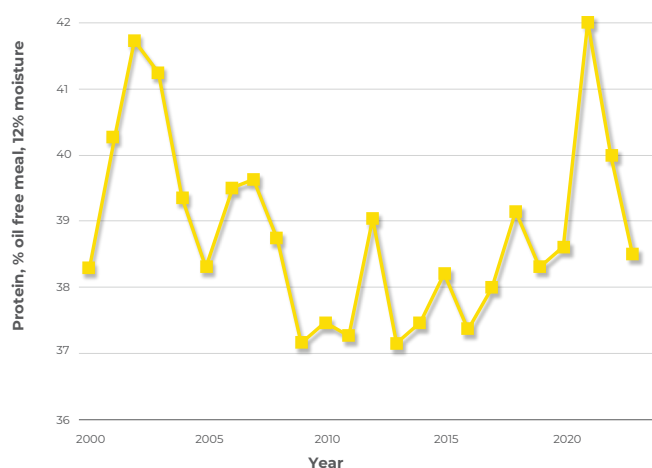
The amino acid profile of canola meal is well suited for animal feeding (Table 2). Like many vegetable protein sources, canola meal is limiting in lysine, but the meal is noted for having high levels of methionine and cysteine. The amino acid profile values in Table 2 were corrected to a 36% protein 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.
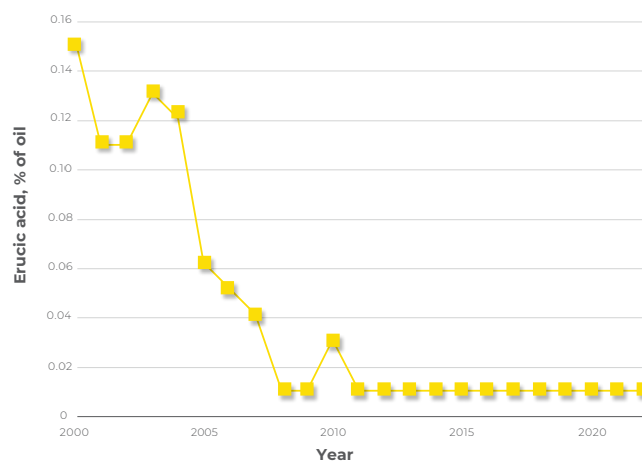
Erucic acid

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).

| Components | REFERENCE | | | |
	Feedi-pedia, 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 RUMINANT

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.

Item	DIET		
	Canola meal	Soybean meal	Soybean meal + methionine
Canola meal, % of DM1	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.

Ref[2]	MEAL[1]			METHANE OUTPUT		
	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].

Variable	CANOLA MEAL INCLUSION LEVEL, % OF DM			
	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].

Protein	Score	LIMITING AMINO ACID		
		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].

Protein	Score	LIMITING AMINO ACID		
		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].

Nutrient	TREATMENT	
	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].

Item	CONCENTRATION OF IODINE IN THE DIET, MG/KG DM					
	0.5			2.0		
Canola meal, % of DM	0	3.9	13.9	0	3.9	13.9
Blood serum iodine, 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].

Ingredient	CATIONS		ANIONS		
	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.

Trial[2]	Length, weeks	INCLUSION, % OF DM		MILK YIELD, KG		ECM/DMI	
		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.

Reference	PROTEIN SOURCE		Difference
	Canola meal	Soybean meal	
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.

Gorka 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).

Variable	TREATMENT (% SOYBEAN MEAL REPLACEMENT)				
	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., 2001[1]	Solvent canola meal	28.6
	Expeller canola meal	30.0
	Heated expeller canola meal	30.0
Jones et al., 2001[2]	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).

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