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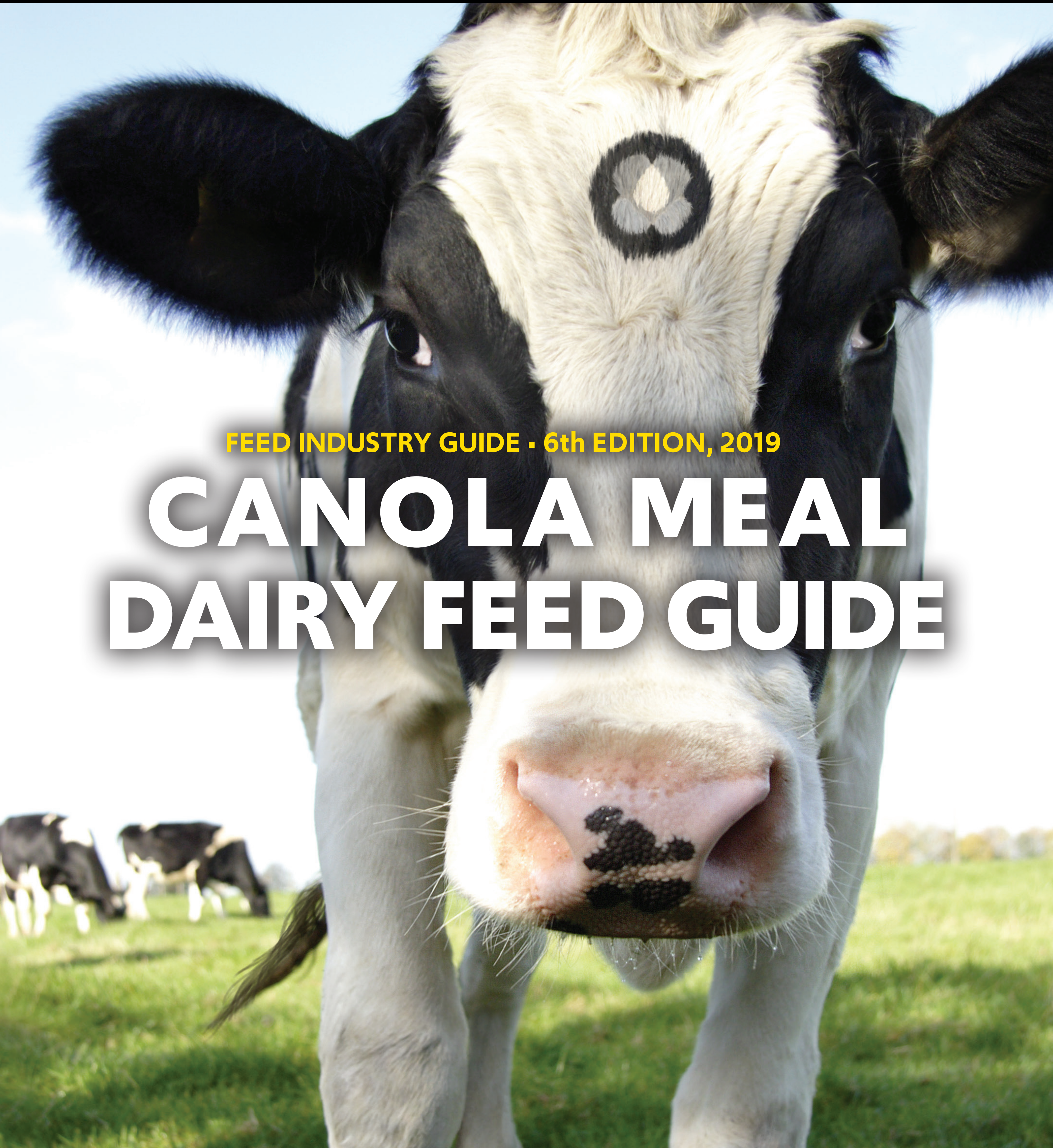

FEED INDUSTRY GUIDE • 6th EDITION, 2019

CANOLA MEAL DAIRY FEED GUIDE

CANOLA MEAL:

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

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

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

- Updated nutrient profile of canola meal obtained through a collection of meal samples from processors across Canada over a seven-year period
- Information on protein degradation, fibre digestion and amino acid supply of canola meal in the rumen and its impact on milk production

A copy of this publication can be found on the Canola Council of Canada's website www.canolacouncil.org, as well as on Canolamazing.com and may be downloaded at no cost.

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CANOLA MEAL: A BASIC INTRODUCTION

Canola is one of Canada's most important crops, and is also the second most traded protein in the world. The vast, fertile fields of Western Canada are the primary canola production region. In early summer, canola fields dot the countryside with brilliant yellow flowers, yielding about 20 million metric tonnes of canola each fall. These tiny round seeds, containing approximately 44% oil, are extracted for use as one of the world's healthiest culinary oils. After the oil is extracted, the seed solids are processed into a protein-packed meal coproduct that is an excellent addition to livestock feed.

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

Production and Markets

Canola production in Canada has been steadily increasing, and currently sits at approximately 20 million metric tonnes of canola seed per year. The Canadian canola industry is targeting an increase in yield to 26 million metric tonnes per year by 2025, in response to rising world demand. The plan focuses on increasing yields in a sustainable way, while building consumer understanding of canola's value and achieving stable, open trading relationships.

As Figure 1 shows, canola crop research has results in almost a doubling of yields in the last 20 years. The industry's goal is to reach 52 bushels/acre (197 kg/mu) by 2025.

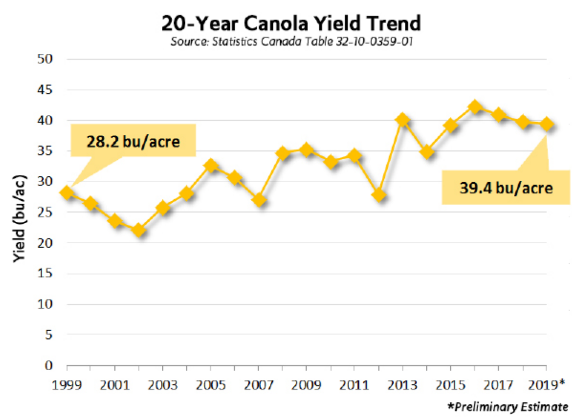


Figure 1. Yields/acre of canola seed from 1998 through 2018

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

Canadian canola meal is traded under the rules outlined in Table 2. Canola and rapeseed meals are commonly used in animal feeds around the world. Together, they are the second-most widely traded protein ingredients after soybean meal. The major producers of canola and rapeseed meal are Canada, Australia , China, the European Union and India. The use of canola meal varies considerably from market to market.

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

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

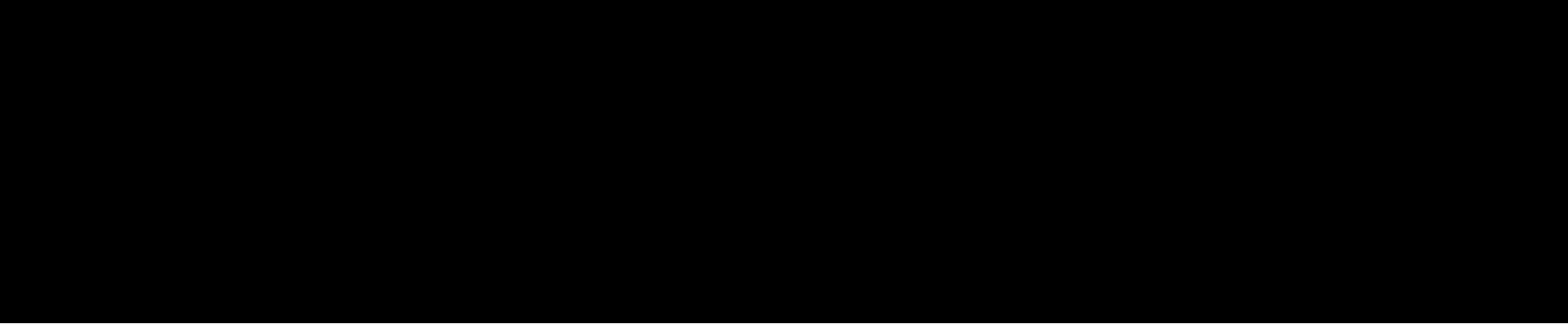
	--------CROP YEAR--------			
	2014/2015	2015/2016	2016/2017	2017/2018
Total seed production	16,410	18,377	19,599	21,328
Total seed export	9,137	10,268	11,052	10,771
China	4,032	4,016	3,999	4,319
Japan	2,177	2,179	2,214	2,584
Mexico	1,491	1,382	1,565	1,474
United Arab Emirates	220	587	807	637
Pakistan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

[1]Statistics Canada

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

CHARACTERISTIC (AS FED)	CANADA AND U.S.	EXPORT
Protein, % minimum	36 minimum	-
Protein-fat (combined), % by mass	-	37 minimum
Fat (oil) (typical), solvent extracted, % by mass	2 minimum	-
Fat (oil) (typical), expeller pressed, % by mass	10 minimum	-
Moisture, % by mass	12 maximum	12 maximum
Crude Fibre, % by mass	12 maximum	12 maximum
Sand and/or silica, % by mass	-	1 maximum

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



MEAL PRODUCTION METHODS

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

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

A small proportion of Canadian canola seed is processed by using expeller processing, also termed double pressing. The seed is expelled twice to extract oil rather than using solvent to extract the residual oil. Up to the point of solvent extraction, the process is similar to the traditional preprocess solvent extraction process. However, it excludes the solvent extraction, desolventization, and drying and cooling stages. The resulting meal has higher oil content, which can range from 8–11%.

Effects of Processing on Meal Quality

The quality of the meal can be both enhanced and diminished by altering the processing conditions in the processing plant.

Minimum processing temperatures are needed in order to deactivate the myrosinase enzyme, which, if not destroyed, will break down glucosinolates into their toxic metabolites (aglucones) in the animal's digestive tract.

Canola processing can also cause thermal degradation of 30–70% of glucosinolates in the meal (Daun and Adolphe, 1997). However, if temperatures are too high for too long, then the protein quality of the meal can decrease.

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

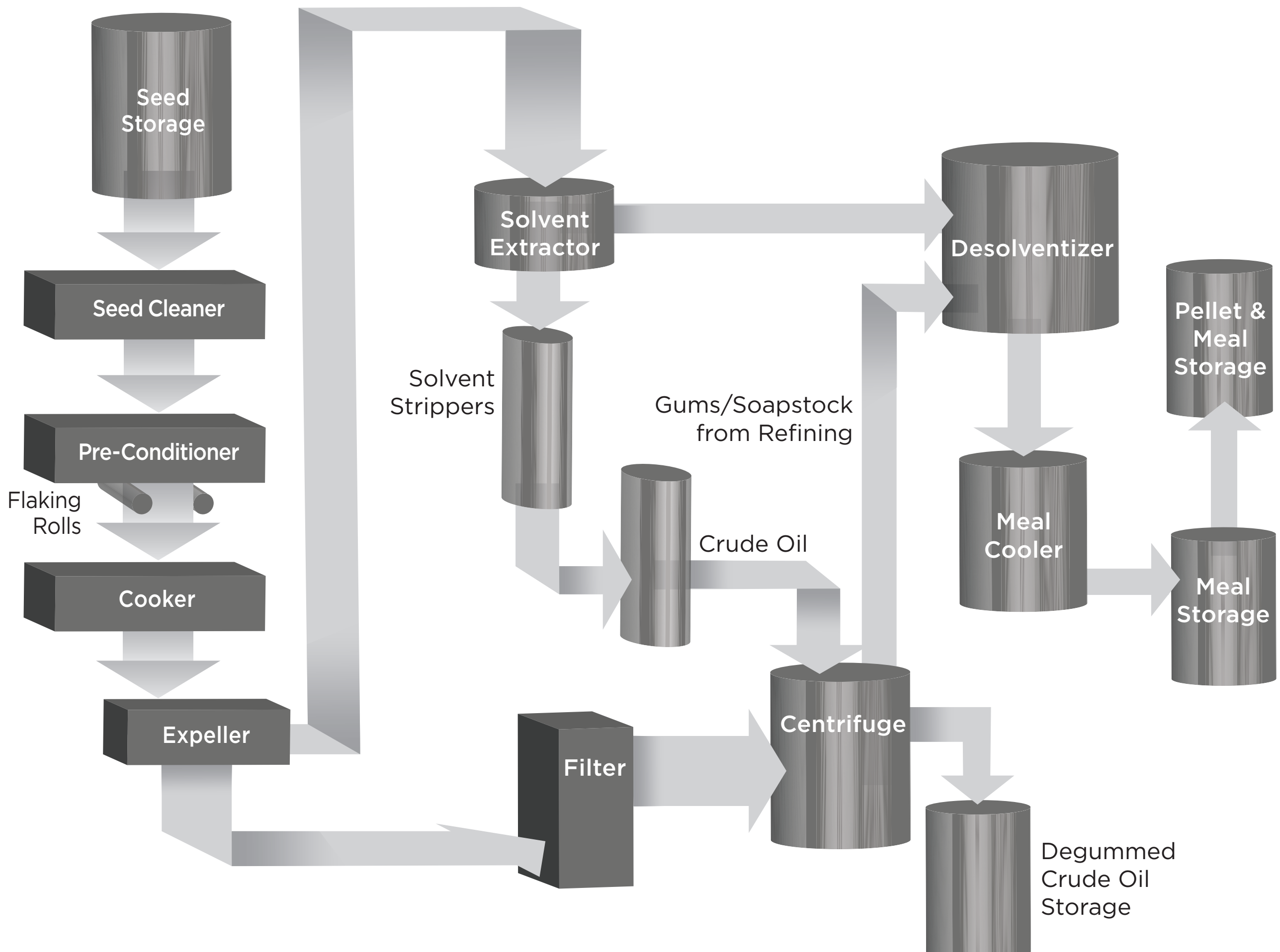


Figure 2. Schematic of solvent extraction process

CANOLA MEAL NUTRIENT COMPOSITION

Nutrient Composition of Solvent Extracted Meal

Canadian solvent-extracted canola meal is derived from a blend of *Brassica napus, Brassica rapa* and *Brassica juncea* seed. The majority (> 95%) of the seed produced in Canada is *Brassica napus.* As with any crop, there is some variability in the nutrient composition of canola meal due to variation in environmental conditions during the growing of the crop, harvest conditions, and to a minor extent, by cultivar and processing of the seed and meal. The basic nutrient composition of canola meal is shown in Table 1. These results are based on an extensive survey of 13 processing sites, conducted over a seven-year period.

Protein and Amino Acids

For trading purposes, the minimum crude protein value of solvent extracted canola meal is 36%, on a 12% moisture basis. While the minimum crude protein guarantee for Canadian canola meal is 36% (12% moisture basis), the actual protein content can range between 36 and 39%. The minimum allows for yearly variation in canola seed composition due to growing conditions. The influence of weather and soil conditions on the protein content of Canadian canola meal from 2000 to 2018 is shown in Figure 1. As the chart indicates, the protein content of canola meal varies from about 37–42% when calculated on an oil-free, 12% moisture basis (Figure 1).

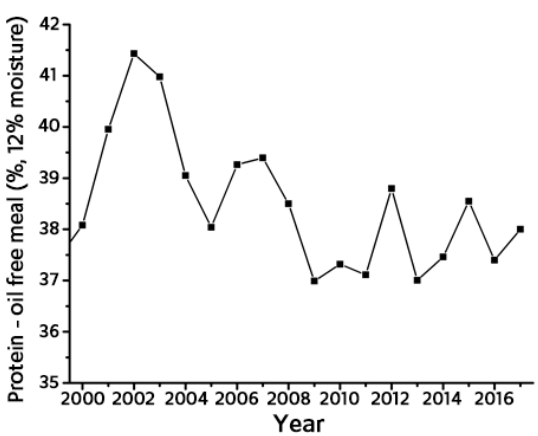


Figure 1. Protein content of canola meal from 2000 to 2017. Canadian Grains Commission, 2018.

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

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

[1]Radfar et al., 2017
[2]Broderick et al, 2016
[3]Ross, 2014

The amino acid profile of canola meal is well suited for animal feeding (Table 2). Like many vegetable protein sources, canola meal is limiting in lysine, but it is noted for having high levels of methionine and cysteine. The amino acid profile was corrected to a 36% protein basis, and is therefore likely lower than actual. Amino acid content varies with protein content, and can be calculated by multiplying the crude protein content of the meal by the proportion of amino acid as a percentage of protein (as shown in Table 2).

Fat Content

The ether extract content of Canadian canola meal tends to be relatively high at 3.2% (Table 1) compared to 1–2% in canola and rapeseed meals produced in most other countries. In Canada, it is general practice to include canola glycolipids and phospholipids back with the meal during refining the oil. Likewise, canola meal may further contain 1–2% of the free fatty acids that are derived from canola oil refining. These components increase the energy value of the meal, and help to reduce dustiness.

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

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

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

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

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

[1]Zambiasi, et al., 2007

Table 3 provides the complete fatty acid analysis for canola oil. As the table shows, this oil contains only a small amount of saturated fatty acids, and a high concentration of oleic acid. Canola meal provides a 2:1 ratio of omega-6 to omega-3 fatty acids, and is a good source of omega-3 fatty acids. Canola oil is sometimes used in diets to enrich the fatty acid profile of milk, meat or eggs (Gallardo, et al., 2012; Gül, et al., 2012; Chelikani, et al., 2004).

Carbohydrates and Fibre

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

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

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

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

Minerals

Most references on the mineral content of canola meal use the values derived by Bell and Keith (1991), which were reconfirmed in a survey by Bell, et al. (1999), and again by the current survey (Broderick, et al., 2016; Adewole et al., 2016). The data show that canola meal is a relatively good source of essential minerals (Table 5) compared to other oilseed meals. Canola meal is an especially good source of selenium and phosphorus. Similar to other vegetable sources of phosphorus, a portion of the total is in the form of phytate.

Vitamins

Information on the vitamin content of canola meal is very limited, but it appears to be rich in choline, biotin, folic acid, niacin, riboflavin and thiamine (NRC 2012, Table 6). As is recommended with most natural sources of vitamins in animal feeds, users should not place too much reliance on these values, and use supplemental vitamin premixes instead.

Anti-nutritional Factors

Rapeseed meal, the parent of canola meal, is recognized as an ingredient that may need to be limited in diets for livestock and fish due to certain anti-nutritional factors, primarily glucosinolates. These factors have been reduced in canola meal to levels that do not pose threats to performance and feeding for most species.

Glucosinolates are a large group of secondary plant metabolites common to all cruciferous plants. While nontoxic on their own, breakdown products of glucosinolates can adversely affect animal performance. The low glucosinolate content of canola, compared to previous cultivars of rapeseed, constitutes the major improvement in meal quality achieved by plant breeders. Canola glucosinolates are composed of two main types, aliphatic and indolyl (or indol) glucosinolates. Aliphatic glucosinolates make up approximately 85% of the glucosinolates present in canola meal, while indolyl glucosinolates account for the other 15% (Adewole et al., 2016).

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

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

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

Table 6. Vitamin content of canola meal[1]

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

[1]NRC, 2012.

The average total glucosinolate content of Canadian canola meal, based on seven years of data, is 3.6 µmol/g (Slominski and Rogiewicz, unpublished). By comparison, traditional rapeseed meal contains levels as high as 120 µmol/g of total glucosinolates. The reason that glucosinolates are expressed on a molecular (µmol/g) basis rather than on a weight (mg/kg) basis is that glucosinolates have significantly different molecular weights, depending on the size of their aliphatic side chain. Since the negative effect on the animal is at the molecular level, the most accurate estimate of this effect must be gauged by expressing glucosinolate concentration on a molecular basis.

The concentrations of glucosinolates in Canadian canola seed has continued to decrease in recent years, due to selection pressure by canola plant breeders. The level of glucosinolates in Canadian canola seed prior to processing has averaged around 10 µmol/g over the last seven years. Glucosinolate content is then concentrated in the meal; after that, it is further reduced during processing to values averaging 3.6 µmol/g.

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

Nutritional Composition of Expeller Canola Meal

Several terms are used interchangeably to differentiate solvent-extracted versus expeller-extracted meals. Terms commonly used to describe the meal include expeller meal, double-press meal and presscake. Currently in Canada, a small percentage of seed is processed using the expeller method. Smaller oilseed plants as well as those associated with some biodiesel plants use double-press expeller processing rather than solvent extraction. Since the oil is extracted simply by mechanical means, the resulting meal contains significantly more oil than that of standard solvent-extracted canola meal.

The nutritional profile of the meal is similar to that of canola meal, except that it contains 8–12% fat and therefore has much higher energy values. The nutritional composition of expeller meal is provided in Table 7. Fat content can vary widely, so it is important that the expeller cake is analyzed for fat, and the energy value adjusted accordingly. High levels of fat will also dilute other nutrients in the resultant meal, relative to solvent-extracted canola meal.

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

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

[1]Adewole et al., 2016
[2]Broderick et al., 2016

Nutrient Composition of Canola Seed

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

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

	--------REFERENCE--------			
	1	2	3	4
Moisture, %	6.8	10.1	5.0	5.7
Crude protein, %	18.4	18.0	20.0	20.7
Ether extract, %	40.5	36.5	43.8	38.6
Linoleic acid, %	8.3	7.3	8.5	7.9
Linolenic acid, %	4.1	3.4	4.2	3.9
Ash, %	3.8	4.0	3.7	4.1
Crude fibre, %	8.9	-	-	-
ADF, %	12.7	9.7	-	10.6
NDF, %	17.9	15.7	16.6	12.9
Calcium, %	0.43	0.38	-	-
Phosphorus, %	0.64	0.60	-	-

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

THE VALUE OF CANOLA MEAL IN RUMINANT DIETS

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

Palatability for Ruminants

Canola meal is a highly palatable source of protein for ruminant animals, and this has been demonstrated repeatedly in feeding trials. Ravichandran et al. (2008) examined the impact of feeding canola meal versus rapeseed meal with differing levels of residual glucosinolates to 5-month-old calves. Calves fed canola meal that contained less than 20μmol/g of glucosinolates consumed virtually the same quantity of feed as control calves fed diets without canola meal (1.10 kg vs. 1.08 kg/day, respectively). However, calves fed a concentrate containing high-glucosinolate rapeseed meal (> 100 μmol/g) only consumed 0.76 kg. Another study conducted with calves (Hadam et al., 2015) saw no differences in feeding behavior or intake in calves during the transition from weaning to solid feed. Intakes of the starter diet from 1 to 35 days of age were numerically lower with the canola meal diet when compared to a diet where the major protein source was soybean meal (269 vs 315 g/head/day).

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

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

Energy for Ruminants

Like most concentrate ingredients, canola meal is a good source of energy, providing nutrients for microbial growth, and supporting animal productivity. In the past, the energy value of canola meal has been undervalued (NRC, 2001; NRC, 2015) and remains in error in many publications. Several popular feed formulation programs use lignin to discount the digestibility of the cell wall. For example, NRC (2001) estimates of unavailable neutral detergent fibre (NDF) approach 65%, with the potentially available NDF estimated at 35%. Depending on rate of passage, the actual amount digested would be even less.

Using a newly developed indigestible NDF assay, Cotanch et al. (2014) demonstrated that the unavailable NDF in canola meal was 32% of the total NDF after 120 hours of rumen incubation, and that the potentially digestible cell wall was therefore 68%. Again, actual digestibility would be lower due to potentially digestible cell wall exiting the rumen before digestion is complete. Based on the results of a 4-year survey of 12 processing plants (144 samples), Paula et al. (2017b) determined that NDF digestibility at 288 hours of rumen incubation to be 80.2% of NDF, and estimated actual rumen digestibility at 3 times maintenance intake to be 60.2%. These results corroborate some older studies that show that approximately half of the NDF is actually digested in lactating dairy cows (Mustafa et al., 1996, 1997), and higher percentages are digested in sheep (Hentz et al., 2012) and beef cattle (Patterson et al., 1999a).

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

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

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

Protein and Amino Acids in Canola Meal for Ruminants

Canola meal has long been prized in rations for ruminants for its valuable protein. The amino acid profile of the meal was recognized early on to more closely match requirements for maintenance and milk than other vegetable proteins (Schingoethe, 1991). The values given in Table 2 were obtained for the rumen-undegraded protein (RUP) fraction as well as the intact canola meal using the procedure developed by Ross et al. (2013), based on a subset of results from the 2011-2014 survey. These results show that canola meal contributes a significant amount of methionine, which is often the first limiting amino acid in production.

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

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

[1]Ross, 2015

Rumen Undegraded Protein in Canola Meal

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

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

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

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

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

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

The RUP content of canola meal is thus very much dependent on the system of analysis that is used. Older methods, such as in sacco loss from nylon bags, do not take into account the contribution of the soluble-protein fraction to the RUP available to the animal (Table 3), or small particles that can wash out of the bags (Maxin et al., 2013b). Newer systems of modeling and analyses are now adjusting for these contributions to RUP. This updated insight into the rumen metabolism of protein has allowed diets to be formulated with lower concentrations of protein. Canola meal has been particularly advantageous to supporting milk production and growth when diets are formulated on the basis correct RUP values.

Even more relevant to the feeding value of canola meal are comparisons of RUP values between canola meal and other proteins, in particular soybean meal. Table 4 provides RUP (% of the protein) values for solvent-extracted canola meal relative to soybean meal from a number of recent studies. Each reference cited represents slightly different method of analysis. Overall, the RUP of canola meal as a percent of the protein tends to be somewhat higher than that of soybean meal, and the relationship between the RUP values of these two proteins can be used to adjust formulation programs so that canola meal is more accurately represented.

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

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

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

Rumen Microbial Protein Production

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

Canola Fatty Acids in the Rumen

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

He and Armentano (2011) added large amounts of vegetable oils (5% of DM) varying in fatty acid composition to the diet of lactating cows. Fat yield declined from 1.14 kg/cow/day to 1.02 kg/cow/day for the diets with the added C18:1 and 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 a number of diets differing in fatty acid composition, but the added fat sources were provided at levels that would be typical of practical feeding situations. The effects on milk fat percentage and milk fat yields were strikingly different for the diets. Milk fat yield was 1.44 with the high C18:1 diet as compared to 1.31 kg/cow/day for the high C18:2 diet. Fat yield with the low oil control diet was 1.41 kg/cow/day.

Minerals and Vitamins

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

Phosphorus

Canola meal is a rich source of phosphorus, with most of this mineral in the form of phytate phosphorus. Unlike monogastric animals, this form is available to ruminants, due to the presence of bacterial phytases in the rumen that rapidly degrade phytate (Spears, 2003).

In fact, studies have shown that phytate phosphorus is more highly available to ruminants than non-phytate phosphorus. Garikipati (2004) provided diets to dairy cows in which approximately half of the phosphorus was in the form of phytate. The overall digestibility of the phosphorus was 49%. However, the digestibility of the phytate-bound phosphorus was 79%. Skrivanova et al. (2004) likewise found that the digestibility of phosphorus by 10-week-old calves was 72%, with 97% of the phytate portion digestible.

Iodine

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

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

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

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

[1]Weiss et al., 2015

Dietary Cation Anion Difference

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

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

Anionic salts can be added to the diet, but these sometimes reduce palatability of the diet and reduce DM intake. Because the anions and cations in the diet originate from the feedstuffs offered as well as mineral supplements, the selection of ingredients can be beneficial in attaining the desired balance, and reduce the need for added anionic salts. Ingredients that contribute large amounts of cations to the diet increase the need for larger quantities of anionic salts. As Table 6 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.

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

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

[1]Erdman and Iwaniuk, 2017

Feeding Solvent Extracted Canola Meal to Lactating Cows

Meta Analyses of Feeding Value

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

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

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

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

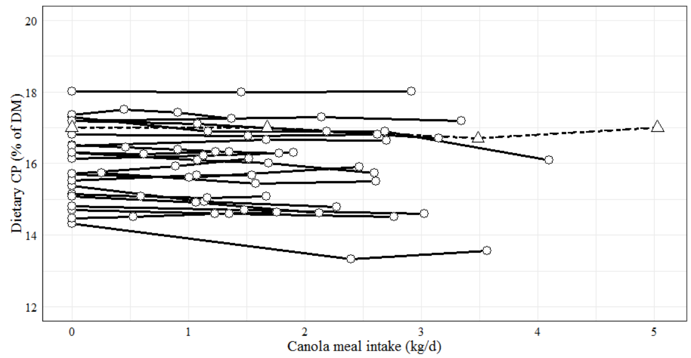


Figure 1. Effects of increasing canola meal in the diet on DMI as determined in numerous studies (Martineau et al, 2019). Higher intakes of canola meal do not reduce DM intake.

Individual Feeding Trials

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

Chinese Feeding Trials

The dairy industry in China has been steadily growing, and with it, the need for reliable protein ingredients. In recognition of this need, the Canola Council of Canada supported several feeding demonstration trials in China in 2011. All of the studies involved well-managed herds, and milk production averaged 35 L in all but one study, in which production was 25 L, levels very similar to those found in North American studies. Results from the demonstration trials are provided in Table 8. Even at fairly low inclusion rates, when canola meal replaced high-priced protein ingredients, milk production was maintained or increased.

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

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

Table 7 (continued)

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

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

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

Feeding Expeller Canola Meal to Lactating Cows

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

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

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

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

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

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

Feeding Canola Seed and Canola Oil to Dairy Cows

Generally speaking very little seed and oil are used in diets for dairy cows. In the past, there has been interest in feeding rumen-protected canola oil and canola seed for the creation of designer meat and milk. A study by Chicholowski et al. (2005) demonstrated the benefits of feeding ground canola seed as compared to expeller-pressed canola meal to ruminants. Supplementation with ground canola seed resulted in a reduced omega-6 to omega-3 ratio and a higher proportion of conjugated linoleic acid (CLA) and trans vaccenic acid (precursor to CLA) in the milk, suggesting a healthier product can be produced in this manner, while having no impact on milk production.

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

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

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

Canola Products in Rations for Beef Cattle

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

In an early study, Petit and Veira (1994) determined that supplementing grass silage with canola meal increased weight gains in growing beef steers. The same group of researchers fed supplemental canola meal to finishing steer calves, and noted increased daily gain and fewer days on feed. He et al. (2013) fed finishing cattle diets that contained 15 and 30% canola meal in place of barley grain. Both expeller and solvent-extracted meals were evaluated at these levels of inclusion. There were no differences in average daily gain. Diets with the highest level of canola meal increased DMI and reduced feed efficiency relative to the lower level and the barley control diet. Damiran and McKinnon (2018) replaced 10% and 20% of the barley in a balanced finishing diet with canola meal, and found no differences in performance from the control diet. While it's unusual to feed such high levels of canola meal, the study showed that the cattle had no aversion to it.

Canola meal has been used to supplement protein in gestating and lactating beef cows. Patterson et al. (1999a, 1999b) evaluated beans, sunflower meal or canola meal as a protein supplement for beef cows grazing poor-quality pasture. Results for calf birth weight, calf weaning weight and cow body condition changes were similar for all meals. Weight loss during gestation was lowest with canola meal. A study conducted by Auldist et al. (2014) revealed that grazing beef cows produced more milk when canola meal partially replaced wheat in the feed supplement. This was confirmed in a later study (Damiran et al., 2016).

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

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

As well, oil from canola has been shown to improve the fatty acid profile of fat in meat animals. Rule et al. (1994) demonstrated that full-fat canola increased the monounsaturated and omega-3 fatty acid content of beef subcutaneous fat and muscle fat. He et al. (2013) similarly revealed an improved fatty acid profile in beef in association with the lipid fraction of the meal.

Canola Products in Rations for Calves

There are only a few publications reviewing the use of canola meal in diets for calves before weaning. In a Canadian study, Miller-Cushon et al. (2014) found that preweaning calves offered low-protein starter pellets and either canola meal or soybean meal pellets chose to consume more soybean pellets than canola meal pellets. Hadam et al. (2016) provided preweaned calves with diets that contained 24% soybean meal, 12.5% soybean meal plus 16.5% canola meal or 35% canola meal. There were 12 calves per treatment. No statistically significant differences were found in starter intakes for the first 35 days of life. However, intakes were numerically lower with the two diets containing canola meal. While again not statistically significant, feed efficiency favored the soybean meal diet. The researchers suggested that a flavour agent might have improved intakes with the very high canola meal diet.

Canola meal can be given to growing dairy and beef calves without restriction. Anderson and Schoonmaker (2004) compared canola meal to pulses (field peas, chickpeas and lentils) as proteins for post-weaning beef calves. Diets contained 16% crude protein. The calves given the canola meal diet gained slightly less (1.67 as compared to 1.89 kg/day), but had better feed/gain ratios (4.1 vs. 3.8) with the diet containing 9.4% canola meal. In a recent dairy calf study, Terré and Bach (2014) evaluated intakes of 18% crude protein starter diets and growth rates of calves given diets in which the primary protein source was either canola meal or soybean meal. Intakes and rates of gain were similar for the two diets. The researchers concluded that flavouring agents were not required for calves given diets with canola meal after weaning. Corn DDGS could only partially be used to replace canola meal in diets for growing heifers from 12 months of age (Suarez-Mena et al., 2015) before digestibility and nitrogen retention declined.

Unlike canola meal, soybean meal contains high concentrations of phytoestrogens. Phytoestrogens can mimic the action of estrogen, and alter hormonal cycles (Woclawek-Potocka et al., 2005; Cools et al., 2014). Gordon et al. (2012) provided diets containing either soybean meal or canola meal to dairy heifers from 8 to 24 weeks of age. Heifers were then placed on a common diet until 60 weeks of age, at which time they were bred. Pregnancy rates were 66.7% for the heifers given canola meal during prepubertal development, but only 41.7% for the heifers that had received soybean meal. Proteins with low levels of phytoestrogens, such as canola meal, might provide an alternative if breeding difficulties arise.

Using Canola Meal for Small Ruminants

Canola meal is an ideal supplement for the production of wool and mohair, due to the high-sulfur amino acid requirement of these animals (Reis et al., 1990). In addition, canola meal has been shown to support weight gain in these meat animals. Lupins have traditionally been the vegetable protein of choice for lambs in Australia, but Wiese (2004) determined that canola meal is superior to lupins in supporting weight gain (272 vs. 233 grams/day) and feed efficiency. More recently, Malau-Aduli et al. (2009) also found that canola meal was superior to lupins for weight gain in lambs. In a Canadian study (Agbossamey et al., 1998), canola meal was superior to fish meal in diets for growing lambs.

Canola meal supports growth in small ruminants as well. Mandiki et al. (1999) fed lambs diets containing up to 30% canola-quality rapeseed meal (6.3 µmols/g of glucosinolates in the concentrate). There were no effects on weight gain or feed intake, despite the fact that thyroid weight was marginally higher and thyroid hormone production was marginally lower at the higher dietary inclusion levels of rapeseed meal. Asadollahi et al (2017) determined that a diet with 7% roasted canola seeds improved growth rates, intramuscular fat, loin eye area, and sensory characteristics of lambs as compared to a standard diet. The incorporation of canola oil into the diet of growing goats increased muscle omega-3 fatty acid, reduced organ fat and improved oxidative stability of the meat relative to palm oil (Karami et al., 2013).

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

Practical Inclusion levels of canola meal in ruminant diets

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

References

Processing

COPA, 2019. Canadian Oilseed Processors Association. Trading rules. https://copacanada.com/trading-rules/, Winnipeg, Manitoba

Daun, J.K. and Adolphe, D. 1997. A revision to the canola definition. *GCIRC Bulletin.* July 1997. pp.134–141.

Composition

Adewole, D.I., Rogiewicz, A., Dyck, B. and Slominski, B.A., 2016. Chemical and nutritive characteristics of canola meal from Canadian processing facilities. *Animal feed science and technology*, 222, pp.17-30.

Assadi, E., Janmohammadi, H., Taghizadeh, A. and Alijani, S., 2011. Nutrient composition of different varieties of full-fat canola seed and nitrogen-corrected true metabolizable energy of full-fat canola seed with or without enzyme addition and thermal processing. *Journal of applied poultry research*, 20(1), pp.95-101.

Bell, J.M. and Keith, M.O., 1991. A survey of variation in the chemical composition of commercial canola meal produced in Western Canadian crushing plants. *Canadian journal of animal science*, 71(2), pp.469-480.

Bell, J.M., Rakow, G. and Downey, R.K., 1999. Mineral composition of oil-free seeds of Brassica napus, B. rapa and B. juncea as affected by location and year. *Canadian journal of animal science*, 79(3), pp.405-408.

Broderick, G.A., Colombini, S., Costa, S., Karsli, M.A. and Faciola, A.P., 2016. Chemical and ruminal in vitro evaluation of Canadian canola meals produced over 4 years. *Journal of dairy science*, 99(10), pp.7956-7970.

Chelikani, P.K., Bell, J.A. and Kennelly, J.J., 2004. Effects of feeding or abomasal infusion of canola oil in Holstein cows 1. Nutrient digestion and milk composition. *Journal of dairy research*, 71(3), pp.279-287.

Evonik, AminoDat Platinum. 2018. https://animal-nutrition.evonik.com/product/feed-additives/en/services/animal-nutrition/aminodat/

Gallardo, M.A., Pérez, D.D. and Leighton, F.M., 2012. Modification of fatty acid composition in broiler chickens fed canola oil. *Biological research*, 45(2), pp.149-161.

Gül, M., Yörük, M.A., Aksu, T., Kaya, A. and Kaynar, Ö., 2012. The effect of different levels of canola oil on performance, egg shell quality and fatty acid composition of laying hens. *International journal of poultry science*, 11(12), p.769.

Khajali, F. and Slominski, B.A., 2012. Factors that affect the nutritive value of canola meal for poultry. *Poultry science*, 91(10), pp.2564-2575.

Leterme, P., Kish, P. and Beaulieu, A.D., 2008. Digestibility energy determination of canola meal and full-fat canola seeds in pigs: limitations of the substitution method. *Journal of animal science*, 86 (Suppl. 2) pp. 186.

Montoya, C.A. and Leterme, P., 2010. Validation of the net energy content of canola meal and full-fat canola seeds in growing pigs. Canadian journal of animal science, 90(2), pp.213-219.

NRC. 2001. Nutrient Requirements of Dairy Cattle. National Academy of Sciences, Washington, D.C.

NRC. 2012. Nutrient Requirements of Swine. National Academy of Sciences, Washington, D.C.

Sauvant, D., Perez, J.M. and Tran, G, 2004. Tables of composition and nutritional value of feed materials. Wageningen Academic Publishers, INRA Editions.

Radfar, M., Rogiewicz, A. and Slominski, B.A., 2017. Chemical composition and nutritive value of canola-quality Brassica juncea meal for poultry and the effect of enzyme supplementation. *Animal feed science and technology*, 225, pp.97-108.

Ruminant

Abeysekara, S. and Mutsvangwa, T., 2016. Effects of feeding canola meal or wheat dried distillers' grains with solubles alone or in combination as the major protein sources on ruminal function and production in dairy cows. *Journal of animal science*, 94, pp.755-756

Acharya, I.P., Schingoethe, D.J., Kalscheur, K.F. and Casper, D.P., 2015. Response of lactating dairy cows to dietary protein from canola meal or distillers' grains on dry matter intake, milk production, milk composition, and amino acid status. *Canadian journal of animal science*, 95(2), pp.267-279.

Agbossamey, Y.R., Petit, H.V., Seoane, J.R. and St-Laurent, G.J., 1998. Performance of lambs fed either hay or silage supplemented with canola or fish meals. *Canadian journal of animal science*, 78(1), pp.135-141.

Andrade, P.V.D. and Schmidely, P., 2006. Influence of percentage of concentrate in combination with rolled canola seeds on performance, rumen fermentation and milk fatty acid composition in dairy goats. *Livestock science*, 104(1-2), pp.77-90.

Asadollahi, S., Sari, M., Erafanimajd, N., Kiani, A. and Ponnampalam, E.N., 2017. Supplementation of sugar beet pulp and roasted canola seed in a concentrate diet altered carcass traits, muscle (longissimus dorsi) composition and meat sensory properties of Arabian fattening lambs. *Small ruminant research*, 153, pp.95-102.

Auldist, M.J., Marett, L.C., Greenwood, J.S., Wright, M.M., Hannah, M., Jacobs, J.L. and Wales, W.J., 2014. Replacing wheat with canola meal in a partial mixed ration increases the milk production of cows grazing at a restricted pasture allowance in spring. *Animal production science*, 54(7), pp.869-878.

Bach, A., Ruiz Moreno, M., Thrune, M. and Stern, M.D., 2008. Evaluation of the fermentation dynamics of soluble crude protein from three protein sources in continuous culture fermenters. *Journal of animal science*, 86(6), pp.1364-1371.

Bayourthe, C., Enjalbert, F. and Moncoulon, R., 2000. Effects of different forms of canola oil fatty acids plus canola meal on milk composition and physical properties of butter. *Journal of dairy science*, 83(4), pp.690-696.

Beauchemin, K.A., McGinn, S.M., Benchaar, C. and Holtshausen, L., 2009. Crushed sunflower, flax, or canola seeds in lactating dairy cow diets: Effects on methane production, rumen fermentation, and milk production. *Journal of dairy science*, 92(5), pp.2118-2127.

Beaulieu, A.D., Olubobokun, J.A. and Christensen, D.A., 1990. The utilization of canola and its constituents by lactating dairy cows. *Animal feed science and technology*, 30(3-4), pp.289-300.

Brito, A.F., Broderick, G.A. and Reynal, S.M., 2007. Effects of Different Protein Supplements on Omasal Nutrient Flow and Microbial Protein Synthesis in Lactating Dairy Cows1. *Journal of dairy science*, 90(4), pp.1828-1841.

Broderick, G.A., Colombini, S., Costa, S., Karsli, M.A. and Faciola, A.P., 2016. Chemical and ruminal in vitro evaluation of Canadian canola meals produced over 4 years. *Journal of dairy science*, 99(10), pp.7956-7970.

Broderick, G.A. and Faciola, A.P., 2014. Effects of supplementing rumen-protected met and lys on diets containing soybean meal or canola meal in lactating dairy cows. *Journal of dairy science*, 97, (Suppl 1), pp.750-751.

Broderick, G.A., Faciola, A.P. and Armentano, L.E., 2015. Replacing dietary soybean meal with canola meal improves production and efficiency of lactating dairy cows. *Journal of dairy science*, 98(8), pp.5672-5687

Broderick. G.A, Faciola, A.P,. Nernberg, L., and Hickling D., 2012. Effect of replacing dietary soybean meal with canola meal on production of lactating dairy cows . Journal of dairy science. 95(Suppl 2): 249

Chibisa, G.E., Christensen, D.A. and Mutsvangwa, T., 2012. Effects of replacing canola meal as the major protein source with wheat dried distillers grains with solubles on ruminal function, microbial protein synthesis, omasal flow, and milk production in cows. *Journal of dairy science*, 95(2), pp.824-841.

Chichlowski, M.W., Schroeder, J.W., Park, C.S., Keller, W.L. and Schimek, D.E., 2005. Altering the fatty acids in milk fat by including canola seed in dairy cattle diets. *Journal of dairy science*, 88(9), pp.3084-3094.

Christen, K.A., Schingoethe, D.J., Kalscheur, K.F., Hippen, A.R., Karges, K.K. and Gibson, M.L., 2010. Response of lactating dairy cows to high protein distillers grains or 3 other protein supplements. *Journal of Dairy Science*, 93(5), pp.2095-2104.

Claassen, R.M., Christensen, D.A. and Mutsvangwa, T., 2016. Effects of extruding wheat dried distillers grains with solubles with peas or canola meal on ruminal fermentation, microbial protein synthesis, nutrient digestion, and milk production in dairy cows. *Journal of dairy science*, 99(9), pp.7143-7158.

Cools, S., Van Den Broeck, W., Vanhaecke, L., Heyerick, A., Bossaert, P., Hostens, M. and Opsomer, G., 2014. Feeding soybean meal increases the blood level of isoflavones and reduces the steroidogenic capacity in bovine corpora lutea, without affecting peripheral progesterone concentrations. *Animal reproduction science*, 144(3-4), pp.79-89.

Cotanch, K.W., Grant, R.J., Van Amburgh, M.E., Zontini, A., Fustini, M., Palmonari, A. and Formigoni, A., 2014. Applications of uNDF in ration modeling and formulation. Proceedings Cornell Nutrition Conference pp.114-131.

Damiran, D., Lardner, H.A., Jefferson, P.G., Larson, K. and McKinnon, J.J., 2016. Effects of supplementing spring-calving beef cows grazing barley crop residue with canola meal and wheat-based dry distillers grains with solubles on performance, reproductive efficiency, and system cost. *The professional animal scientist*, 32(4), pp.400-410.

Damiran, D. and McKinnon, J.J., 2018. Evaluation of wheat-based dried distillers grains with solubles or canola meal derived from Brassica napus seed as an energy source for feedlot steers. *Translational animal science*, 2(suppl_1), pp.S139-S144.

Erdman, R. and M. Iwaniuk. 2017. DCAD: It's not just for dry cows. Proc. Florida Nutrition Conf.

Faciola, A.P. and Broderick, G., 2013. Effects of replacing soybean meal with canola meal for lactating dairy cows fed three different ratios of alfalfa to corn silage. *Journal of dairy science*, 96,(E-Suppl 1) p.452.

Flachowsky, G., Franke, K., Meyer, U., Leiterer, M. and Schöne, F., 2014. Influencing factors on iodine content of cow milk. *European journal of nutrition*, 53(2), pp.351-365.

Galindo, C.E. , D.R. Ouellet, G. Maxin, R. Martneau, D.Pellerin and H.Lapierre. 2017. Effects of protein and forage sources on milk production, rumen parameters and intestinal digestibility in lactating dairy cows. *Journal of dairy science*, 100 (Suppl 1) p. 111.

Garikipati, D.K. 2004. Effect of endogenous phytase addition to diets on phytate phosphorus digestibility in dairy cows. MS Thesis, Washington State University.

Gidlund, H., Hetta, M. and Huhtanen, P., 2017. Milk production and methane emissions from dairy cows fed a low or high proportion of red clover silage and an incremental level of rapeseed expeller. *Livestock science*, 197, pp.73-81.

Gidlund, H., Hetta, M., Krizsan, S.J., Lemosquet, S. and Huhtanen, P., 2015. Effects of soybean meal or canola meal on milk production and methane emissions in lactating dairy cows fed grass silage-based diets. *Journal of dairy science*, 98(11), pp.8093-8106.

Good, A.C., McKinnon, J.J., Penner, G.B., McAllister, T.A. and Mutsvangwa, T., 2017. Evaluation of canola meal versus soybean meal as a protein supplement on performance and carcass characteristics of growing and finishing beef cattle. *Journal of animal science*, 95(Suppl 4), pp.125-126.

Gordon, M.B., Thompson,E Gowan,T., Mosely,D., Small, J.A. and. Barrett, D.M.W., . 2012. The effects of a soybean and canola diet during pre-pubertal growth on dairy heifer fertility. *Journal of dairy science*, 95(E-Suppl 1):800.

Hadam, D., Kański, J., Burakowska, K., Penner, G.B., Kowalski, Z.M. and Górka, P., 2016. Effect of canola meal use as a protein source in a starter mixture on feeding behavior and performance of calves during the weaning transition. *Journal of dairy science*, 99(2), pp.1247-1252.

He, M. and Armentano, L.E., 2011. Effect of fatty acid profile in vegetable oils and antioxidant supplementation on dairy cattle performance and milk fat depression. *Journal of dairy science*, 94(5), pp.2481-2491.

He, M.L., Gibb, D., McKinnon, J.J. and McAllister, T.A., 2013. Effect of high dietary levels of canola meal on growth performance, carcass quality and meat fatty acid profiles of feedlot cattle. *Canadian journal of animal science*, 93(2), pp.269-280.

He, M., Perfield, K.L., Green, H.B. and Armentano, L.E., 2012. Effect of dietary fat blend enriched in oleic or linoleic acid and monensin supplementation on dairy cattle performance, milk fatty acid profiles, and milk fat depression. *Journal of dairy science*, 95(3), p.1447.

Hedqvist, H. and Udén, P., 2006. Measurement of soluble protein degradation in the rumen. *Animal feed science and technology*, 126(1-2), pp.1-21.

Heim, R. and Krebs, G., 2018. Expeller barrel dry heat and moist heat pressure duration induce changes in canola meal protein for ruminant utilisation. *Animals*, 8(9), p.147.

Hentz, F., Kozloski, G.V., Orlandi, T., Avila, S.C., Castagnino, P.S., Stefanello, C.M. and Pacheco, G.F.E., 2012. Intake and digestion by wethers fed a tropical grass-based diet supplemented with increasing levels of canola meal. *Livestock science*, 147(1-3), pp.89-95.

Hristov, A.N., Domitrovich, C., Wachter, A., Cassidy, T., Lee, C., Shingfield, K.J., Kairenius, P., Davis, J. and Brown, J., 2011. Effect of replacing solvent-extracted canola meal with high-oil traditional canola, high-oleic acid canola, or high-erucic acid rapeseed meals on rumen fermentation, digestibility, milk production, and milk fatty acid composition in lactating dairy cows. *Journal of dairy science*, 94(8), pp.4057-4074.

Huang, X., Khan, N.A., Zhang, X. and Yu, P., 2015. Effects of canola meal pellet conditioning temperature and time on ruminal and intestinal digestion, hourly effective degradation ratio, and potential nitrogen to energy synchronization in dairy cows. *Journal of dairy science*, 98(12), pp.8836-8845.

Huhtanen, P., Hetta, M. and Swensson, C., 2011. Evaluation of canola meal as a protein supplement for dairy cows: a review and a meta-analysis. *Canadian journal of animal science*, 91(4), pp.529-543.

Jayasinghe, N., K. F. Kalscheur, J. L. Anderson, and D. P. Casper. 2014. Ruminal degradability and intestinal digestibility of protein and amino acids in canola meal. *Journal of dairy science* (E-Suppl.1), pp.566-577.

Johansson, B. and Nadeau, E., 2006. Performance of dairy cows fed an entirely organic diet containing cold-pressed rapeseed cake. *Acta agriculturae scand Section A*, 56(3-4), pp.128-136.

Johnson, K.A., Kincaid, R.L., Westberg, H.H., Gaskins, C.T., Lamb, B.K. and Cronrath, J.D., 2002. The effect of oilseeds in diets of lactating cows on milk production and methane emissions. *Journal of dairy science*, 85(6), pp.1509-1515.

Jones, R.A., Mustafa, A.F., Christensen, D.A. and McKinnon, J.J., 2001. Effects of untreated and heat-treated canola presscake on milk yield and composition of dairy cows. *Animal feed science and technology*, 89(1-2), pp.97-111.

Karami, M., Ponnampalam, E.N. and Hopkins, D.L., 2013. The effect of palm oil or canola oil on feedlot performance, plasma and tissue fatty acid profile and meat quality in goats. *Meat science*, 94(2), pp.165-169.

Krizsan, S.J., Gidlund, H., Fatehi, F. and Huhtanen, P., 2017. Effect of dietary supplementation with heat-treated canola meal on ruminal nutrient metabolism in lactating dairy cows. *Journal of dairy science*, 100(10), pp.8004-8017.

Li, C., Beauchemin, K.A. and Yang, W.Z., 2013. Effects of supplemental canola meal and various types of distillers grains on ruminal degradability, duodenal flow, and intestinal digestibility of protein and amino acids in backgrounded heifers. *Journal of animal science*, 91(11), pp.5399-5409.

Liu, G., Ma, Z., Shan, A., Wang, L. and Bi, Z., 2016. Effects of dietary rumen-protected lysine on milk yield and composition in lactating cows fed diets containing double-low rapeseed meal. *International journal of dairy technology*, 69(3), pp.380-385.

Llewellyn, D.A., Rohwer, G., Norberg, O.S., Kimura, E., Neibergs, J.S. and Fransen, S.C., 2015. Case study: evaluating farm processed canola and camelina meals as protein supplements for beef cattle. *Journal of the national association of country agricultural agents*, 8(2).

Malau-Aduli, A.E.O., Sykes, J.M. and Bignell, C.W., 2009. Influence of lupins and canola supplements on plasma amino acids, wool fibre diameter and liveweight in genetically divergent first cross Merino lambs. Proceedings, World Congress on Fats and Oils.

Mandiki, S.N.M., Bister, J.L., Derycke, G., Wathelet, J.P., Mabon, N., Marlier, N. and Paquay, R., 1999. Optimal level of rapeseed meal in diets of lambs. In Proceedings, 10th International Rapeseed Congress, Canberra, Australia.

Maesoomi, S.M., Ghorbani, G.R., Alikhani, M. and Nikkhah, A., 2006. Canola meal as a substitute for cottonseed meal in diet of midlactation Holsteins. *Journal of dairy science*, 89(5), pp.1673-1677.

Martineau, R., Ouellet, D.R. and Lapierre, H., 2013. Feeding canola meal to dairy cows: A meta-analysis on lactational responses. *Journal of dairy science*, 96(3), pp.1701-1714.

Martineau, R., Ouellet, D.R. and Lapierre, H., 2014. The effect of feeding canola meal on concentrations of plasma amino acids. *Journal of dairy science*, 97(3), pp.1603-1610.

Martineau, R., Ouellet, D.R. and Lapierre, K. 2019. Does blending canola meal with other protein sources improve production responses in lactating dairy cows? A multilevel mixed-effects meta-analysis. *Journal of dairy science* (in Press)

Miller-Cushon, E.K., Terré, M., DeVries, T.J. and Bach, A., 2014. The effect of palatability of protein source on dietary selection in dairy calves. *Journal of dairy science*, 97(7), pp.4444-4454.

Maxin, G., Ouellet, D.R. and Lapierre, H., 2013a. Effect of substitution of soybean meal by canola meal or distillers grains in dairy rations on amino acid and glucose availability. *Journal of dairy science*, 96(12), pp.7806-7817.

Maxin, G., Ouellet, D.R. and Lapierre, H., 2013b. Ruminal degradability of dry matter, crude protein, and amino acids in soybean meal, canola meal, corn, and wheat dried distillers grains. Journal of dairy science, 96(8), pp.5151-5160.

Moate, P.J., Williams, S.R.O., Grainger, C., Hannah, M.C., Ponnampalam, E.N. and Eckard, R.J., 2011. Influence of cold-pressed canola, brewers grains and hominy meal as dietary supplements suitable for reducing enteric methane emissions from lactating dairy cows. *Animal Feed Science and Technology*, 166, pp.254-264.

Moore, S.A. E. and K. J. Kalscheur. 2016. Canola meal in dairy cow diets during early lactation increases production compared with soybean meal. *Journal of dairy science* (Suppl 1) 99: 719.

Mulrooney, C.N., Schingoethe, D.J., Kalscheur, K.F. and Hippen, A.R., 2009. Canola meal replacing distillers grains with solubles for lactating dairy cows. *Journal of dairy science*, 92(11), pp.5669-5676.

Mustafa, A.F., Christensen, D.A. and McKinnon, J.J., 1996. Chemical characterization and nutrient availability of high and low fiber canola meal. *Canadian journal of animal science*, 76(4), pp.579-586.

Mustafa, A.F., Christensen, D.A. and McKinnon, J.J., 1997. The effects of feeding high fiber canola meal on total tract digestibility and milk production. *Canadian journal of animal science*, 77(1), pp.133-140.

Mutsvangwa, T., Kiran, D. and Abeysekara, S., 2016. Effects of feeding canola meal or wheat dried distillers grains with solubles as a major protein source in low-or high-crude protein diets on ruminal fermentation, omasal flow, and production in cows. *Journal of dairy science*, 99(2), pp.1216-1227.

Nair, J., Penner, G.B., Yu, P., Lardner, H.A., McAllister, T.A., Damiran, D. and McKinnon, J.J., 2016. Evaluation of canola meal derived from Brassica juncea and Brassica napus on rumen fermentation and nutrient digestibility by feedlot heifers fed finishing diets. *Canadian Journal of animal science*, 96(3), pp.342-353.

Nair, J., Penner, G.B., Yu, P., Lardner, H.A., McAllister, T., Damiran, D. and McKinnon, J.J., 2015. Evaluation of canola meal derived from Brassica juncea and Brassica napus seed as an energy source for feedlot steers. *Canadian journal of animal science*, 95(4), pp.599-607.

NRC. 2001. Nutrient Requirements of Dairy Cattle. National Research Council, Washington, D.C.

NRC. 2015. Nutrient Requirements of Beef Cattle. National Research Council, Washington, D.C.

Patterson, H.H., Whittier, J.C., Rittenhouse, L.R., Larsen, L. and Howes, A.D., 1999. Effects of Cull Beans, Sunflower Meal, and Canola Meal as Protein Supplements to Beef Steers Consuming Grass Hay on In Situ Digestion Kinetics1. *The professional animal scientist*, 15(3), pp.185-190.

Paula, E.M., Danes, M.A.C., Lobos, N.E., Zanton, G.I., Broderick, G.A. and Faciola, A.P., 2015. Effects of replacing soybean meal with canola meal or treated canola meal on performance of lactating dairy cows. *Journal of dairy science*, 98(2), p.387.

Paula, E.M., Broderick, G.A., Danes, M.A.C., Lobos, N.E., Zanton, G.I. and Faciola, A.P., 2018. Effects of replacing soybean meal with canola meal or treated canola meal on ruminal digestion, omasal nutrient flow, and performance in lactating dairy cows. *Journal of dairy science*, 101(1), pp.328-339.

Paula, E.M., Monteiro, H.F., Silva, L.G., Benedeti, P.D.B., Daniel, J.L.P., Shenkoru, T., Broderick, G.A. and Faciola, A.P., 2017a. Effects of replacing soybean meal with canola meal differing in rumen-undegradable protein content on ruminal fermentation and gas production kinetics using 2 in vitro systems. *Journal of dairy science*, 100(7), pp.5281-5292.

Paula, E.M., Daniel, L.P., Silva, L.G., Costa H.H.A., and Faciola, A.P.2017b. Assessing potentially digestible NDF and energy content of canola meal from twelve Canadian crushing plants over four production years. *Journal of dairy science*, 100 (Suppl2) 329-330.

Perera, S.P., McIntosh, T.C. and Wanasundara, J.P., 2016. Structural properties of cruciferin and napin of Brassica napus (canola) show distinct responses to changes in pH and temperature. *Plants*, 5(3), p.36.

Petit, H.V. and Veira, D.M., 1994. Effect of post-weaning protein supplementation of beef steers fed grass silage on performance during the finishing phase, and carcass quality. *Canadian journal of animal science*, 74(4), pp.699-701.

Ravichandiran, S., Sharma, K., Dutta, N., Patianaik, A.K., Chauhan, J.S., Agnihotri, A. and Kumar, A., 2008. Performance of crossbred calves on supplements containing soybean meal or rapeseed-mustard cake with varying glucosinolate levels. *Indian journal of animal sciences,* 78, pp. 85-90.

Puhakka, L., Jaakkola, S., Simpura, I., Kokkonen, T. and Vanhatalo, A., 2016. Effects of replacing rapeseed meal with fava bean at 2 concentrate crude protein levels on feed intake, nutrient digestion, and milk production in cows fed grass silage–based diets. *Journal of dairy science*, 99(10), pp.7993-8006.

Rezamand, P., Hatch, B.P., Carnahan, K.G. and McGuire, M.A., 2016. Effects of alpha-linolenic acid-enriched diets on gene expression of key inflammatory mediators in immune and milk cells obtained from Holstein dairy cows. *Journal of dairy research*, 83(1), pp.20-27.

Rinne, M., Kuoppala, K., Ahvenjärvi, S. and Vanhatalo, A., 2015. Dairy cow responses to graded levels of rapeseed and soya bean expeller supplementation on a red clover/grass silage-based diet. *Animal*, 9(12), pp.1958-1969.

Ross,D. 2015. Personal communication.

Ross, D.A., Gutierrez-Botero, M. and Van Amburgh, M.E. 2013. Development of an in-vitro intestinal digestibility assay for ruminant feeds. Proceedings of the Cornell Nutrition Conference. pp. 190–202.

Salehi, R., Ambrose, D.J. and Oba, M., 2016. Effects of prepartum diets supplemented with rolled oilseeds on Brix values and fatty acid profile of colostrum. *Journal of dairy science*, 99(5), pp.3598-3601.

Salehi, R., Colazo, M.G., Oba, M. and Ambrose, D.J., 2016. Effects of prepartum diets supplemented with rolled oilseeds on calf birth weight, postpartum health, feed intake, milk yield, and reproductive performance of dairy cows. *Journal of dairy science*, 99(5), pp.3584-3597.

Shingfield, K.J., Vanhatalo, A. and Huhtanen, P., 2003. Comparison of heat-treated rapeseed expeller and solvent-extracted soya-bean meal as protein supplements for dairy cows given grass silage-based diets. *Animal Science.* 77,pp. 305-317.

Skrivanova, V., Marounek, M. and Dvorak, R., 2004. Digestibility of total and phytate phosphorus in young calves. *Veterinarni medicina-UZPI*, 49, 191-196.

Spears, J.W., 2003. Trace mineral bioavailability in ruminants. *The journal of nutrition*, 133(5), pp.1506S-1509S.

Stefański, T., Ahvenjärvi, S., Huhtanen, P. and Shingfield, K.J., 2013. Metabolism of soluble rapeseed meal (Brassica rapa L.) protein during incubations with buffered bovine rumen contents in vitro. *Journal of dairy science*, 96(1), pp.440-450.

Stoffel, C.M., Crump, P.M. and Armentano, L.E., 2015. Effect of dietary fatty acid supplements, varying in fatty acid composition, on milk fat secretion in dairy cattle fed diets supplemented to less than 3% total fatty acids. *Journal of dairy science*, 98(1), pp.431-442.

Suarez-Mena, F.X., Lascano, G.J., Rico, D.E. and Heinrichs, A.J., 2015. Effect of forage level and replacing canola meal with dry distillers grains with solubles in precision-fed heifer diets: Digestibility and rumen fermentation. *Journal of dairy science*, 98(11), pp.8054-8065.

Swanepoel, N., Robinson, P.H. and Erasmus, L.J., 2014. Determining the optimal ratio of canola meal and high protein dried distillers grain protein in diets of high producing Holstein dairy cows.

Animal Feed science and technology, 189, pp.41-53.

Swanepoel, N., Robinson, P.H. and Erasmus, L.J., 2016. Impacts of adding ruminally protected phenylalanine to rations containing high levels of canola meal on performance of high producing Holstein cows. *Animal Feed science and technology*, 216, pp.108-120.

Theodoridou, K. and Yu, P., 2013. Application potential of ATR-FT/IR molecular spectroscopy in animal nutrition: revelation of protein molecular structures of canola meal and presscake, as affected by heat-processing methods, in relationship with their protein digestive behavior and utilization for dairy cattle. *Journal of agricultural and food chemistry*, 61(23), pp.5449-5458.

Trøan, G., Pihlava, J.M., Brandt-Kjelsen, A., Salbu, B. and Prestløkken, E., 2018. Heat-treated rapeseed expeller press cake with extremely low glucosinolate content reduce transfer of iodine to cow milk. *Animal feed science and technology*, 239, pp.66-73.

Tylutki, T.P., Fox, D.G., Durbal, V.M., Tedeschi, L.O., Russell, J.B., Van Amburgh, M.E., Overton, T.R., Chase, L.E. and Pell, A.N., 2008. Cornell Net Carbohydrate and Protein System: A model for precision feeding of dairy cattle. *Animal Feed science and technology*, 143(1-4), pp.174-202.

Veselý, A., Křížová, L., Třináctý, J., Hadrová, S., Navrátilová, M., Herzig, I. and Fišera, M., 2009. Changes in fatty acid profile and iodine content in milk as influenced by the inclusion of extruded rapeseed cake in the diet of dairy cows. *Czech journal of animal science*, 54 (9),pp.201-209.

Vincent, I.C., Hill, R. and Campling, R.C., 1990. A note on the use of rapeseed, sunflower and soyabean meals as protein sources in compound foods for milking cattle. *Animal science*, 50(3), pp.541-543.

Weiss, W.P., Wyatt, D.J., Kleinschmit, D.H. and Socha, M.T., 2015. Effect of including canola meal and supplemental iodine in diets of dairy cows on short-term changes in iodine concentrations in milk. *Journal of dairy science*, 98(7), pp.4841-4849.

Wiese, S.C., White, C.L., Masters, D.G., Milton, J.T.B. and Davidson, R.H., 2003. Growth and carcass characteristics of prime lambs fed diets containing urea, lupins or canola meal as a crude protein source. *Australian journal of experimental agriculture*, 43(10), pp.1193-1197.

Woclawek-Potocka, I., Acosta, T.J., Korzekwa, A., Bah, M.M., Shibaya, M., Okuda, K. and Skarzynski, D.J., 2005. Phytoestrogens modulate prostaglandin production in bovine endometrium: cell type specificity and intracellular mechanisms. *Experimental biology and medicine*, 230(5), pp.326-333.

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