

Canola Meal for Dairy and Other Ruminants

Practical Inclusion Levels of Canola Meal in Diets for Dairy and Other 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

Updated June 2023

For more information, please visit canolamazing.com or contact:

Dr. Essi Evans essievans@sympatico.ca or
Brittany Wood woodb@canolacouncil.org

Contents

Dairy Cattle	3
Canola Meal Use	3
Canola Meal and Profitability.....	3
Using Canola Meal to Reduce Greenhouse Gas Emissions	4
Canola Meal Palatability.....	6
Using Canola Meal as a Protein Source.....	7
Amino acid composition	7
Rumen undegraded protein in canola meal.....	8
Rumen microbial protein production.....	10
Energy for Ruminants.....	10
Canola Fatty Acids	11
Micronutrients in Canola Meal	12
Phosphorus	12
Iodine	13
Dietary cation anion difference.....	13
Antioxidants	14
Feeding Solvent Extracted Canola Meal to Lactating Cows	14
Meta-analyses of feeding value	14
Canola meal in early lactation.....	15
Mid lactation feeding trials	16
Canola Meal for Growth.....	17
Canola meal for calves preweaning	17
Canola meal for calves during weaning transition.....	19
Canola meal effects on gut health and development	20
Canola meal for growing heifers	20
Chinese feeding trials.....	20
Feeding Expeller Canola Meal to Lactating Cows.....	21
Feeding Canola Seed to Dairy Cows.....	22
Beef Cattle	23
Small Ruminants	24
Sheep	24
Goats	25
References	26

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

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

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.

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.

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

Reference ²	Meal ¹		ECM, kg ³	Methane output		
	Source	% Of DM		g/day	g/kg DMI	g/kg ECM
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

¹SBM = solvent-extracted soybean meal. CM = solvent-extracted canola meal

²1-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

³ECM = energy-corrected milk

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 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

¹Benchaar 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

¹Hassanat 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			
	0	7.89	15.8	23.7
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.

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

Protein	Score	Limiting amino acid		
		1 st	2 nd	3 rd
Rumen microbial protein	0.78	Histidine	Leucine	Valine
Fish meal	0.75	Leucine	Tryptophan	Isoleucine
<i>Canola meal</i>	<i>0.68</i>	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

	% DM basis		% of protein	
	Intact meal	RUP fraction	Intact meal	RUP fraction
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

While the amino acid profile contributes greatly to the importance of canola meal in ruminant feed 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. Rates of digestion of the soluble fraction of protein in the rumen for selected ingredients.¹

Vegetable protein	Soluble protein, % of total protein	Rate % degraded/hour
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

¹Hedqvist and Udén, 2008



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.

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	
	Solvent extracted	Expeller
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).

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
	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

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.

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 $\mu\text{mol/g}$ 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		
	0	3.9	13.9	0	3.9	13.9
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

¹Weiss 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).

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.

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		DCAD
	K	Na	Cl	S	
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

¹Erdman and Iwaniuk, 2015

Antioxidants

Oxidative stress is 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.

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

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.

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.

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 ¹	
		Canola meal	Soybean meal	Canola meal	Soybean meal	Canola meal	Soybean 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.

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.

Mid lactation feeding trials

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

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

Reference	Protein source		Difference
	Canola meal	Cottonseed meal	
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 Mutsvangwa, 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		
	Canola meal	Cottonseed meal	Soybean meal
Claypool et al., 1985			
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			
Meal % of dry matter	35.0	16.5	24.0
Intake/day preweaning, ² g	269	250	315
Average daily gains, g/day	587	636	684

¹Calves were weaned at 8 weeks of age.

²Calves 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		
	Canola meal	Cottonseed meal	Soybean meal
Claypool et al., 1985			
Meal % of dry matter	17.6	14.1	11.1
Intake/day postweaning, ¹ g			
Average daily gains, g/day	890	890	910
Hadam et al., 2016			
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

¹Calves 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.

²Calves 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. Burakowska 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.

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



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.

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/day
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 Chichlowski 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 Auld 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 $\mu\text{mol/g}$ of glucosinolates in the concentrate or 21 $\mu\text{mol/g}$ 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).

References

- 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.
- Ahsani, M., Mohammadabadi, M., Fozi, M.A., Koshkooieh, A.E., Khezri, A., Babenko, O., Bushtruk, M., Tkachenko, S., Stavetska, R. and Klopenko, N., 2019. Effect of roasted soybean and canola seeds on peroxisome proliferator-activated receptors gamma (PPARG) gene expression and cattle milk characteristics. *Iranian Journal of Applied Animal Science*, 9(4), pp. 635-642.
- Anderson, V.L. and Schoonmaker, J.P., 2004. Effect of pulse grains on performance of newly weaned steer calves. *NDSU Beef Production Field Day Proceedings*, 27, pp. 6-8.
- 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.
- Arce-Cordero, J.A., Paula, E.M., Daniel, J.L., Silva, L.G., Broderick, G.A. and Faciola, A.P., 2021. Effects of neutral detergent fiber digestibility estimation method on calculated energy concentration of canola meals from 12 Canadian processing plants. *Journal of Animal Science*, 99(11), p.skab309.
- 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.
- Auldism, M.J., Marett, L.C., Greenwood, J.S., Wright, M.M., Hannah, M., Jacobs, J.L. and Wales, W.J., 2013. 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.
- Auldism, M.J., Wright, M.M., Marett, L.C., Hannah, M.C., Kennedy, E., Jacobs, J.L. and Wales, W.J., 2019. Milk production of cows grazing pasture supplemented by a partial mixed ration with or without canola meal. *Animal Production Science*, 59(4), pp.778-786.
- Baldin, M., Rico, D.E., Green, M.H. and Harvatine, K.J., 2018. An in vivo method to determine kinetics of unsaturated fatty acid biohydrogenation in the rumen. *Journal of Dairy Science*, 101(5), pp.4259-4267.

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., Kreuzer, M., O'Mara, F. and McAllister, T.A., 2008. Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*, 48(2), pp.21-27.

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.

Benchaar, C., Hassanat, F., Beauchemin, K.A., Gislou, G. and Ouellet, D.R., 2021. Diet supplementation with canola meal improves milk production, reduces enteric methane emissions, and shifts nitrogen excretion from urine to feces in dairy cows. *Journal of Dairy Science*, 104(9), pp.9645-9663.

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 cows. *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, (Supplement 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.

Broderick, G.A., Wallace, R.J. and Ørskov, E.R., 1991. Control of rate and extent of protein degradation. In *Physiological aspects of digestion and metabolism in ruminants* (pp. 541-592). Academic Press.

Burakowska, K., Górka, P., Kent-Dennis, C., Kowalski, Z.M., Laarveld, B. and Penner, G.B., 2020. Effect of heat-treated canola meal and glycerol inclusion on performance and gastrointestinal development of Holstein calves. *Journal of Dairy Science*, 103(9), pp.7998-8019.

Burakowska, K., Górka, P. and Penner, G.B., 2021. Effects of canola meal inclusion rate in starter mixtures for Holstein heifer calves on dry matter intake, average daily gain, ruminal fermentation, plasma metabolites, and total-tract digestibility. *Journal of Dairy Science*, 104(8), pp.8736-8745.

Burakowska, K., Penner, G.B., Flaga, J., Kowalski, Z.M., Korytkowski, and Górka, P., 2021. Canola meal or soybean meal as protein source and the effect of microencapsulated sodium butyrate supplementation in calf starter mixture. I. Performance, digestibility and selected blood variables. *Journal of Dairy Science*, 104(6), pp.6646-6662.

Burakowska, K., Penner, G.B., Flaga, J., Przybyło, M., Barc, J., Wojciechowska-Puchałka, J., Wojtysiak, D., Kowalski, Z.M. and Górka, P., 2021b. Canola meal or soybean meal as protein source and the effect of microencapsulated sodium butyrate supplementation in calf starter mixture. II. Development of the gastrointestinal tract. *Journal of Dairy Science*, 104(6), pp.6663-6676.

Burakowska, K., Przybyło, M., Penner, G.B. and Górka, P., 2017. Evaluating the effect of protein source and micro-encapsulated sodium butyrate in starter mixtures on gastrointestinal tract development of dairy calves. *Journal of Dairy Science*, 100(Suppl. 2), pp347

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.

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.

Chmielewska, A., Kozłowska, M., Rachwał, D., Wnukowski, P., Amarowicz, R., Nebesny, E. and Rosicka-Kaczmarek, J., 2021. Canola/rapeseed protein—nutritional value, functionality and food application: a review. *Critical Reviews in Food Science and Nutrition*, 61(22), pp.3836-3856.

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.

Claypool, D.W., Hoffman, C.H., Oldfield, J.E. and Adams, H.P., 1985. Canola meal, cottonseed, and soybean meals as protein supplements for calves. *Journal of Dairy Science*, 68(1), pp.67-70.

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.

Dorea, J.R.R. and Armentano, L.E., 2017. Effects of common dietary fatty acids on milk yield and concentrations of fat and fatty acids in dairy cattle. *Animal Production Science*, 57(11), pp.2224-2236.

Easton, E., Edwards, J.H. and White, C., 1998. The effect of adding salt to a canola meal supplement on wool growth in weaner sheep. *Animal Production in Australia*, 22, pp.257-260.

Elshereef, A.A., Arroyave-Jaramillo, J., Zavala-Escalante, L.M., Piñeiro-Vázquez, A.T., Aguilar-Pérez, C.F., Solorio-Sánchez, F.J. and Ku-Vera, J.C., 2020. Enteric methane emissions in crossbred heifers fed a basal ration of low-quality tropical grass supplemented with different nitrogen sources. *Czech Journal of Animal Science*, 65(4), pp.135-144.

Eugène, M., Massé, D., Chiquette, J. and Benchaar, C., 2008. Meta-analysis on the effects of lipid supplementation on methane production in lactating dairy cows. *Canadian Journal of Animal Science*, 88(2), pp.331-337.

Faldet, M. 2018. Evaluating feed financials. 2018. *Proceedings 4-State Dairy Nutrition Conference*, pp.152-157.

Flachowsky, G., Franke, K., Meyer, U., Leiterer, M. and Schone, 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, Pellerin D. 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 exogenous phytase addition to diets on phytate phosphorus digestibility in dairy cows. MS Thesis, Washington State University.

Gauthier, H., Swanepoel, N. and Robinson, P.H., 2019. Impacts of incremental substitution of soybean meal for canola meal in lactating dairy cow diets containing a constant base level of corn derived dried distillers' grains with solubles. *Animal Feed Science and Technology*, 252, pp.51-63.

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., 2018. Evaluation of canola meal versus soybean meal as a protein supplement for beef cattle: effects on growth performance, carcass characteristics, rumen fermentation and nutrient digestion. (Doctoral dissertation, University of Saskatchewan).

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.

Gorka, P. and Penner, G.B., 2020. Rapeseed and canola meal as protein sources in starter diets for calves: current knowledge and directions of future studies. *Ankara Üniversitesi Veteriner Fakültesi Dergisi*, 67(3), pp.313-321.

Grande, P.A., Alcalde, C.R., Lima, L.S.D., Zambom, M.A. and Macedo, F.D., 2014. Effect of whole oilseeds feeding on performance and nutritive values of diets of young growing saanen goats. *Ciência e Agrotecnologia*, 38, pp.181-187.

Hadam, D., Kański, J., Burakowska, K., Penner, G.B., Kowalski, Z.M. and Górk, 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.

Hassanat, F., Gislou, G., Beauchemin, K.A. and Benchaar, C. 2020. Canola meal in dairy cow diets: Effect on nitrogen utilization. *Journal of Dairy Science*, 103(supplement 1), pp.288.

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), 1447-1461.

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.

Heim, R. and Krebs, G., 2020. Utilisation of canola meal as protein source in dairy cow diets: a review. *Agriculture and Natural Resources*, 54(6), pp.623-632.

Hentz, F., Kozloski, G.V., Orlandi, T., Ávila, 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.

Holtshausen, L., Benchaar, C., Kröbel, R. and Beauchemin, K.A., 2021. Canola meal versus Soybean meal as protein supplemented in the diets of lactating dairy cows affects the greenhouse gas intensity of milk. *Animals*, 11(6), p.1636.

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.

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., Kalscheur, K.F., Anderson, J.L. and Casper, D.P. 2014. Ruminant 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 Scandinavica 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.

Kobayashi, Y., 2010. Abatement of methane production from ruminants: trends in the manipulation of rumen fermentation. *Asian-Australasian Journal of Animal Sciences*, 23(3), pp.410-416.

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.

Kuehnl, J.M. and Kalscheur, K.F., 2021. Production and temporal plasma metabolite effects of soybean meal versus canola meal fed to dairy cows during the transition period and early lactation. *Journal of Dairy Science* 104(Supplement 1), pp.23.

Kuehnl, J. and Kalscheur, K. 2022. Canola meal enhances early lactation milk production. *Hoard's Dairyman*. Available at: <https://hoards.com/article-31588-canola-meal-enhances-early-lactation-milk-production.html>. Accessed May 3, 2023.

Kuehnl, J. and Kalscheur, K. 2022. Production effects of feeding soybean meal versus canola meal to dairy cows with low versus high residual feed intake. *Journal of Dairy Science* 105(Supplement 1), pp.71 (abstract).

Lage, C.F.A., Räisänen, S.E., Stefenoni, H., Melgar, A., Chen, X., Oh, J., Fetter, M.E., Kniffen, D.M., Fabin, R.A. and Hristov, A.N., 2021. Lactational performance, enteric gas emissions, and plasma amino acid profile of dairy cows fed diets with soybean or canola meals included on an equal protein basis. *Journal of Dairy Science*, 104(3), pp.3052-3066.

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.

Loganes, C., Ballali, S. and Minto, C., 2016. Main properties of canola oil components: A descriptive review of current knowledge. *The Open Agriculture Journal*, 10(Suppl 1) 69-74.

Lopes, J.C., Harper, M.T., Giallongo, F., Oh, J., Smith, L., Ortega-Perez, A.M., Harper, S.A., Melgar, A., Kniffen, D.M., Fabin, R.A. and Hristov, A.N., 2017. Effect of high-oleic-acid soybeans on production performance, milk fatty acid composition, and enteric methane emission in dairy cows. *Journal of Dairy Science*, 100(2), pp.1122-1135.

Lynch, E.E., Campbell, M.A., Piltz, J.W., Krebs, G.L. and Friend, M.A., 2021. Responses to varying inclusion levels of canola meal as a grassfed supplement for weaner calves. In *Proceedings of the 33rd Biennial Conference of the Australian Association of Animal Sciences*. CSIRO Publishing.

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.

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

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

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, H., 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*, 102(6), pp.5066-5078.

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.

McNabb, W.C., Spencer, D., Higgins, T.J. and Barry, T.N., 1994. In-vitro rates of rumen proteolysis of ribulose-1, 5-bisphosphate carboxylase (rubisco) from lucerne leaves, and of ovalbumin, vicilin and sunflower albumin & storage proteins. *Journal of the Science of Food and Agriculture*, 64(1), pp.53-61.

Melendez, P., Ramirez, R., Marin, M.P., Duchens, M. and Pinedo, P., 2020. Comparison between linseed expeller and canola expeller on concentrate intake, and circulating inflammatory mediators in Holstein calves. *Animal Nutrition*, 6(1), pp.47-53.

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.

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 Kalscheur K.J. 2016. Canola meal in dairy cow diets during early lactation increases production compared with soybean meal. *Journal of Animal Science*, 94(Suppl 1), p.731.

Moore, S.A.E., Kalscheur, K.F., Aguerre, M.J. and Powell, M.J., 2016. Effects of canola meal and soybean meal as protein sources on methane and ammonia emissions of high producing dairy cows. *Journal of Animal Science*, 94(Suppl E), p.572.

Moura, D.C, Alessi, K.C., Assis, J.R., Torres, R.N., Soares, S.R., Donadia, A.B. and Silva, H.M. 2018. Meta-analysis of the use of canola meal in diets for dairy cows. *Journal of Dairy Science*, 100 (Supplement 2) pp. 107 (Abstract).

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.

NASEM. 2021. Nutrient Requirements of Dairy Cattle. National Research Council, National Academies Press, Washington, D.C.

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

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

Patterson, H.H., Whittier, J.C., Rittenhouse, L.R., Larsen, L. and Howes, A.D., 1999a. Effects of cull beans, sunflower meal and canola meal as protein supplements to beef steers consuming grass hay on in-situ digestion kinetics.¹ *The Professional Animal Scientist*, 15(3), pp.185-190.

Patterson, H.H., Whittier, J.C., Rittenhouse, L.R. and Schutz, D.N., 1999b. Performance of beef cows receiving cull beans, sunflower meal, and canola meal as protein supplements while grazing native winter range in eastern Colorado. *Journal of Animal Science*, 77(3), pp.750-755.

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., Broderick, G.A. and Faciola, A.P., 2020. Effects of replacing soybean meal with canola meal for lactating dairy cows fed 3 different ratios of alfalfa to corn silage. *Journal of Dairy Science*, 103(2), pp.1463-1471.

Paula, E.M., Daniel, J.L.P., Silva, L.G., Costa H.H.A., and Faciola, A.P.2017. Assessing potentially digestible NDF and energy content of canola meal from twelve Canadian crushing plants over four production years. *Journal of Dairy Science*, 100(Suppl 2) pp. 329-330.

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 (Suppl 2), p.387.

Perera, S.P., McIntosh, T.C. and Wanasundara, J.P.D., 2016. Structural properties of cruciferin and napin of *Brassica napus* (canola) show distinct responses to changes in pH and temperature. *Plants*, 5(3), pp.36-60.

Pereira, A.B.D., Moura, D.C., Whitehouse, N.L. and Brito, A.F., 2020. Production and nitrogen metabolism in lactating dairy cows fed finely ground field pea plus soybean meal or canola meal with or without rumen-protected methionine supplementation. *Journal of Dairy Science*, 103(4), pp.3161-3176.

Prado, I.N.D. and Martins, A.D.S., 1999. Effect of cottonseed meal replacement by canola meal on performance of feedlot Nellore heifers. *Revista Brasileira de Zootecnia*, 28(6), pp.1390-1396.

Prom, C.M. and Lock, A.L., 2021. Replacing stearic acid with oleic acid in supplemental fat blends improves fatty acid digestibility of lactating dairy cows. *Journal of Dairy Science*, 104(9), pp.9956-9966.

Prom, C.M., dos Santos Neto, J.M., Newbold, J.R. and Lock, A.L., 2021. Abomasal infusion of oleic acid increases fatty acid digestibility and plasma insulin of lactating dairy cows. *Journal of Dairy Science*, 104(12), pp.12616-12627.

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.

Ramirez-Bribiesca, J.E., McAllister, T., Ungerfeld, E. and Ortega-Cerrilla, M.E., 2018. In vitro rumen fermentation and effect of protein fractions of canola meals on methane production. *Scientia Agricola*, 75(1), pp.12-17.

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*.

Reynolds, M.A., Brown-Brandl, T.M., Judy, J.V., Herrick, K.J., Hales, K.E., Watson, A.K. and Kononoff, P.J., 2019. Use of indirect calorimetry to evaluate utilization of energy in lactating Jersey dairy cattle consuming common coproducts. *Journal of Dairy Science*, 102(1), pp.320-333.

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.

Robles Jimenez, L.E., Sanchez, A.Z., Ortega, O.A.C., Avalos, J.O., Florez, J.G.E., Gonzalez-Ronquillo, M and Bello-Perez, E.V. 2021. Effect of different growth stages of canola on nutrient intake and digestibility, nitrogen balance, and rumen fermentation kinetics in sheep diets. *Journal of Dairy Science*, 104 (Supplement 1), pp. 195.

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.

Sánchez-Duarte, J.I., Kalscheur, K.F., Casper, D.P. and García, A.D., 2019. Performance of dairy cows fed diets formulated at 2 starch concentrations with either canola meal or soybean meal as the protein supplement. *Journal of Dairy Science*, 102(9), pp.7970-7979.

Schingoethe, D.J., 1996. Balancing the amino acid needs of the dairy cow. *Animal Feed Science and Technology*, 60(3-4), pp.153-160.

Schmidely, P. and Andrade, P.V.D., 2011. Dairy performance and milk fatty acid composition of dairy goats fed high or low concentrate diet in combination with soybeans or canola seed supplementation. *Small Ruminant Research*, 99(2-3), pp.135-142.

Sekali, M., Mlambo, V., Marume, U. and Mathuthu, M., 2020. Replacement of soybean meal with heat-treated canola meal in finishing diets of meatmaster lambs: physiological and meat quality responses. *Animals*, 10(10), p.1735.

Seo, S., Tedeschi, L.O., Lanzas, C., Schwab, C.G. and Fox, D.G., 2006. Development and evaluation of empirical equations to predict feed passage rate in cattle. *Animal Feed Science and Technology*, 128(1-2), pp.67-83.

Silva, L.H.P., Reyes, D.C., Sacramento, P. Geng, Y., Ghelichkhan, M., Dillard, S.L., Soder, K.J. and Brito, A.F. 2022. Energy utilization in Jersey cows fed TMR or partial TMR plus forage canola. *Journal of Dairy Science*, 105(Supplement 1), pp. 121.

Skrivanova, V., Marounek, M. and Dvorak, R., 2004. Digestibility of total and phytate phosphorus in young calves. *Veterinarni medicina-UZPI*, 49(6), 191-196.

Soliva, C.R., Zeleke, A.B., Clement, C., Hess, H.D., Fievez, V. and Kreuzer, M., 2008. In vitro screening of various tropical foliage, seeds, fruits and medicinal plants for low methane and high ammonia generating potentials in the rumen. *Animal Feed Science and Technology*, 147(1-3), pp.53-71.

Spears, J.W., 2003. Trace mineral bioavailability in ruminants. *The Journal of Nutrition*, 133(5 Suppl 1), pp.1506S-1509S.



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 Conley, A., 2020. Impacts of substitution of canola meal with soybean meal, with and without ruminally protected methionine, on production, reproduction and health of early lactation multiparous Holstein cows through 160 days in milk. *Animal Feed Science and Technology*, 264, p.114494.

Swanepoel, N., Robinson, P.H. and Conley, A., 2020. Impacts of substitution of canola meal with soybean meal, with and without ruminally protected methionine, on production, reproduction and health of early lactation multiparous Holstein cows through 160 days in milk. *Animal Feed Science and Technology*, 264, p.114494.

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.

Tajaddini, M.A., Dayani, O., Khezri, A., Tahmasbi, R. and Sharifi-Hoseini, M.M., 2021. Production efficiency, milk yield, and milk composition and fatty acids profile of lactating goats feeding formaldehyde-treated canola meal in two levels of dietary crude protein. *Small Ruminant Research*, 204, p.106519.

Terré, M. and Bach, A. 2014. The use of favored or unfavored ingredients in starter feeds for preweaned calves. *Journal of Dairy Science*, 97(E-Suppl. 1), p.809.

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 press cake, 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.

Troan, G., Pihlava, J.-M., Brandt-Kjelsen, A., Salbu, B. and Prestlokken, 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.

Urie, N.J., Lombard, J.E., Shivley, C.B., Koprak, C.A., Adams, A.E., Earleywine, T.J., Olson, J.D. and Garry, F.B., 2018. Preweaned heifer management on US dairy operations: Part V. Factors associated with morbidity and mortality in preweaned dairy heifer calves. *Journal of Dairy Science*, 101(10), pp.9229-9244.

Vesely, A., Křižova, L., Třinactý, J., Hadrova, S., Navratilova, 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.

Vuorela, S., Meyer, A.S. and Heinonen, M., 2004. Impact of isolation method on the antioxidant activity of rapeseed meal phenolics. *Journal of Agricultural and Food Chemistry*, 52(26), pp.8202-8207.

Wallace, R.J., 1983. Hydrolysis of ¹⁴C-labelled proteins by rumen micro-organisms and by proteolytic enzymes prepared from rumen bacteria. *British Journal of Nutrition*, 50(2), pp.345-355.

Wanasundara, U.N., Amarowicz, R. and Shahidi, F., 1995. Partial characterization of natural antioxidants in canola meal. *Food Research International*, 28(6), pp.525-530.

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.; 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.

White, C.L., Young, P., Phillips, N. and Rodehutsord, M., 2000. The effect of dietary protein source and protected methionine (Lactet) on wool growth and microbial protein synthesis in Merino wethers. *Australian Journal of Agricultural Research*, 51(2), pp.173-183.

Williams, S.R.O., Hannah, M.C., Eckard, R.J., Wales, W.J. and Moate, P.J., 2020. Supplementing the diet of dairy cows with fat or tannin reduces methane yield, and additively when fed in combination. *Animal*, 14(Suppl 3), pp.s464-s472.

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.

Wu, D., Xu, L., Tang, S., Guan, L., He, Z., Guan, Y., Tan, Z., Han, X., Zhou, C., Kang, J. and Wang, M., 2016. Influence of oleic acid on rumen fermentation and fatty acid formation in vitro. *PLoS One*, 11(6), p.e0156835.

Wu, W.X., Liu, J.X., Xu, G.Z. and Ye, J.A., 2008. Calcium homeostasis, acid–base balance, and health status in periparturient Holstein cows fed diets with low cation–anion difference. *Livestock Science*, 117(1), pp.7-14.

Yang, W.Z., Xu, L., Li, C. and Beauchemin, K.A., 2013. Effects of supplemental canola meal and various types of distillers' grains on growth performance of backgrounded steers. *Canadian Journal of Animal Science*, 93(2), pp.281-286.



Yoon, B., Jackman, J., Valle-González, E. and Cho, N.J., 2018. Antibacterial free fatty acids and monoglycerides: biological activities, experimental testing, and therapeutic applications. *International Journal of Molecular Sciences*, 19(4), p.1114.

Zimpel, R., Marinho, M.N., Almeida, K.V., Ruiz, A.R., Perdomo, M.C., Poindexter, M.B., Vieira-Neto, A., Arshad, U., Husnain, A., Nelson, C.D. and Santos, J.E.P., 2021. Prepartum level of dietary cation-anion difference fed to nulliparous cows: Acid-base balance, mineral metabolism, and health responses. *Journal of Dairy Science*, 104(12), pp.12580-12599.