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Review Article

Canola Meal as a Feed Ingredient for Lactating Dairy Cows: A Review

Essi Evans[1]*, **Brittany Wood**[2]

[1]*Department of Nutrition, Essi Evans Technical Advisory Services Inc., Bowmanville, ON, Canada;* [2]*Director of Canola Utilization, Canola Council of Canada, Winnipeg, MB, Canada*

ABSTRACT

The objective of this review is to compile the most recent research into the use of canola meal as a feed ingredient for lactating dairy cows. Canola is a relatively new oilseed derived largely from rapeseed and bred to remove the prominent anti nutritional factors found in the oil (erucic acid) and the meal (glucosinolates). Canola meal is the residue remaining after oil extraction and solvent extracted canola meal contains on average 42% crude protein (dry matter basis) and is used primarily as a protein supplement. Canola meal is more fibrous than solvent extracted soybean meal and therefore supplies less energy than soybean meal but a greater rumen escape protein value (% of protein basis) along with an amino acid profile similar to that of milk, making it well suited for lactating dairy cows. Values for the nutrient content and nutrient digestibility are reviewed. Results from early and mid-lactation feeding studies in which canola meal was substituted for soybean meal are summarized. Similarly, findings from mid lactation feeding trials involving other vegetable proteins are given. Recent information regarding the contribution of canola meal to reduce greenhouse gas emissions is provided.

Keywords: Canola meal; Lactating dairy cows; Milk production; Greenhouse gas mitigation

Abbreviations: CM: Canola Meal; DCAD: Dietary Cation-Anion Difference; DDGS: Distillers' Grains and Solubles; DM: Dry Matter; DMI: Dry Matter Intake; NDF: Neutral Detergent Fiber; RUP: Rumen Undegraded Protein

INTRODUCTION

Canola is derived largely from Brassica napus (95%), with the remaining portions from Brassica rapa and Brassica juncea seed [1]. Canola differs from rapeseed by having been bred through traditional plant breeding techniques to contain very low levels of the two most prominent anti nutritional factors erucic acid and glucosinolates. Rapeseed with low levels of these anti nutrients is often referred to as "canola quality" rapeseed, or double low rapeseed. True canola is produced in Canada and Australia. Canola meal and canola-quality rapeseed meals are the residues remaining after the highly prized oil are extracted from seeds. Canola meal, along with its parent crop rapeseed meal, ranks second with respect to protein meals traded globally [1,2]. The nutrient compositions of canola meal from Canada and Australia along with European canola-quality rapeseed meal are provided in Table 1.

Canola meal is a relatively new and evolving ingredient, and the bulk of the relevant research with respect to contemporary dairy production has been conducted in the last 15 years. The purpose of this review is to highlight the true feeding value of canola meal and to dispel misconceptions regarding this meal that persist from earlier research, testing varieties of the meal that are no longer available, and not tested with cows with lower levels of milk production. Most of the research referenced in this review relates to Canadian solvent extracted canola meal.

LITERATURE REVIEW

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, provided dairy cows with diets containing 0, 8, 16 or 24 percent canola meal, replacing soybean meal [3-7]. Dry Matter (DM) intakes increased linearly with canola meal inclusion contributing to greater milk yield (Table 2). Broderick and Faciola replaced 8.7% of soybean meal with 11.7% canola meal [8]. Cows consumed 0.5 kg more DM with the canola meal diet. Substituted 20.8% canola meal in replacement of 13.7% soybean meal, with cows consuming

Correspondence to: Essi Evans, Department of Nutrition, Essi Evans Technical Advisory Services Inc., Bowmanville, ON, Canada, E-mail: essievans@sympatico.ca

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23.6 and 24.0 kg of DM for the two diets, respectively [9]. Fed up to 20% of DM as canola meal to high-producing cows in exchange for high-protein distillers' grains, with no reduction in Dry Matter Intake (DMI) [10]. Three early lactation trials [11-13] noted a one-kg increase in intake when canola meal replaced soybean meal in the diet. Heim and Krebs 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 [1,14].

Protein value of canola meal

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 demonstrated that the amino acid profile of canola meal matched the needs of dairy cows for milk yield (Table 3) and complemented rumen microbial protein to a greater degree than other vegetable proteins [15]. This was recently underscored by Kuehnl and Kalscheur who examined the effect of amino acids in early lactation and showed that the efficiency of amino acid utilization was superior for canola meal [16]. The amino acid composition of the intact meal and the Rumen Undegraded Protein (RUP) fraction of the meal are provided in Table 4. These values were determined by Ross based on the RUP method developed [6,17]. The samples were a subset of a survey of samples obtained between 2011 and 2014 from 13 processing plants across Canada [18-20].

Rumen under graded protein in canola meal: While the amino acid profile contributes greatly to the importance of canola meal in ruminant feeds systems, equally so does the RUP component of the meal. Approximately half of the protein in canola meal is in the form of RUP, an amount greater than that found for solvent extracted soybean meal (Table 5) [5,6,12,21-23].

Table 1: Nutrient composition of Canadian and Australian solvent extracted canola meal and European rapeseed meal (dm basis)[1,2,3].

Item	Canadian	Australian	European
Moisture, %	10.4	10.7	11.0
Crude Protein, %	42.0	41.7	38.1
Rumen escape protein (NRC method) [4], % of protein	43.5	35.0	-
Rumen escape protein (CNCPS method) [2], % of protein	53.0	-	-
Ether Extract, %	3.20	3.80	2.40
Oleic acid, %	1.98		1.17
Linoleic acid, %	0.64	1	0.39
Linolenic acid	0.27	-	0.18
Erucic Acid, %	0	-	0.01
Ash, %	7.30	8.17	7.60
Calcium, %	0.76	0.62	0.86
Phosphorus, %	1.17	1.07	1.27
Acid detergent fibe, %r	19.6	18.3	20.7
Neutral detergent fiber, %	29.0	26.9	31.6
Sinapine, %	1.00	0.88	-
Glucosinolates, umol/g	3.57	1.90	-

Note: [1]Canola meal Feeding Guide [1]; [2]Australian Canola Meal Guide for the Feed Industry [3]; [3]INRAE-CIRAD Feed Tables [4]; [4]Broderick et al [5]; [5]Ross, 2015 [6]

Table 2: Effect of increasing dietary canola meal on dry matter intake[1].

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

Note: [1]Benchaar et al. [7]

Table 3: Milk protein score system used to compare proteins (1.00 = perfect) [1]

		Limiting amino acid		
Protein	**Score**	**1st**	**2nd**	**3rd**
Rumen microbial protein	0.78	Histidine	Leucine	Valine
Fish meal	0.75	Leucine	Tryptophan	Isoleucine
Canola meal	0.68	Isoleucine	Leucine	Lysine
Cottonseed meal	0.46	Methionine	Isoleucine	Lysine
Soybean meal	0.46	Methionine	Valine	Isoleucine
Sunflower meal	0.46	Lysine	Leucine	Methionine
Meat and bone meal	0.43	Tryptophan	Isoleucine	Methionine
Brewers' grains	0.4	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

Note: [1]Shingoethe [15]

Table 4: Essential amino acid composition of canola meal and canola meal RUP fraction as determined by Cornell University using the Ross method[1,2].

	% DM		% Crude Protein	
Amino acid	**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	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	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	4.28

Note: [1]Ross [6] 2 RUP determined to be 52.5% of crude protein

Table 5: The RUP value for canola meal and soybean meal, as determined by newer methods of analysis (% of total protein).

Determined RUP values		
Canola meal	**Soybean meal**	**Reference**
46.3	30.5	[5]
56.3	27	[20]
42.8	31	[21]
52.5	41.5	[22]
52.3	41.5	[6]
41.8	38.3	[23]

The *in-situ* nylon bag method was the standard procedure used to partition feed protein into RUP and Rumen Degraded Protein (RDP fractions) in early studies. The error in this method resides in the fact that soluble protein, along with protein that becomes soluble and leaves the porous bags are presumed to be completely degraded by the microbes in the rumen, and therefore unavailable as an amino acid source for the cow. Indeed, so entrenched is the notion that solubility and degradation are equal, that the recently released NASEM did not update this concept since the last publication where the inaccuracy was mentioned. Errors in estimating how feed proteins are partitioned hamper the ability of feed formulators to ensure nutrient availability to support optimum rumen microbial growth, as well as to accurately determine the amounts of amino acids entering the intestine from microbial and feed ingredient sources [18,19].

The actual rumen degradability of soluble protein is highly variable and has long been described as such. The degradation of protein and amino acids results in the release of ammonia nitrogen in the rumen. Determined that the amount of ammonia generated under in vitro conditions indicated that peptides and amino acids can accumulate [21-24]. The authors clearly 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 [25,26] The two major storage proteins in canola meal are napin, an albumin protein and cruciferin, a globulin protein [27].Both proteins can readily become soluble, with napin highly likely to become soluble under rumen conditions [28]. 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 6 references examples of true degradation rates for the soluble fraction of proteins as determined by Hedqvist and Udén [20]. The soluble protein in canola meal is broken down much more slowly than the soluble protein in the remaining test ingredients except for flax meal, resulting in considerable opportunity for the soluble fraction from canola meal to reach the intestine. Adding to this the fact that soluble protein exits the rumen with the liquid outflow, which is at least twice as fast as the solid turnover rate [29].

Rumen under graded protein in canola meal: Using direct measurement of abomasal nitrogen flow, 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 [30,31]. Results from two feeding trials using urinary purine derivatives to estimate microbial protein yield found no differences in the two sources of protein, while using the same methodology found that the canola meal diet promoted rumen conditions to improve microbial growth [32-34]. Determined that there were no differences in microbial protein yield for soybean meal or canola meal diets in a dual flow fermentation study [35].

In a different experimental model in which heat-treated canola meal was substituted for barley, rumen microbial growth was decreased with higher levels of canola meal. Increasing concentrations of heat-treated canola meal resulted in greater amounts of rumen escape protein and lesser amounts of rumen microbial protein [36]. However, by substituting heat-treated canola meal for barley in the diets the level of available starch needed to support microbial growth was reduced.

Energy value of canola meal

Like most concentrate ingredients, canola meal is a good source of energy, providing nutrients for rumen microbial growth, and supporting animal productivity. In the past, the energy in canola meal has been undervalued and remains in error in many publications mainly resulting from the underestimation of Neutral Detergent Fiber (NDF) digestibility [19,37]. Several popular feed formulation programs use multiples of lignin percentage to discount the digestibility of the cell wall. Using lignin, NRC estimated unavailable NDF in canola meal approached 65%, with the potentially available NDF estimated at 35% [19]. Using a newly developed indigestible NDF assay, 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% [38]. Again, actual digestibility would be lower due to potentially digestible cell wall exiting the rumen before digestion is complete. The recently released NASEM system, which recommends a 48-hour NDF digestibility determination, is more accurate and provides a more realistic energy value than the previous calculation from lignin [18].

Based on the results of a 4-year survey of 12 canola processing plants (144 samples), 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% [39]. In a follow up to this, determined that the calculated Net Energy of Lactation (NE-L) at 3 times maintenance intake would be 1.87 Mcal/kg [40]. These results corroborate with some older studies that show that approximately half of the NDF is truly digested in lactating dairy cows [41,42].

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 that could be associated with the protein sources [43]. Saw no differences in DMI or body condition score when up to 20% canola meal replaced high-protein corn distillers' grains [10]. 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. Built on these newer results, the average energy values for canola meal provided in Table 7.

Table 6: Rates of digestion of the soluble fraction of protein in the rumen for selected ingredients[1].

Vegetable protein	Soluble protein	Rate
	% of total protein	% 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

Note: [1]Hedqvist and Udén [20]

Table 7: Average energy values for solvent extracted and expeller canola meal [1,2].

	Canola meal processing method	
Item	**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)	1.87	2.01
Net Energy Maintenance (NEM)	1.92	2.16
Net Energy of Gain (NEG)	1.27	1.47

Note: [1]Paula et al. [39] [2]Arce-Cordero et al. [40]

Canola fatty acids

Solvent extracted canola meal of Canadian origin 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 bio hydrogenation 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 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). Oilseeds with higher C18:1 concentrations are likely to increase milk fat concentration and yield as well as the C18:1 content of milk indairy cows, compared with oils containing C18:2 [44,45].

He and Armentano added large amounts of vegetable oils (5% of DM) varying in fatty acid composition to the diet of lactating cows [46]. 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, determined that C18:2 was a more potent fatty acid than C18:1 for causing milk fat depression [47]. 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 [48]. The effects on milk fat percentage and milk fat yields were strikingly different for the diets. Milk fat yield was 1.44 kg/cow/day with the high C18:1 diet as compared to 1.31 kg/cow/day for the high C18:2 diets. 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 when provided at normal feeding levels.

Furthermore, the common unsaturated fatty acids (C18:1, C18:2 and C18:3) can interfere with microbial metabolism by destabilizing the cell membrane, increasing the permeability of the membrane [49]. This effect is greatest as the number of double bonds increases (C18:3>C18:2>C18:1).

In contrast, some studies have indicated that rumen digestibility increases with C18:1 added approximately 6.5% canola oil (62% C18:1) into diets for late lactation cows and evaluated ruminal digestibility [50]. As Table 8 shows, rumen digestibility values were greater for the diet to which the canola oil had been added. Prom and Lock found that added oleic acid improved rumen DM and NDF digestibility [51].

The rate of bio hydrogenation of C18:1 has been shown to be lower than the more saturated fatty acids [52] resulting in greater rumen escape of this fatty acid. Unlike other C18 fatty acids, C18:1 has been shown to act as an amphiphilic agent and improve nutrient digestibility [53,54]. Compared diets containing conventional (high C18:2) soybean meal to a genetically modified high C18:1 soybean meal variety [45]. Total tract digestibility was greater with the high C18:1 meal. The only difference in the diets was the composition of the fatty acids. In another study infusing C18:1 into the abomasum improved fatty acid digestibility [55].

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 [56].

Iodine: Cruciferous plants such as canola and rapeseed contain glucosinolates that reduce iodine uptake by the thyroid gland and mammary gland [57]. While levels of glucosinolates are extremely low in current day canola meal and double zero rapeseed meal, several studies have shown that milk iodine concentrations are reduced when these protein sources are provided at higher levels of intake [58,59]. Cows with diets containing 0, 6, 14 or 20% expeller rapeseed meal, which contained a total of 1.07 µ mol/g of glucosinolates [59]. They determined that the proportion of iodine consumed that was transferred to milk was 25, 19, 13 and 10% for the four respective diets. The benefit of this was shown in a study [60]. 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 9) and this would permit the benefits of higher iodine inclusion to be manifested, without producing unacceptable levels of iodine in milk.

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

Erdman and Iwaniukdemonstrated that canola meal, unlike many other grains and protein meals, has a negative DCAD value (-76 mEq/kg DM), which can be beneficial when formulating diets for this parameter, reducing the need for often unpalatable anionic salts [61].

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, vitamin E and carotinoids [62-64].These may contribute to the reduction of free radical compounds and concomitant cellular damage produced by them.

Feeding 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. Evaluated results from 122 studies where supplemental protein was supplied by either soybean meal or canola meal [65]. In all trials, 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.

Using different data selection criteria, compared the effects of replacing vegetable proteins in the diet with the same amount of protein from canola meal [66]. 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.

In a continuation of the previous meta-analysis, compared the response in plasma amino acids to changes in the protein source in the diet [67]. Results from 10 feeding experiments and 21 treatment comparisons were available. 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. The conclusion from this report was canola meal increased the availability of essential amino acids.

Collected data from 37 peer-reviewed manuscripts evaluating the use of canola meal to replace other vegetable protein sources [68]. Mean treatment differences were compared in this analysis. Differences attained significance for all values shown in Table 10.

To incorporate some more recent research findings, conducted a final meta-analysis to compare feeding results from studies limited to those in which canola meal was compared to another protein in full and in part [69]. 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 [70-75].

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 11). All trials showed that cows given canola meal produced greater yields of milk. Feed efficiency values were similar for both protein sources, with one exception where there was a significant advantage for the canola meal diet [11,76-80].

Although there were no differences in feed efficiency in the experiments conducted and showed lower losses in body condition when cows received the diets containing canola meal. Both were large herd studies conducted under actual farm conditions [34,13].

Mid lactation feeding trials: Tables 12 and 13 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, although there have been trials involving other proteins As the results illustrate, canola meal performed as well or better than the alternative meals evaluated for milk production potential in most published studies [81-89].

Table 8: Rumen digestibility of nutrients by cows receiving supplemental canola oil [1].

	Treatment	
Nutrient	**Control**	**Canola oil**
Dry matter intake, Kg/day	14	14.5
Total Fatty Acid intake, g/day	244	1154
	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

Note: [1]Chelikani et al. [50]

Table 9: Effects of feeding canola meal on iodine concentrations in blood serum and milk (ug/L)[1].

Item	Diet iodine concentration, mg/kg DM					
	0.5			2		
Canola meal, % of DM	0	3.9	13.9	0	3.9	13.9
Serum iodine, ug/L	99	142	148	175	251	320
Milk iodine, ug/L	358	289	169	733	524	408

Note: [1]Weiss et al. [60]

Table 10: Meta-analysis of the use of canola meal in diets for dairy cows [68]

Item	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

Note: Moura *et al.* [68]

Table 11: Performance of cows receiving canola meal or soybean meal in early lactation[1].

Trial Length	Inclusion, % of DM		Milk yield, Kg		ECM/DMI[1]		
Weeks	Canola meal	Soybean meal	Canola meal	Soybean meal	Canola meal	Soybean meal	Trial
16	19.4	14.5	56.5	52.3	2.31	2.17	[11]
16	11.9	8.9	54.8	50.1	2.22	2.16	[11]
22	13.0	7.0	44.5	42.3	1.53	1.50	[12]
22	14.3	6.3	51.3	49.6	1.79	1.73	[34][2]
22	14.3	6.3	51.3	49.9	1.79	1.77	[34]
16	16.5	12.1	52.8	50.9	2.18	2.13	[13]

Note: [1]Energy corrected milk/dry matter intake; [2]both soybean meal diets contained 6.5% canola meal. The second soybean meal treatment provided additional methionine.

Table 12: Comparison of milk production (kg) by cows where the major supplemental protein was provided by canola meal or soybean meal.

Protein source			
Canola meal	Soybean meal	Difference	Reference
42.2	40.4	1.8	[7]
41.1	40	1.1	[30]
40.7	39.7	1.0	[70]
39.5	38.5	1	[71]
38.8	38.2	0.6	[8]
31.7	31.7	0	[43]
46	43.7	2.3	[72]
44.5	42.3	2.2	[12]
44.5	44.8	-0.3	[12]
30.2	29.5	0.7	[73]
34.2	35	-0.8	[74]
44.3	41.4	2.9	[75]
43.8	41.1	2.7	[32]
30.9	31.9	-1	[9]
55.7	51.2	4.5	[11]
40.3	39.4	0.9	[76]
44.1	42.9	1.2	[31]
37.2	36.4	0.8	[77]
38.2	37.5	0.7	[78]
51.3	49.6	1.7	[34
51.3	49.9	1.4	[34]
39.4	37.6	1.8	[60]

Table 13: Comparison of milk production (kg) by cows where the major supplemental protein was provided by canola meal or another vegetable protein.

Protein source			
Canola meal	**Cottonseed meal**	**Difference**	**Reference**
41.1	40.5	0.6	[79]
28	27	1	[80]
Canola meal	**Corn DDGS[1]**		
34.9	35.5	-0.6	[81]
31.7	31.2	0.5	[43]
30.9	32.2	-1.3	[22]
35.2	34.3	0.9	[82]
47.9	44.9	3	[10]
Canola meal	**Wheat DDGS**		
40.4	40.2	0.2	[83]
45	45	0	[84]
30.9	30.8	0.1	[22]
43.4	42.4	1	[85]
Canola meal	**Sunflower meal**		
27	26.7	0.3	[86]
26.7	25.1	1.6	[87]
Canola meal	**Brewery grains**		
23.4	22.3	1.1	[88]
Canola meal	**Flax meal**		
27	26.8	0.2	[86]
Canola meal	**Rapeseed meal**		
47.1	45	2.1	[89]
Canola meal	**Expeller SBM**		
43.8	42.6	1.2	[32]
Note: [1]DDGS= distillers' dry grains and solubles			0.5

DISCUSSION

Using canola meal to reduce greenhouse gas emissions

Several recent studies have indicated that canola meal may have application in diets to reduce emissions in lactating Holstein dairy cows and can provide a potentially economical mechanism for lowering enteric methane and output, the two greenhouse gases of greatest importance to livestock production [86,87].

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) or maturity of the animal, as well as level of 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, as is referred to as methane yield. Methane intensity is a measure of methane output/unit of meat or milk produced [88-90].

Table 14 provides results from recent studies where canola meal was used to replace soybean meal as a protein source in experimental rations. Only one trial was available with Jersey cows, and the inclusion of 10.1% CM in that study did not reduce methane output, as determined using the indirect calorimetry method [90]. The results show 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 percent when expressed as grams/day, yield or intensity, respectively [7,32,74,90,93,94].

There are many factors that influence the extent to which enteric methane output is reduced by the inclusion of canola meal in the diet, such as the forage sources or the forage to concentrate ratio. The level of canola meal inclusion appears to be a factor as well. In a recent experiment cows received 16% crude protein diets that varied from 0%-24% canola meal [7]. As Table 4 shows, methane output was reduced as the level of inclusion increased.

Part of the methane reduction value of canola meal can be associated with the lipid profile, which is rich in 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 [91]. 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 revealed that methane was reduced by 2.2% for each 1% addition of lipid to the diet of dairy cows. Similarly, found that dietary lipids reduced methane by 5.6% for each 1% lipid added to diets for beef cattle [92].

The reduction in methane that occurs with the feeding of canola meal is only partially related to the contribution of the lipid fraction determined that when canola, flax or sunflower oil were added to diets already containing canola meal, all supported reduced methane output, demonstrating additivity between the meal and oil fractions [86,93,94]. Furthermore, found that the fermentation of canola meal increases propionate, resulting in less one carbon moieties available to contribute to gas production [95]. 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) determined that tannins can likewise reduce methane, with the effect being additive to the effects of fat [96]. The seed hull of canola is a notable source of tannins (Table 15).

Additionally, canola meal has been shown to reduce nitrous oxide output by dairy cows. Many research papers, as described in two recent meta-analyses have shown that the efficient use of absorbed protein results in lower blood urea nitrogen when compared to other vegetable protein meals [66,69]. Excreted urea nitrogen is rapidly converted to ammonia gas, which can thereby indirectly contribute to atmospheric nitrous oxide. As Table 16 illustrates, urine nitrogen excretion is reduced and milk nitrogen (protein) is elevated as canola meal in the diet is increased [96]. Modifying the level of canola oil in diets containing canola meal did not alter nitrous oxide production [89].

Table 14: Comparison of methane output for diets in which canola meal replaced soybean meal as the primary source of protein.

	Meal		Methane output		
Source [1]	**% of DM**	**ECM, kg**[2]	**g/kg DMI**	**g/kg ECM**	**Reference**
SBM	17	44	19	11.1	[7]
CM	24	46.2	16.6	10	
SBM	15	29.4	24.1	17.8	[93]
CM	20.8	30.7	22.5	15.8	
SBM	10.2	32	17.6	13.8	[74]
CM	13	33.1	15.7	12.2	
SBM	13.6	40.3	17	10.4	[32]
CM	17.1	41.1	15	9.5	
SBM	14.5	55.4	20.3	9.7	[94]
CM	19.4	55.4	18	8.4	
SBM	13.7	31	19.1	10.8	[90]
CM	10.1	31.7	20.5	11.4	

Note: [a]SBM= solvent extracted soybean meal. CM = solvent extracted canola meal [b]ECM = energy corrected milk 17.8

Table 15: Relationship between the level of inclusion of canola meal in the diet and methane output as determined in one study[1].

	Canola meal inclusion level, % of DM			
Item	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/kgECM	12.5	12.0	11.6	11.3

Note: [1]Benchaar et al. [7]

Table 16: 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

Note: [1]Hassanat et al. [97]

CONCLUSION

Feed represents a large part of the cost of dairy production. Selection of ingredients for inclusion in diets for dairy cows therefore requires careful consideration with respect to costs, nutrient delivery and cow performance. The data provided herein should assist nutritionists and feed formulators in determining the advantages or disadvantages of including canola meal in diets for lactating dairy cattle.

DISCLOSURES

Competing interests

The authors have no competing interests.

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Author's contributions

EE Gathered available literature and prepared the first draft. BW revised the manuscript and added information. EE and BW prepared the final draft and approved the final manuscript prior to submission.

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