The True Value of Feeding Canola Meal

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Take Home Messages

- Canola meal (CM) is a highly palatable feed ingredient for dairy cows, and it can be included in dairy cow diets up to 20% of dietary dry matter.
- Cows fed CM as a protein source produce, on average, 1.4 kg/day more milk compared with cows fed other protein sources, and 0.7 kg/d more milk compared with cows fed soybean meal (SBM).
- Newer research shows that CM has a greater content of ruminally-undegradable protein (RUP; bypass protein) than has been previously reported, and CM RUP is at least equal to, if not greater, than that of SBM.
- Compared to other protein sources like SBM, CM is an excellent source of essential amino acids like methionine and histidine.
- Although CM contains greater amounts of fibre compared with other protein sources, recent research shows that the energy value of CM is higher than previously thought because the fibre is more digestible and can provide more energy for milk production.

Introduction

In lactating dairy cows, nitrogen (N) in the form of crude protein (CP) is an important feed nutrient for use in maintenance and productive functions such as milk protein synthesis, and numerous studies have focused on strategies to optimize milk N efficiency (MNE: the quantity of N secreted in milk expressed as a proportion of feed N intake). It is well-established that the type, amount and quality (e.g., true protein vs. non-protein nitrogen) of protein supplements that are included in dairy cow diets are among some of the key factors that can influence MNE, primarily through their effects on ruminal fermentation and the flow of microbial protein to the small intestine (Clark et al., 1992; NRC, 2001; Ipharraguerre and Clark, 2005). Also, protein is one of the most expensive components of dairy cow diets, so poor MNE can be economically costly through higher feed costs. In addition, poor MNE can also result in excessive losses of N into the environment, thus contributing to environmental pollution. Therefore, when formulating dairy cow diets, the choice of protein supplement(s) is an important decision that dairy nutritionists have to make. In western Canada and parts of the U.S., dairy cow diets typically contain canola meal (CM) as the principal source of protein because it is readily available and is a high quality protein supplement (Hickling, 2008; Mulrooney et al., 2009). In most regions of Canada and the U.S., however, soybean meal (SBM) is the principal source of protein in dairy cow diets (Huhtanen et al., 2011; Martineau et al., 2013). Recently, a rapid expansion of the ethanol industry in North America has resulted in large quantities of dried distillers grains with solubles (DDGS) becoming available for feeding dairy cows, with corn DDGS (C-DDGS) and wheat DDGS (W-DDGS; primarily in western Canada) being the major forms of DDGS (Mulroney et al., 2009; Chibisa et al., 2012). There are major differences primarily in CP content, essential amino acid profile, and ruminal degradability of CM, SBM, C-DDGS, and W-DDGS (NRC, 2001; Huhtanen et al., 2011; Maxin et al., 2013a) that might influence the responses of dairy cows when these ingredients are fed as the major sources of protein; thus, many experiments have been conducted to compare lactational performances of dairy cows when CM, SBM, C-DDGS and W-DDGS were fed as the major protein supplements. In meta-analytical studies involving 122 (Huhtanen et al., 2011) and 49 (Martineau et al., 2013) experiments, it was concluded that cows fed CM as the principal source of protein yielded 1.3 to 1.4 kg/d more milk compared to cows fed the other protein sources. These studies suggest that CM might be a superior source of protein for dairy cows compared with SBM, C-DDGS and W-DDGS.

▪ What is Canola Meal (CM)?

The Canola Meal Feeding Guide (2015), published by the Canola Council of Canada, contains excellent information on the origins of canola, solvent-extraction of canola seed to produce edible oil and CM, and the chemical composition of CM, so the reader is referred to that publication for more detailed information. Canola is improved rapeseed that was developed by Canadian researchers in the 1970s from two varieties of rapeseed (*Brassica napus* and *B. campestris*) (Bell, 1984; Canola Meal Feeding Guide, 2015). Original varieties of rapeseed contained high levels of erucic acid, which made rapeseed oil undesirable for human consumption due to the toxic effects of erucic acid. Also, original rapeseed varieties contained high levels of glucosinolates, which made CM unpalatable to livestock and could also result in negative effects on animal health. Canola is also known as “double-zero” or “double-low” rapeseed. Solvent-extraction of canola seed produces edible oil that contains <2% erucic acid, together with CM as a byproduct that contains <30 μmol/g glucosinolates (Canola Meal Feeding Guide, 2015).

Because of its low levels of erucic acid and glucosinolates, canola is now a very important source of food for humans and feed for livestock, and there has been a tremendous increase in the production of canola around the world. In Canada, approximately 20 million acres (or 8 million hectares) are devoted to canola production every year, with the production of canola expanding rapidly from 12,789,000 in 2010/2011 to 17,960,000 metric tonnes in 2013/2014 (Canola Feeding Guide, 2015). During the same period, the production of CM increased from 3,568,000 to 4,034,000 metric tonnes, with approximately 15% of that being used locally in Canada and the remainder being exported, primarily to the U.S. (>95% of exports; Canola Meal Feeding Guide, 2015).

▪ The Nutrient Composition of CM and Other Major Protein Sources

For the proper utilization of different protein supplements in dairy cow diets, it is important to have detailed and reliable information on their nutrient composition that can be used in diet formulation. Various publications and databases (e.g., NRC, 2001) are available that contain detailed information on the nutrient composition of various protein supplements, and perusal of those sources of information indicate that the nutrient composition of protein supplements can be quite variable. This variability can be caused by many factors, including differences in cultivar, growing conditions of the crop (e.g., soil type and level of rainfall), and processing conditions of the seed and meal (Canola Meal Feed Guide, 2015). The nutrient composition of CM, SBM, C-DDGS and W-DDGS are presented in Table 1. For comparative purposes only, it was decided to obtain these data mainly from a single study (Maxin et al., 2013a) that used similar analytical methods to determine the chemical composition of these protein supplements. It should be noted that for some nutrients, data were not reported by Maxin et al. (2013a), so the data for those nutrients were obtained from other sources as indicated in Table 1.

Of the 4 protein supplements, SBM contains the highest CP level, whereas CM, C-DDGS and W-DDGS are similar (Table 1). The CP contents that are reported by Maxin et al. (2013a) are in agreement with values that have been published by others (NRC, 2001; Canola Meal Feed Guide, 2015). According to the Canola Meal Feeding Guide (2015), the CP content of CM can range from 36 to 39%, with the variability being attributed to yearly variation in growing conditions of canola. For soluble CP content (expressed as a % of CP), CM, SBM and W-DDGS are comparable (mean = 28.6%), whereas C-DDGS has a much lower soluble CP content compared with the other 3 protein sources (Table 1).

Table 1. Nutrient composition of common protein supplements fed to cows[1]

	Protein supplement[2]			
Item[3]	CM	SBM	C-DDGS	W-DDGS
CP, % of DM	40.1	53.6	40.3	37.2
Soluble CP, % of CP	25.3	31.0	12.0	29.5
NDICP, % of CP	16.7	4.0	8.8	9.1
ADICP, % of CP	7.7	1.5	10.1	8.8
RUP, % of CP				
NDF, % of DM	31.9	9.5	26.2	27.9
ADF, % of DM	22.5	6.4	13.5	14.6
Ether extract, % of DM	3.6	1.5	4.0	5.6
Starch, % of DM	1.6	1.5	7.0	3.4
Ash, % of DM	8.0	6.9	3.5	6.2
Calcium, % of DM	0.65	0.40	0.22	0.10
Phosphorus, % of DM	0.99	0.71	0.83	0.96
Essential AA, % of CP				
Arginine	6.62	7.32	4.06	1.48
Histidine	2.54	2.55	2.53	2.21
Isoleucine	3.72	3.89	3.77	3.61
Leucine	6.78	7.52	12.83	7.27
Lysine	4.88	5.91	2.72	2.53
Methionine	2.32	1.55	2.26	2.10
Cysteine	2.29	1.50	1.86	0.34
Phenylalanine	3.95	5.02	5.17	4.77
Threonine	4.40	4.07	3.81	3.37
Tryptophan	1.33	1.26	0.87	0.40
Valine	4.35	3.76	4.26	4.07
Total essential AA	43.2	44.4	44.1	32.2

[1]Data on nutrient composition were obtained from Maxin et al. (2013). Nutrient composition data for C-DDGS are for high-protein C-DDGS. For Ca, P, arginine, cysteine, and tryptophan, data for CM were obtained from the Canola Meal Feeding Guide (2015), those for SBM and C-DDGS were obtained from NRC (2001), and those for W-DDGS were obtained from the Wheat DDGS Feed Guide (2013).
[2]CM = canola meal; SBM = soybean meal; C-DDGS corn-based distillers grains with solubles; and W-DDGS = wheat-based distillers grains with solubles.
[3]CP = crude protein; DM = dry matter; NDICP = neutral detergent insoluble crude protein; ADICP = acid detergent insoluble crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; and AA = amino acids.

Neutral detergent insoluble crude protein (NDICP) is the component of the CP that is associated with the residue remaining after performing neutral detergent fibre (NDF) analysis, and it estimates the portion of the ruminally-undegradable protein (RUP; which is commonly referred to as bypass protein and represents that portion of dietary protein that escapes degradation in the rumen) that is potentially available to the animal (NRC, 2001). In the study by Maxin et al. (2013a), the NDICP (% of CP) for the 4 protein supplements was quite variable (Table 1), with SBM having the lowest value (4.0%) and CM having the highest value (16.7%). These data suggest that CM potentially has a greater RUP fraction than the other 3 protein sources. The implications of these differences in RUP fractions will be discussed elsewhere in this paper. Feed contents of acid detergent insoluble crude protein (ADICP) varied from 1.5% for SBM to 10.1% for C-DDGS, with CM having an intermediate value (7.7%). The ADICP is the CP fraction of feedstuffs that is bound to the acid detergent fibre (ADF) fraction, and it represents protein that has been heat-damaged. Heat damage makes the protein largely indigestible in the rumen and post-ruminally; thus, it is unavailable to the animal and is recovered in the feces (NRC, 2001). The NDF (31.9%) and ADF (22.5%) values for CM that were reported by Maxin et al. (2013a; Table 1) were greater than those reported for the other protein sources. Based on a larger number of samples that were analyzed over 3 years, the Canola Meal Feeding Guide (2015) reported NDF and ADF values of 25.4 and 16.2%, respectively. For the ether extract (EE) fraction, values ranged from 1.5% for SBM to 5.6% for W-DDGS (Maxin et al., 2013a; Table 1). According to the Canola Meal Feeding Guide (2015), the EE content of Canadian CM is typically 3.5%, which is greater than the 1 to 2% EE that is contained in CM and rapeseed meals that are produced in other parts of the world. The greater EE content of locally-produced CM can be attributed to the canola gums (that contain variable amounts of glycolipids, phospholipids, triacylgycerols, fatty acids etc.) that are added to CM at inclusion levels of 1 to 2% during the production process of CM (Canola Meal Feeding Guide, 2015).

Maximizing the intestinal supply of metabolizable protein is important for high-producing dairy cows as this will dictate the extent of milk protein synthesis (NRC, 2001; Ipharraguerre and Clark, 2005). Metabolizable protein is composed of microbial protein and RUP. Although ruminally-synthesized microbial protein is the major component of metabolizable protein, the contribution of RUP to the intestinal supply of essential amino acids (EAA) is also important in meeting animal requirements (NRC, 2001). Of the EAA, lysine and methionine are considered the two most limiting for milk and milk protein synthesis on a wide variety of diets that are typically fed to dairy cows in North America (Schwab et al., 1992), so the major challenge when feeding dairy cows is to ensure that sufficient amounts of these EAA are provided for intestinal absorption. Both SBM (5.91% of CP) and CM (4.88%) had greater contents of lysine compared with C-DDGS (2.72%) and W-DDGS (2.53%; Table 1). It should be noted that the lysine content for CM reported by Maxin et al. (2013a) is lower (5.95% of CP) than that reported in the Canola Meal Feeding Guide (2015). For methionine, SBM (1.55%) had the lowest content, with the other 3 protein sources being comparable (mean = 2.23%; Maxin et al., 2013a). For cows fed grass silage-based diets, Kim et al. (1999) and Vanhatalo et al. (1999) postulated that histidine was the most limiting EAA for milk production. Recently, Lee et al. (2012) postulated that, for cows fed corn silage- and alfalfa haylage-based diets, histidine might be the most limiting EAA. Based on the study by Maxin et al. (2013a), CM, SBM and C-DDGS contained similar amounts of histidine (mean = 2.54% of CP) and this was greater than for W-DDGS (2.21%). It should be noted, however, that the histidine content for CM (2.54%) reported by Maxin et al. (2013a) is lower than that (3.39%) reported in the Canola Meal Feed Guide (2015). Some of these differences in EAA content among protein sources could partly account for the observed differences in milk and milk protein production in dairy cows fed these feedstuffs as the major source of protein.

▪ Responses in Milk Production to Dietary Inclusion of Canola Meal

Canola meal is a common ingredient in dairy cow diets that are typically fed in western Canada and parts of the USA, primarily because CM is readily available and is considered to be a high quality protein supplement (Hickling, 2008; Mulrooney et al., 2009). When included in the diet, CM is a highly palatable feed ingredient for dairy cows, and the available research indicates that dietary inclusion levels for CM can be as high as 20%, while maintaining (or even increasing) feed intake (Canola Meal Feeding Guide, 2015). As indicated below, the dietary inclusion of CM as a replacement for other protein sources like SBM can actually promote greater feed intakes (Huhtanen et al., 2011; Martineau et al., 2013; Broderick et al., 2015). Based on numerous feeding experiments that have evaluated the feeding value of various protein sources, it appears that cows fed CM produce more milk compared with those fed other protein sources (Brito and Broderick, 2007; Huhtanen et al., 2011; Martineau et al., 2013; Broderick et al., 2015; Mutsvangwa et al., 2016).

Brito and Broderick (2007) examined the effects of feeding supplemental protein as urea, SBM, cottonseed meal (CSM), or CM on milk production and nutrient utilization. The choice of SBM, CSM, and CM was based on the fact that these protein supplements differ markedly in their RUP and EAA contents. Feed intakes and levels of milk production were greater when true protein supplements (SBM, CSM, and CM) replaced urea, but there were no differences in feed intake, milk yield, and fat-corrected milk yield (FCM) among cows receiving true supplemental protein sources; however, cows fed CM produced numerically more milk (+1.7 to +2.1 kg/day) compared with cows fed SBM and CSM. In a follow-up study, Broderick et al. (2015) compared CM and SBM at 15 and 17% total dietary CP to determine animal responses to incremental dietary CP levels with the 2 protein sources. Cows fed CM had a greater feed intake (+0.4 kg/day) and produced more milk (+1.0 kg/day) and energy-corrected milk (ECM; +1.0 kg/day) compared with cows fed SBM (Table 2).

Table 2. Production responses to the substitution of canola meal (CM) for other protein sources in dairy cow diets

	Protein source			
Item[1]	CM	Other	Response	*P* value
Broderick et al. (2015)[2]				
DMI, kg/d	25.2	24.8	+0.4	0.05
Milk yield, kg/d	40.3	39.3	+1.0	<0.01
ECM yield, kg/d	39.5	38.5	+1.0	0.04
True protein (TP), %	3.06	3.04	+0.02	0.51
TP yield, kg/d	1.22	1.19	+0.03	0.02
MUN, mg/dL	10.3	11.5	-1.2	<0.01
Moore and Kalscheur (2016)[2]				
DMI, kg/d	25.8	25.0	+0.8	0.09
Milk yield, kg/d	55.7	51.2	+4.5	<0.01
ECM yield, kg/d	57.6	53.6	+4.0	<0.01
MUN, mg/dL	10.9	11.4	-0.5	0.10
Mutsvangwa et al. (2016)[3]				
DMI, kg/d	31.1	31.6	-0.5	0.23
Milk yield, kg/d	43.7	42.6	+1.1	0.35
3.5% FCM yield, kg/d	43.4	42.4	+1.0	0.28
Protein, %	3.24	3.24	-	0.97
Protein yield, kg/d	1.41	1.38	+0.03	0.42
MUN, mg/dL	17.5	17.1	+0.4	0.46

[1]DMI = dry matter intake; ECM = energy-corrected milk; MUN = milk urea-nitrogen; FCM = fact-corrected milk.
[2]For these studies, canola meal was compared with soybean meal (SBM).
[3]For this study, canola meal was compared with wheat-based dried distillers grains with solubles (W-DDGS).

A recently-completed study at the University of Wisconsin-Madison (Moore and Kalscheur et al., 2016) compared CM and SBM as major protein sources in diets fed to early-lactating cows at 15.4 and 17.6% dietary CP (Table 2). Cows fed CM tended to have greater feed intake (+0.8 kg/day) than those fed SBM; what was more dramatic were the responses in milk yield, as cows fed

CM had greater actual milk yield (+4.5 kg/day) and energy-corrected milk yield (+4.0 kg/day) compared with those fed SBM (Moore and Kalscheur, 2016).

In western Canada, major growth of the ethanol industry has resulted in large quantities of W-DDGS being available as an alternative protein supplement for dairy cows. Because W-DDGS is usually cheaper than CM (Mutsvangwa et al., 2016), dairy nutritionists have become interested in the relative feeding values of CM and W-DDGS as protein sources. For this reason, my research group at the University of Saskatchewan has conducted experiments with dairy cows to compare production and metabolic responses in dairy cows fed CM or W-DDGS as the major protein sources (Chibisa et al., 2012; Mutsvangwa et al., 2015). In one study (Mutsvangwa et al., 2016) to determine animal responses to incremental dietary CP levels, we evaluated CM and W-DDGS at 15 and 17% dietary CP. Our results (Table 2) indicated that feed intake was unaffected by the source of dietary protein. Although milk production was not statistically different when CM or W-DDGS were fed as protein sources, it was noteworthy that cows fed CM produced numerically more milk (+1.1 kg/day) compared with those fed W-DDGS.

In an effort to obtain a better understanding of how cows respond in terms of milk production and other parameters when CM substitutes for other protein sources, various research groups (Huhtanen et al., 2011; Martineau et al., 2013) have recently conducted meta-analytical studies. With this meta-analysis approach, statistical procedures are used to combine the results of multiple feeding experiments in which supplemental protein sources have been compared. A major benefit of meta-analysis is the aggregation of information from multiple studies into a large dataset, thus leading to a higher statistical power and more robust conclusions than can be obtained from any single study. Huhtanen et al. (2011) combined data from 122 studies that compared CM and SBM as protein sources, and concluded that milk yield increased by 3.4 kg/day for every 1 kg/day increase in CP intake when CM was the source of dietary protein, whereas the increase in milk yield with SBM was only 2.1 kg/day. Martineau et al. (2013) combined information from 49 experiments that compared CM with other protein sources, with dietary inclusion levels for CM ranging from 1 to 4 kg/day (mean = 2.3 kg/day). Overall, that meta-analysis demonstrated that cows fed CM produced 1.4 kg/day more milk compared with cows fed other protein sources; however, the response in milk yield when CM was compared with SBM was smaller at +0.7 kg/day (Martineau et al., 2013). These studies clearly indicate a production advantage when CM replaces other protein sources in dairy cow diets, so the question is, what mechanisms are responsible for this response?

▪ How Does Canola Meal Increase Milk Production When It substitutes for Other Protein Sources in Dairy Cow Diets?

Greater Feed Intake with Canola Meal

It appears that the positive responses in milk production when CM replaces other protein sources in dairy cow diets can be partly attributed to greater feed intakes with CM. Various studies (Vanhatalo et al., 2003; Brito and Broderick, 2007; Broderick et al., 2015) reported greater feed intakes when CM replaced other protein sources, including SBM. Based on a meta-analysis of numerous published studies, Huhtanen et al. (2011) and Martineau et al. (2013) concluded that CM stimulated greater feed intake compared with other commonly-used protein sources. In general, milk yield is positively correlated to DM intake (NRC, 2001), so the greater feed intake in cows fed CM is partly the mechanism that is responsible for the improved milk yields.

Greater RUP and Amino Acid Supply with Canola Meal

The substitution of CM for other protein sources in dairy cow diets has improved milk production, and milk protein content and yield (Huhtanen et al., 2011; Martineau et al., 2013). Huhtanen et al. (2011) suggested that these positive responses could be partly attributed to a greater supply of EAA at the small intestine or the supply of metabolizable protein that has an EAA profile that closely matches that of milk. The contribution of CM to RUP flow and its EAA profile is an area that has received research attention in recent years. For a variety of reasons, protein sources vary in their rates and extents of ruminal degradation; consequently, the RUP content of protein sources will vary. Most models that are based on data from older studies (e.g., NRC, 2001) assign a lower RUP value to CM compared with other protein sources like SBM. Part of the reason for this is that CM has a high soluble protein fraction (designated fraction A in these models) compared with other protein sources, and the soluble protein fraction was assumed to be completely degraded in the rumen with rates of degradation ranging from 100 to 500%/hr. However, Hedqvist and Udén (2006) demonstrated that, for various proteinaceous feedstuffs, the in vitro degradability of the A (soluble) fraction varied tremendously, and that as much as 56% of CM fraction A can escape ruminal degradation and contribute to RUP reaching the small intestine. Using in vitro methodologies, 56% (Hedqvist and Udén, 2006), 63% (Bach et al., 2008), and 57% (Stefanski et al., 2013) of the soluble fraction of CM was demonstrated to escape ruminal degradation. Using the newer in vitro methodologies (rather than the in situ technique) to determine the RUP values of CM and SBM, more recent experiments have provided evidence that the RUP value of CM was greater or at least comparable to that SBM. In an in vivo study (Brito et al., 2007) that compared urea, SBM, CSM and CM as protein sources for cows, RUP values for SBM, CM and CSM were estimated to be 29, 34, and 51%, respectively, with no statistical difference between CM and SBM.

Another major factor that might influence animal responses to source of dietary protein is the profile of EAA flowing to the duodenum. It is well-established that the profile of EAA reaching the duodenum should closely match that of milk protein in order to positively influence milk production in dairy cows (NRC, 2001). Protein sources like CM and SBM differ in their EAA content, so these differences could influence the EAA profile of RUP fraction that escapes ruminal degradation. Although not statistically different, omasal flows of lysine, methionine, and histidine (which are EAA that are often referred to as limiting for milk protein synthesis in dairy cows) were numerically greater in cows fed CM compared with those fed SBM (Brito et al., 2007). At the University of Saskatchewan, we compared CM and W-DDGS as protein sources (Mutsvangwa et al., 2016) and observed that omasal flows of EAA such as lysine (+20 g/d), histidine (+13 g/d), threonine (+24 g/d), and tryptophan (+5 g/d) were greater in cows fed CM compared with those fed W-DDGS. Maxin et al. (2013b) showed that cows fed CM exhibited the greatest plasma concentrations of most EAA compared with cows fed SBM or DDGS, suggesting that the post-ruminal supply of EAA in digestible RUP was greatest with CM. The greater post-ruminal flow of EAA with CM could supply more substrate for milk protein synthesis and, overall, milk production.

Greater Fibre Digestibility with Canola Meal

The true value of CM might also be underestimated in terms of its NE_L value for dairy cows. This underestimation arises from unreliable estimates of the digestibility of NDF from CM that are then used to calculate the energy value of CM by older models such as the NRC (2001) and CNCPS (Tylutki et al., 2008). Canola meal contains relatively high amounts of NDF (25.4 to 31.9%; Maxin et al., 2013a; Canola Meal Feeding Guide, 2015), with a lignin content of 5.8 to 6.6% (Canola Meal Feeding Guide, 2015). Generally, lignin content is negatively associated with NDF digestibility; as a result, older models like NRC (2001) estimated the indigestible NDF (iNDF) content of feedstuffs using the lignin content as acid-detergent lignin (ADL) x 2.4/NDF (NRC, 2001). The suitability of this approach for calculating iNDF in non-forage fibre and/or by-product feeds has been questioned (Cotanch et al., 2014). Recently, the Cornell group and others have determined iNDF contents in non-forage fibre and/or by-product feeds using a modified in vitro Tilley and Terry system (Raffrenato and Van Amburgh, 2010) that requires up to 240 h of incubation (Cotanch et al., 2014). Using this newer approach, Cotanch et al. (2014) determined that the iNDF content of CM was 42% (as a % of total NDF), whereas it was 81% when using the ADL x 2.4/NDF equation, thus suggesting that the older method of estimating iNDF grossly overestimated the iNDF content of CM. With greater NDF digestibility of CM based on the newer methods, it appears that the energy value of CM is greater than what would be predicted by older models like NRC (2001), which could partly explain the greater milk production of cows fed CM compared with other protein sources.

▪ Summary

A preponderance of the available research indicates that CM can be included in dairy cow diets up to 20% of dietary dry matter as a replacement for other protein sources like SBM without any negative effects on feed intake and milk production. In fact, a meta-analysis of available research indicates that cows fed CM consume more feed and produce more milk compared with cows fed other protein sources. Besides the greater feed intake, the positive response in milk production can be attributed to a greater RUP value for CM, a more balanced EAA profile of the RUP fraction, and a greater energy value for CM than was previously thought.

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