

FEEDING VARIOUS FAT SOURCES TO LACTATING DAIRY COWS AND THEIR EFFECTS ON MILK QUALITY

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INTRODUCTION

Adding fat to dairy rations can affect productive efficiency of dairy cows through a combination of caloric and noncaloric effects. Caloric effects are attributable to greater energy content and energetic efficiency for lipid compared to carbohydrate or protein with the overall benefit being increased milk production. Noncaloric effects are caused by benefits from added fat that are not directly attributable to its energy content or increased milk production. Examples of proposed noncaloric effects include improved reproductive performance, and altered fatty acid profile of milk.

Noncaloric benefits related to milk quality are emphasized in this paper. The effects of fat supplements on milk components, including protein and fat percentages, have been detailed in previous conferences and publications. Therefore, this paper will focus on changes in milk fatty acid composition including what types of changes are regarded as most beneficial and what fat supplements are best suited to achieve these desirable modifications.

FAT SOURCES AND THEIR CHARACTERISTICS

Classification of Fat Sources

A useful way to classify fat supplements for dairy rations is based on their expected rumen response. Terminology varies widely for classifying fat sources according to nutritional effects, but most groupings consider the extent that a fat source depresses digestibility of the basal feed ingredients and the extent that the fat source resists biohydrogenation. On this basis, fats can be classified as rumen-active, rumen-inert, or protected.

Rumen-inert fats. The term “rumen-inert” has been assigned to fats that were specifically designed to have little, if any, negative effect on feed digestibility when fed to dairy cattle. Rumen-inert fats often have the added advantage of being dry fats that are easily transported and can be mixed into the diet without the need for specialized equipment. Rumen-inert fats are often high in calcium salts of fatty acids, saturated fatty acids, or hydrogenated fats. Fats in this category have also been referred to as “bypass” fats.

Rumen-active fats. The “rumen-active” fats have the potential to interfere with microbial fermentation in the rumen and reduce feed digestibility to varying degrees. Digestibility of the fibrous carbohydrate fraction is especially susceptible to antimicrobial effects of rumen-active fats. Generally, unsaturated fatty acids depress fiber digestibility more than saturated fatty acids. Rumen-active fats include fats of animal origin (tallow, grease, etc), plant oils (soybean oil, canola oil, etc), oilseeds (cottonseeds, soybeans, etc), and high fat byproducts such as residues from food processing plants. Rumen-active fats undergo biohydrogenation by ruminal microbes and generally have little impact on modifying milk fatty acid profile.

Protected fats. The term “protected fat” is most applicable to fat sources specifically designed to resist biohydrogenation by ruminal microbes and modify fatty acid profile of body tissues and milk. Many of the protected fats are based on surrounding unsaturated fatty acids by a protective capsule, such as formaldehyde-treated proteins, that act to shield the internal fatty acids from biohydrogenation. Another strategy for protection is chemical modification of unsaturated fatty acids to chemical forms that resist biohydrogenation, such as calcium salts of fatty acids or fatty amides.

A single fat source may overlap two, or even all three fat groups to some extent. For example, at normal levels of supplementation, some rumen-active fats, such as tallow, are fed to dairy cows without evidence of consistent problems with fiber digestion. Even whole oilseeds help to lessen the severity of digestion problems by encapsulation of antimicrobial fatty acids within their hard outer seed coat. However, classification according to ruminal digestion is better defined at high levels of supplementation, where the frequency of digestibility problems for tallow and oilseeds is much greater than for the rumen-inert fats. The oilseeds may also overlap as protected fats in instances where their hard outer seed coat provides protection from biohydrogenation. However, disruption of the outer seed coat by chewing and rumination often leads to oilseeds having little ability to enhance unsaturated fatty acids in milk.

Energy Values of Fat Supplements

The energy value of fat supplements is determined almost exclusively by the type and amount of fatty acid present in the supplement. Most fat supplements are comprised of different proportions of 5-8 common fatty acids all of which have similar energy values (approximately 9.4 kcal/g). Therefore, fatty acid content (g fatty acid/100 g fat supplement) is much more important than fatty acid composition (g fatty acid/100 g total fatty acids) in determining GE value of the supplement.

Fat supplements can be diluted by nonfatty acid components that have lower or no energy value. Fat content has traditionally been determined as the ether-extractable component of the feed. When defined in this manner, there can be considerable variation in lipid content among feed fats. Among the lowest is the ether extract in grains and forages. In addition to extracting fat, ether also extracts some carbohydrate, vitamins, and pigments. Therefore, fatty acids in corn grain is only 65% of the ether extract, and in alfalfa hay is only 40% of the ether extract (Palmquist and Jenkins, 1980). Because of the problems inherent with ether extract, many laboratories have moved to determining fatty acid content of feeds by gas chromatography instead of by ether extract.

With only a few exceptions, fats of plant and animal origin contain 100% ether extract with a high percentage (usually 90 to 100%) of fatty acids. The impurities extracted, such as water and pigments, are removed during refining leaving the commercial plant (soybean oil, canola oil, corn oil, etc) and animal (tallow, grease, etc) fats with mainly triglycerides consisting of 90-93% fatty acids. The remaining 7-10% is referred to as unsaponifiables and is mainly glycerol. Glycerol is readily utilized as an energy source, but only contains the energy of carbohydrates. Caution is advised when obtaining fats from unknown vendors to be sure that considerable impurities do not still remain in the product that lower the fatty acid and energy content. Rather than guessing, it pays to have a sample of the fat analyzed for fatty acid content and profile.

Fat Sources and Ruminal Fermentation

Fatty acids, especially unsaturated fatty acids, are antimicrobial and interfere with normal function of the ruminal microbes. As a result, fiber digestion can be depressed by added fat. The depression can be serious enough that much of the extra energy from the fat supplement can be offset by increased excretion of fiber energy in the feces. As an illustration, a reasonable intake of digestible energy for cows consuming 55 lb/day (DM basis) of a typical lactation ration is 77 Mcal/day. If 3% of this ration is replaced with fat, intake of digestible energy increases to 80 Mcal/day if energy digestibility remains constant at 67.5% for both diets. However, fat only needs to reduce energy digestibility just three percentage units (from 67.5% to 64.6%) in this example and the energy benefit of the added fat is lost.

Feeding fat reduces fiber digestion by inhibiting microbial fermentation in the rumen. Fiber is also a major energy source for milk production provided that ruminal microbes ferment it to energy substrates that can be used by the mammary gland. If the ability of the microorganisms to ferment fiber is inhibited by fat, then fiber energy is lost in feces. This is illustrated by an experiment that infused 0, 13, 26, and 40 ml oil per day into the rumen of sheep resulting in fiber digestibilities in the rumen of 44, 28, 18 and 14%, respectively (Ikwuegbu and Sutton, 1982). The fiber digestibility depression in the whole digestive tract is often less severe due to some limited hindgut fermentation. Depression of fiber digestion is most severe for fat sources high in unsaturated fatty acids, which inhibit growth and function of ruminal microbes more than saturated fatty acids (Jenkins, 1993). The exact mechanism of how fat interferes with microbial fermentation is not known but believed to result from either coating of feed particles or a direct toxic effect on the ruminal microorganisms.

Digestibility of Fat Sources

Reduced digestibility of fatty acids is generally attributable to the nature of its fatty acid composition. Under certain circumstances, digestibility can be lower for saturated fatty acids than for unsaturated fatty acids. Firkins and Eastridge (1994) showed that iodine values (IV) that were 50 or above had little effect on fatty acid digestibility. However, digestibility declined as IV declined below 50, especially as IV dropped from 27 to 11. To confirm this relationship, several digestibility studies with lactating cows were summarized to determine true fatty acid digestibilities for fats greater and less than 40 IV. True fatty acid digestibilities were determined from the slopes relating fatty acid digested to fatty acids consumed. At low fatty acid intakes, true fatty acid digestibilities were 89% and 74% for fats with IV >40 and <40, respectively. However, fatty acid digestibility declined more with increasing intake for fatty acids having IV >40.

Fats with low IV have increased in popularity because their high saturated fatty acid content cause fewer problems with ruminal fermentation and digestion. However, fatty acid digestibility in the small intestine can be compromised if the fats become too hard. When yellow grease was fully hydrogenated, digestibility by lactating Holstein cows declined from 67.8 to 47.4% (Jenkins and Jenny, 1989). Partial hydrogenation of tallow also was shown to reduce fatty acid digestibility (Eastridge and Firkins, 1991). Among the saturated fatty acids, beneficial effects of higher C₁₆:C₁₈ ratio were reported for fatty acid digestibility (Firkins and Eastridge, 1994). Similar observations were reported by Weisbjerg et al. (1992), where fatty acid digestibilities of a stearic acid-rich supplement were lower than a palmitic acid-rich supplement at two levels of intake.

Based on a compilation of results from published studies done by Moate et al. (2000), the true intestinal digestibility of individual fatty acids varied from 70 to 90% in ruminants. Stearic acid had lower digestibility in the intestines than unsaturated fatty acids. However, appreciable flow of stearic acid to the duodenum of dairy cows occurs regardless of the quantity of stearic acid consumed (Jenkins, 1999). Fatty acid digestibility in the intestines was appreciably lower and more variable when duodenal flow of stearic acid exceeded 400 g/day.

Simple energy calculations illustrate that the failure of fat supplements to increase DE consumed can be caused by dramatic reductions in fatty acid digestibility, or much smaller reductions in feed intake or digestibility of the basal feed ingredients. The latter occur more often and probably are the major reasons why fat supplements fail to increase milk yield in most situations. For these reasons, improving production responses to added fat should continue to consider digestibility of the fat supplement, but focus most attention on the impact of the fat supplement on intake and utilization of the basal ration.

FAT SOURCES AND MILK COMPOSITION

Milk Components

Unsaturated oils cause milk fat depression (MFD) when fed to lactating dairy cows. Strong evidence in recent years points to their interference with fatty acid biohydrogenation as the likely cause of the MFD. Specifically, they block terminal steps of ruminal biohydrogenation which leads to the accumulation of trans fatty acid intermediates that were shown to cause MFD.

For instance, Gaynor et al. (1994) infused *cis* fat, composed of 65% high oleic sunflower oil and 35% cocoa butter, or *trans* fat, composed of 93% shortening and 7% corn oil, into the abomasum of lactating dairy cows. Milk yield was not changed, however, milk fat percentage and milk fat yield were lower for the *trans* treatment. Similarly, Romo et al. (1996) infused into the intestines of cattle either a fat mixture high in *cis*-C_{18:1} isomers or a mixture high in *trans*-C_{18:1} isomers. Only the *trans*-C_{18:1} treatment resulted in reduced milk fat content. Others followed with similar dairy cattle studies showing marked depressions in milk fat content during abomasal infusion of *trans* fatty acids (Chouinard et al., 1999; Loores and Herbein, 1998).

Recent studies have reported that not all *trans* fatty acid isomers are responsible for the MFD noted previously. When various combinations of fat and fiber were fed to dairy cattle to cause MFD, the treatments causing the greatest decline in milk fat were accompanied by larger increases in *trans*-10 than any other positional isomers (Griinari et al., 1998). Baumgard et al. (2000) provided more direct evidence that *trans*-10 fatty acids were the positional isomers most responsible for milk fat depression in dairy cows. When they infused either *cis*-9, *trans*-11 or *trans*-10, *cis* 12 CLA post-ruminally into dairy cows, only the *trans*-10, *cis*-12 isomer led to significant milk fat depression. With the recent discovery that *trans* fatty acids, and particularly the *trans*-10 positional isomers, have the greatest potency as fat inhibitors, comes questions about the source of *trans*-10 fatty acids and the prospects of enhancing their production in ruminants.

Manufacturing Properties of Milk.

The hardness of milk fat has long been a concern of the dairy industry. Some applications require reducing hardness such as improving the spreadability of butter. Other applications are geared toward increasing hardness such as producing cheeses more desirable for grating.

Hardness is determined by fatty acid composition of the milk fat and the molecular distribution of fatty acids on the triglyceride (Ashes et al., 1997). Processing technologies to alter milk fatty acid composition and distribution are currently being examined, but are hampered by high cost and sometimes complicated, lengthy procedures. An alternative to processing strategies is to utilize feeding, breeding, and environmental factors that influence the composition of milk.

Fatty Acid Nutraceuticals

Diet-conscience consumers continue to make food selections that are driven by concerns about fat content and quality. Preference is usually given to foods that are low in fat, cholesterol, and saturated fatty acids. While the relationship between saturated fatty acid intake and human health risks are unresolved, medical and nutritional advice to consumers is to limit their intake of saturated fatty acids from dairy products. Choices are now available for milk products that vary widely in fat content, but commercial products with reduced saturation have not been developed.

A typical fatty acid composition of milk fat is 70-80% saturated and 20-30% unsaturated. Of the unsaturated fatty acids, the majority (>70%) is oleic acid, which is monounsaturated. The ideal milk fatty acid composition according to members of a Milk Fat Round Table discussion sponsored by the Wisconsin Milk Marketing Board (O'Donnell, 1989) was less than 10% polyunsaturated fatty acids, up to 8% saturated fatty acids, and the remainder (82%) monounsaturated fatty acids.

Conjugated linoleic acid (CLA) is a group of fatty acid isomers that were identified in the last 5 to 10 years as potent antioxidants, anticarcinogens, modulators in the immune system, anti-atherosclerosis agents, and body weight protectors. Meat and dairy products from cattle and sheep are important dietary sources of CLA. Isomerization of linoleic and linolenic acids to CLA occurs through a biohydrogenation process carried on by gut microorganisms within the rumen of the cow. Most attempts to increase CLA in meat and milk are focused on interrupting the completion of biohydrogenation, which leads to accumulation of trans fatty acid intermediates including CLA. Feeding high grain diets or diets with added fat will increase CLA content of meat and milk, but are limited in their use because of their potential to reduce production and cause metabolic disease when fed in high quantity.

Protected Fats and Their Ability to Alter Milk Fatty Acid Composition

Probably the most widely known fat developed to resist biohydrogenation and increase milk polyunsaturated fatty acid levels was formaldehyde-treated lipid. This product consisted of polyunsaturated lipid droplets encapsulated with a formaldehyde protected protein source, such as casein. Polyunsaturated fatty acid levels in tissues of cattle and sheep were significantly elevated by feeding formaldehyde-treated lipid (Faichney et al., 1972; Cook et al., 1972; Faichney et al., 1973). Milk unsaturated fatty acids also increased when formaldehyde-treated lipid was fed to lactating cows. Milk linoleic acid content increased from 3 to 30% of total fatty acids during feeding of the protected supplement, then quickly returned to normal when the supplement was withdrawn (Cook et al., 1972). Formaldehyde-protected canola seed increased yield of monounsaturated and polyunsaturated fatty acids in milk by 54% in a study by Ashes et al. (1992). However, the protected canola in the Ashes et al. (1992) study was compared to a control diet with no added fat and not a diet containing an equal amount of unprotected canola oil or whole canola seed. Commercial application of formaldehyde-protected lipids was never

achieved in the United States, undoubtedly due in large part to health risks associated with the use of formaldehyde.

Feeding whole oilseeds (i.e. whole soybeans, whole cottonseeds, whole sunflower seeds, etc) to cows increases tissue and milk unsaturation according to some reports. When diets containing 0, 10, 15, or 20% whole cottonseed were fed to cows, 18:1 in milk steadily increased from 23.5 to 32.0% of total fatty acids (DePeters et al., 1985). However, there were no changes in milk 18:2 or 18:3 as cottonseed increased in the ration. Processing of the seed can affect the degree of protection from ruminal biohydrogenation and the extent that milk fatty acids are altered. Whole seeds provide some protection from biohydrogenation because of the nature of their hard outer seed coat. Disruption of the seed coat exposes the oil to the microbial population and the potential for fermentation problems and biohydrogenation. The seed coat can be sufficiently broken by chewing and rumination, or through a variety of processing techniques such as extrusion or grinding. Roasting of cottonseed was reported to reduce biohydrogenation (Pires et al., 1997).

Calcium salts of fatty acids have received some attention for partially escaping biohydrogenation. Wu et al. (1991) reported 49% biohydrogenation of fatty acids from calcium salts of palm oil compared to 80% for animal-vegetable fat and 62% for control diet fatty acids. Klusmeyer et al. (1991) similarly found lower biohydrogenation for diets supplemented with calcium salts compared to a control diet. Feeding calcium salts of soybean oil (high in 18:2) or linseed oil (high in 18:3) to lactating cows had only minor effects on the proportions of 18:2 and 18:3 in milk fat (Chouinard et al., 1998). Calcium linoleate fed to sheep failed to increase flow of unsaturated fatty acids to the duodenum (Fotouhi and Jenkins, 1992). They proposed that calcium salts of unsaturated fatty acids were protected from dissociation in the rumen when encapsulated inside an insoluble matrix of saturated calcium salts. If so, protection is only possible if unsaturated fatty acid content is low, which greatly limits the extent that unsaturation of meat or milk can be altered. This was supported by observations of Enjalbert et al. (1997) showing that duodenal flow of 18:2 was greater for calcium salts of palm fatty acids than for calcium salts of rapeseed fatty acid. Intake of unsaturated fatty acids was higher for cows fed the rapeseed calcium salts.

More recently, oleamide has been investigated as a possible source of monounsaturated fatty acid resistant to ruminal biohydrogenation. Reeves et al. (1998) reported that biohydrogenation of *cis*18:1 was reduced 61% by adding it to microbial cultures as oleamide rather than adding it as the free acid (oleic acid). Oleamide added to the microbial cultures maintained higher concentrations of *cis*18:1 and lower 18:0 at 24 and 48 h incubation compared to cultures with added oleic acid. Also, when sheep were fed a diet with added oleamide, fatty acid and energy digestibilities were higher than either the control diet or a diet with added oleic acid.

Oleamide was examined in a dairy study in which nine first lactation Holstein cows were fed three diets in a 3 x 3 Latin square replicated three times (Jenkins, 1998). Each period lasted 3 weeks. The TMR consisted of 42% corn silage and 58% concentrate (DM basis) with either no added fat (control), 3.5% added high oleic canola oil, or 3.5% added oleamide. Dry matter intake was reduced by oleamide, but not by canola oil. Milk yields were the same for all treatments. Canola oil reduced FCM and milk fat concentration but these were not affected by oleamide. Milk protein concentration was lower for oleamide compared to canola oil, but neither fat supplement differed from the control diet.

Milk *cis*18:1 averaged 22.40% of the total fatty acids for the control diet, and increased to 34.59% by feeding canola oil. Feeding oleamide further increased *cis*18:1 to 47.39% of milk total fatty acids. All fatty acids with ≤ 16 C were reduced by oleamide. Oleamide was more

effective than canola oil in this study at increasing the oleic acid content in milk of lactating dairy cows. Oleamide ranked high when compared to other protected fat sources for its ability to enhance oleic acid concentration in milk.

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