Effects of Feeding Fats on Rumen Fermentation and Milk Composition

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Introduction

Milk yields of high-producing dairy cattle demand that energy intake be maximized. Energy intake is not only important during the period of peak milk production but also must be sufficient to maintain persistency of production and support body weight gain following peak milk yield. To increase ration energy density, cereal grains are used to replace forages, but this practice is limited since a certain amount of effective fiber is required to optimize ruminal fermentation, enhance nutrient digestibility, and maintain DM intake. Recent research indicates that low forage diets can be fed if starch digestion is monitored by considering source of starch, processing and particle size of the cereal grain, and nonforage fiber sources are used to dilute starch from the ration (Firkins et al., 2001). Because fat is much higher in energy per unit of weight than cereal grains, it is used to increase energy density of diets. Digestion and absorption of fat, suggested feeding guidelines for various fat sources, and the effects of feeding supplemental fat on milk composition will be discussed in this paper.

Biohydrogenation and Digestion of Fat

Fat digestion begins in the rumen (Figure 1). Bacterial lipases, and possibly to a minor extent plant lipases, break down fat into glycerol and fatty acids (**FA**). Glycerol is used as an energy source by bacteria and is principally converted to propionic acid. The unsaturated FA are biohydrogenated by bacteria, but the bacteria do not use them as an energy source. There is also evidence that ruminal bacteria synthesize small amounts of FA (Wu et al., 1991), with about 100 g/day being synthesized regardless of fat source ($y = 99.7 + 0.79x$, $r^2 = 0.90$, $n = 23$, where y = duodenal FA flow, g/day and x = FA intake, g/day; Pires, et al., 1997; Qiu, 2001, Tice et al., 1994; Wu et al, 1991). Biohydrogenation of course is not complete, with 60 to 90% of the FA becoming hydrogenated depending on fat source, rate of particulate passage, and ruminal conditions (e.g. pH). Adding fat to diets increases the efficiency of microbial protein synthesis in the rumen, possibly because of the decrease in concentration of protozoa (Doreau and Ferlay, 1995; Oldick and Firkins, 2000).

Most of the FA flowing to the small intestine, where absorption takes place, will be free FA but some diglyerdies, monoglycerides, and microbial phospholipids will reach the small intestine. Presence of pacreatic lipase will result in cleavage of the glycerides and phospholipids so the FA can be incorporated into the micelles for absorption. With the nonpolar nature of

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lipids, bile is very critical for emulsification of the FA (for their incorporation into micelles) so that absorption can take place. The FA are reassembled as phospholipids and glycerides and packaged as very low density lipoproteins (VLDL) and chylomicrons that have an outer protein matrix to aid in the transport of lipids throughout the lympathic system.

The desirable characteristics of a fat source are that it should have minimum effects on ruminal fermentation and have a high digestibility; however, these two qualities are not always easy to achieve. Unsaturated fat is highly digestible but may reduce fiber digestibility in the rumen due to inhibitory effects on cellulolytic microorganisms. Saturated fat has less influence on fiber digestion in the rumen, but digestibility of the fat may be inferior depending on the level of saturation (Firkins and Eastridge, 1994; NRC, 2001). When comparing fats based on saturation level, iodine value (**IV**) or total unsaturates can be used. Iodine value is more reflective of level of unsaturation (or saturation) because the relative proportion of unsaturated fatty acids (e.g. C18:1 versus C18:2 versus C18:3) is not reflected within total unsaturates.

Maximum feeding levels of natural fat sources must be followed to minimize problems with ruminal fermentation. One approach is to establish feeding levels based on IV within a supplemental range of 2 to 3% of dietary DM: < 60 IV = 3%, 60 to 100 IV = 2.5%, and > 100 IV = 2%. Another approach is to base the feeding level on the amount of fiber in the diet, with the idea being that diets with higher concentrations of fiber can tolerate more unsaturated fat. Jenkins (1997) developed equations based on concentrations of NDF or ADF in diets. Comparing 19 versus 22% ADF, the IV approach and 22% ADF would result in similar maximum feeding levels except that the ADF approach sets a lower feeding level for the highly unsaturated oilseed sources (Table 1).

The chemical and physical form of fat sources also can affect digestive aspects. For hydrogenated fats, the higher the IV (especially up to an IV of 27) and higher ratio of C16:C18 can improve digestibility (Firkins and Eastridge, 1994). Digestibility of saturated fat may be higher with small particles (prills) compared to large particles (flakes) due to greater surface area for contact with absorptive mechanisms (Eastridge and Firkins, 2000; Elliott et al., 1994). With relation to chemical form, FA appear to be more digestible than triglycerides (Eastridge and Firkins, 1991; Elliott et al., 1994; Pantoja et al., 1995). This is reflected in the new dairy NRC (2001) in comparing the digestibility of hydrolyzed tallow FA (79%) versus partially hydrogenated tallow (**PHT**; triglycerides; 43%). The FA profile and IV of different commercial sources of PHT vary, but only one digestibility is provided by NRC (2001). However, the digestibility reported by NRC is more variable for PHT than hydrolyzed tallow FA (SD = 13 and 8, respectively; coefficient of variability ((SD/mean) x 100) = 30 and 10, respectively). Therefore, when comparing PHT with other sources, one must consider FA profile, IV, and particle size.

The potential negative impact of unsaturated fat from oilseeds may be minimized if the oilseeds are fed either whole or coarsely cracked rather than extruded (Faldet and Satter, 1991; Reddy et al., 1994). This would allow the encapsulated oil to be released at a slower rate in the rumen, or some of the oil may even escape the rumen. Because of fat being nonpolar (hydrophobic), it seeks out particulate matter in the aqueous environment in the rumen, especially attaches to the waxy layer of forages. Free oil from oilseeds should not be added to

ruminant diets because of the rapid contact of the oil with particulate matter and microbes. Grinding soybeans should not be done because of reduced rumen undegraded protein in roasted soybeans (Tice et al., 1993) and the potential increase in oxidative rancidity with ground raw soybeans (unless grinding is frequent).

Fat Sources

Fat sources can be grouped into two major categories: natural fats and commercial or specialty fats. The natural fats can be sub-divided into plant and animal fats. Commercial fats are special preparations made by using animal or plant fats. The chemical and fatty acid compositions of various fat sources are provided in Table 1.

NATURAL FATS. Oilseeds are the major source of fat from plants. Whole cottonseed is a well-balanced feedstuff for dairy cattle because it is relatively high in protein, fiber, and energy. Due to physical characteristics of cottonseed, especially linted cottonseed, they are most easily handled by inclusion in a total-mixed ration. However, the availability of Easiflo™ (coated with 2.5% starch to mat the linters) and pelleted cottonseed provide for increased potential usage. Whole cottonseed contains the pigment gossypol that is toxic to animals, especially non-ruminants. With the levels of cottonseed typically consumed by dairy cattle (< 15% of DM), intake of sufficient gossypol to cause health problems is not likely (Coppock et al., 1987). However, cottonseed should be closely monitored for mycotoxin contamination, especially aflatoxin.

Raw soybeans should not be ground and added to feed mixtures containing urea because soybeans contain urease. Although the trypsin inhibitor in soybeans is a concern when feeding them to non-ruminants, it is assumed that most of the trypsin inhibitor is deactivated in the rumen. On the other hand, some of the trypsin inhibitor may escape ruminal fermentation and decrease crude protein digestibility in the intestines (Palmquist and Conrad, 1971; Tice et al., 1993). Soybeans can be included in total-mixed rations, top dressed, or in the case of cracked beans (whole seeds will separate out), can be added to grain mixtures. As alluded to earlier, exposure of oil and release of lipoxygenase by grinding raw soybeans may lead to rancidity problems, especially during summer months. Potential for the oil to become rancid is greater when the ground soybeans are added to ensiled forages or wet by-products during warm months.

Roasting soybeans will denature the urease, trypsin inhibitor, and lipoxygenase and decrease ruminal degradability of the protein. For example, protein degradability in raw soybeans is about 72% whereas protein degradability in roasted soybeans is about 50%. Quality of the roasting can be quite variable from one roaster to another with such factors as temperature, moisture level of seed, rate of transit through roaster, and handling of beans after exiting the roaster giving rise to some of the quality differences. A few beans should be broken and examined for uniformness of heat penetration - beans should not be raw in the center. Over-heating of beans will reduce protein digestibility; therefore, occurrence of charred seeds should be avoided. Although visual appraisal alone is not adequate for assessing quality of the

roasting, seeds should be light brown in color. The protein dispersibility index (Hsu and Satter, 1995) is available from some labs as a measure of the adequacy of heat processing of soybeans.

Other oilseeds such as canola, safflower seeds, and sunflower seeds can also be fed to dairy cattle. Caution should be exercised in feeding these oilseeds because the oil is highly unsaturated, and they are higher in oil than cottonseed and soybeans, resulting in lower recommended feeding levels. For example, only about one-half as much canola (seeds should be cracked) can be fed as cottonseed or soybeans.

The primary animal fat fed to dairy cattle is tallow. Tallow contains more saturated fatty acids than the oilseeds, but handling is more difficult because it is solid or semi-solid at room temperature. Tallow can be readily purchased in barrels with heating instruments to melt the fat for mixing purposes. Tallow can be of different qualities, and some of the grades are as follows: edible tallow, extra fancy tallow, fancy tallow, bleachable fancy tallow, and prime tallow. The different grades refer to the purity/cleanliness of the tallow, and some of the grades may contain appreciable amounts of lard.

Yellow grease is waste grease from food service operations, and it may contain variable mixtures of vegetable and animal fats. Yellow grease is used as a fat for livestock and pet foods, as an industrial raw material, and as a diluent in higher grade inedible fat products such as bleachable fancy tallow. Several animal-vegetable fat blends also are available for feeding to dairy cattle.

Several other feedstuffs (e.g. hominy, dry distillers grain with solubles, and fish meal) contain a moderate amount of fat. Total fat from all sources in diets should be the focus instead of only supplemental fat from major contributors. Because fish meal contains an appreciable amount of 20 and 22-carbon polyunsaturated FA which are very toxic to ruminal bacteria (Hoover et al., 1989), it should be restricted to a maximum 2 to 3% of dietary DM.

COMMERCIAL FATS. Several commercial fat preparations are available and most of them are marketed as rumen inert sources. These fats fall into two general categories: calcium salts and processed tallow (either hydrolyzed tallow FA or PHT). The calcium salts are made from palm oil (higher in C16:0), soybean oil (higher in C18:2), or blend of fat sources.

Quality Factors

Rendered or processed fats originate primarily as recovered waste fats and can be highly variable in quality. The most important measures of quality are solidification point (titre), saturation/unsaturation (usually measured by IV), total FA (TFA), free FA (FFA), and moisture, insolubles, and unsaponifiables (MIU). Titre and IV both are estimators of unsaturation. Tallow is a triglyceride and has a TFA content of 90% (10% is glycerol). Obviously, FFA should be 100% TFA. Total FA values less than 90% for triglycerides indicate dilution with non-fat substances such as MIU. In many processed fats, the FFA value indicates the amount of "abuse" to which the fat has been subjected, as heating and presence of water tend to hydrolyze or "split"

triglycerides to FFA and glycerol. However, livestock can utilize FFA, and their presence alone is a good indicator of fat quality since water has no energy value and its presence dilutes the value of fat. Furthermore, water promotes splitting of fat, rancidity, and corrosion of storage tanks. Good quality fats should contain no more than 1% moisture. Impurities include such things as plastic, bone, and hair. Many plastics dissolve at rendering temperatures and reform when cooled. These can clog lines, valves, and pumps. Good quality fats are filtered and should have no more than 0.5 to 1% impurities. Unsaponifiables is the term for fat-soluble material that is not FA, and the most worrisome component is polymers formed by heating and oxidation of unsaturated FA until they polymerize or cross link. Although there is some uncertainty as to whether these polymers are toxic to animals, there is no question that they are unabsorbable and dilute the energy value of fat. Unsaponifiables ("unsaps") may range from 1 to > 4% if the quality of the fat is poor. Good quality fats will not have been overheated and may contain added antioxidants to keep unsaponifiables low.

Feeding Practices

One of the original concepts with feeding fat was to reduce body weight (**BW**) loss during early lactation. However, research results do not support this concept. The extra energy consumed by feeding fat in early lactation primarily supports higher milk yield. Since the feeding of fat does not appear to reduce BW loss during early lactation and palatability problems sometimes exist with certain fats, it is advised not to feed high levels of fat until 30 days postpartum. This strategy will allow the cow some time to adjust to the lactational phase before fat is included in the diet; after all, the main strategy during the first 2 to 4 weeks of lactation should be to maximize DM intake rather than energy intake. After intake has reached an acceptable level, then energy intake can be the focus.

There is some evidence that feeding fat may improve reproductive efficiency of dairy cows, independent of any effects on energy balance of the cows (Lucy et al., 1991; Staples et al., 1998). Fat supplementation may increase the number and size of ovarian follicles, increase plasma concentration of progesterone, reduce secretion of prostaglandin metabolites, and increase lifespan of the corpus luteum (Staples et al., 1998). The FA profile of the supplemental fat is important for its positive impact on reproduction, with linoleic acid being one of the causative FA. Therefore, this has lead to increased interest in feeding natural fat sources higher in linoleic acid and the development of calcium salts higher in linoleic acid (Table 1).

The need for fat in diets should be based on the animals' milk yield and body condition, quality of forages in diets (poorer quality forages are lower in energy), and the level of DM intake by animals. As a guideline, cows can efficiently utilize as much dietary fat as produced in milk, with appropriate adjustments for BW change (subtract amount lost or add amount gained in adipose tissue) (Palmquist and Eastridge, 1991). The amount of fat that can actually be included in diets depends on the fat source, level of DM intake, and fiber level in the diet. The importance of fat source in this regard was alluded to earlier. Cows consuming higher amounts of DM and consuming diets adequate to high in fiber compared to diets marginal in fiber can handle a higher level of dietary fat. Using the fiber equations by Jenkins (1997) are more applicable for typical

diets and should be used with caution with low forage diets based on high NDF from nonforage fiber sources.

Since DM intake influences the amount of fat to include in diets, fat levels to feed should be expressed as a percentage of DM intake rather than on a weight basis. To provide supplemental fat, the natural fats should be used as a first priority because of their lower cost. Generally speaking, oilseeds can be added to provide an additional 2% fat or tallow and animal-vegetable blends can be used to provide 2.5 to 3% supplemental fat to diets (Table 1). The benefit of commercial fats become more apparent when total dietary fat level must exceed 5% of dietary DM. Commercial fats are important for their rumen inertness and are convenient due to their ease of handling. Price, availability, and characteristics that relate to palatability, inertness, and digestibility are important for making comparisons among different commercial fats.

Insoluble soaps formed between fatty acids and cations, especially calcium and magnesium, in the lower portion of the small intestine may reduce the absorption of calcium and magnesium (Jenkins and Palmquist, 1984; NRC, 2001). The evidence for this is equivocal, but magnesium and calcium should be increased 20 to 25% in diets containing supplemental fat.

Effects of Supplemental Fat on Milk Composition

Adding fat to diets for lactating cows generally increases milk yield (if energy is limiting in the diet) and increases milk protein yield but decreases milk protein concentration, typically by 0.1 to 0.2 percentage units. The metabolic processes attributing to this decline in milk protein concentration has reviewed considerable attention, but the mechanism may still be uncertain (Schingoethe, 1996; Wu and Huber, 1994).

Interest in the effects of supplemental fat on the FA composition of milk fat has increased and recently has been extensively reviewed (Jensen, 2002). About 50% of the fat in milk is derived from de novo synthesis in the mammary gland (most of the 4:0 to 14:0 and about 50% of 16:0) and 50% from performed FA from either the diet or adipose tissue; however, the relative contribution by preformed FA is higher during early lactation because of mobilization of adipose tissue. Supplemental fat also increases the contribution of performed FA, thereby increasing the long-chain FA and decreasing the short-chain FA in milk. Supplemental dietary fat may increase or have no impact on milk fat percentage, and feeding fat may decrease milk fat percentage if ruminal fermentation is adversely affected, possibly related to the increased *trans*-18:1 in milk (Jensen, 2002).

Alteration of the FA composition of milk and the location of specific FA on glycerol can affect the processing properties of milk and the nature (especially firmness) of dairy products (such as cheeses). Much interest continues in the concentration of conjugated linoleic acid (**CLA**) in milk because of its anti-carcinogenic properties found in laboratory animals. Research continues with attempting to increase CLA in milk by feeding different dietary sources of fat, altering biohydrogenation in the rumen, understanding the role of delta-9 desaturase in the

mammary gland, and understanding why cows on pasture have higher CLA in milk than cows fed stored feeds.

Fat Analysis

Analysis of feeds for fat is not customary for many labs. Only high-fat feeds, by-product feeds, or blended feed mixtures containing supplemental fat are worthy of fat analysis. Some by-product feeds are quite variable in fat, and thus, fat analysis would be advised.

Fat in feeds is usually analyzed either by ether extraction (**EE**) or by gas chromatographic methods. The EE procedure results in higher values because it includes everything that is soluble in ether. The gas chromatographic methods provide a more precise analysis because FA are actually measured. The FA content can be generally estimated from EE values by the following: forage EE x 0.50; concentrate EE x 0.85, and tallow x 0.90. It is important to know which method is used so dietary levels of fat can be consistent and accurate.

Summary

Fats are very useful for increasing energy density of diets for high-producing dairy cows. Similar to other feeding changes, fat should be gradually introduced into diets. Physical and chemical properties of available fat sources, animal's milk yield, body condition, and level of DM intake, and associated costs are factors for consideration when feeding fat to dairy cows. Use of feed grade fats on dairy farms is expected to continue because of increasing milk yield per cow. Different commercial or specialty fats will continue to be available for feeding upper levels of fats in diets and for targeted roles based on new research.

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Figure 1. Digestion and absorption of fat in ruminants (VLDL = very low density lipoproteins).

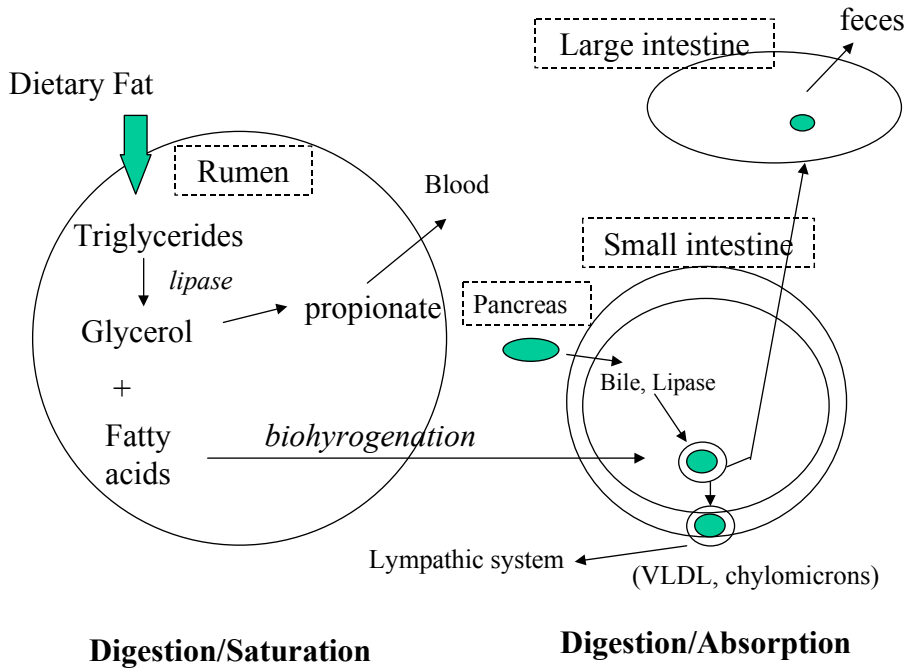

Table 1. Fatty acid composition and characteristics of different fat sources.[1]

Fat Source	Fatty acids (weight %)							Fat (EE) (%)	C_{18} UNSAT FA (%)	IV	Fat digest(%)	NE_L-4X, Mcal/kg	Dietary addition[2] (% of DM)		
													IV	ADF, % of DM	
	14:0	16:0	16:1	18:0	18:1	18:2	18:3							19	22
Oilseeds															
Cottonseed	0.8	22.7	0.8	2.3	17.0	51.5	0.2	19.3	68.7	107	86	1.83	2.0	1.7	1.9
Linseed oil	---	5.3	---	4.1	20.2	12.7	53.3	100	86.2	185	86	---	2.0	1.3	1.5
Rapeseed (canola)	---	4.8	0.5	1.6	53.8	22.1	11.1	40.5	87.0	119	86	3.36	2.0	1.3	1.5
Safflower oil	0.1	6.2	0.4	2.2	11.7	74.1	0.4	100	86.2	145	86	---	2.0	1.3	1.5
Soybeans	0.1	10.3	0.2	3.8	22.8	51.0	6.8	19.0	80.6	131	86	2.58	2.0	1.4	1.6
Sunflower	---	5.4	0.2	3.5	45.3	39.8	0.2	41.9	85.3	113	86	3.22	2.0	1.3	1.5
Animal fats and blends															
Tallow	3.0	24.5	3.7	19.3	40.9	3.2	0.7	99.8	44.8	48	68	4.33	3.0	2.5	2.9
Yellow grease	1.8	22.1	3.5	11.5	43.7	14.6	0.9	99.0	59.2	72	---	---	2.5	1.9	2.2
Choice white grease	1.9	23.4	4.3	13.3	43.4	10.9	1.3	99.0	55.6	62	---	---	2.5	2.1	2.4
Commercial fats															
Calcium salts	1.3	48.6	1.1	4.1	36.5	7.8	0.3	84.5	44.6	49	86	4.80	---	---	---
Ener GII[3]	---	46.5	---	3.0	38.5	10.0	---	85.0	48.5	53	---	---	---	---	---
Megalac[4]	---	47.1	---	4.7	36.5	9.4	1.2	85.0	47.1	53	---	---	---	---	---
Megalac-R[4]	---	25.9	---	3.5	32.9	31.8	4.7	85.0	69.4	100	---	---	---	---	---
Rumolac[5]	---	9.0	---	9.0	31.5	38.5	---	82.0	70.0	98	---	---	---	---	---
Hydrolyzed tallow FA	2.4	39.7	0.7	42.7	10.9	1.0	---	99.2	11.9	12	79	5.17	---	---	---
Partially Hydrogenated Tallow	1.9	25.6	0.5	44.9	22.9	0.5	0.1	99.5	23.5	22	43	2.84	---	---	---

[1]ADF = acid detergent fiber, FA = fatty acids, EE = ether extract, IV = iodine value, NE_L-4X = net energy of lactation based on DM intake at four times maintenance, and UNSAT = unsaturated. Compositional values are from NRC (2001), except for specific calcium salts.
[2]Maximum amount of the fat source that can be supplemented in a dairy ration based on its IV or the amount of ADF in the diet. For the IV basis, the criteria was: < 60 IV = 3.0% of dietary DM, 60 to 100 IV = 2.5%, and > 100 IV = 2.0%. For the ADF basis, the following equation was used (Jenkins, 1997): (6 x ADF)/UFA, where ADF is expressed as a percentage of dietary DM and unsaturated FA (UFA) are 18:1 + 18:2 + 18:3 expressed as a percentage of the total FA in the fat source.
[3]Bioproducts, Inc., Fairlawn, OH
[4]Church and Dwight Co., Inc., Princeton, NJ
[5]Robt Morgan, Inc., Paris, IL.