# Nutritional Management of Milk Fat

Adam L. Lock

Department of Animal Science, Michigan State University, East Lansing, MI 48824
Email: allock@msu.edu

## Take Home Messages

- Fat is typically the most variable component in milk, and is affected by many physiological and environmental factors.
- Milk fat depression is due to changes in rumen biohydrogenation of unsaturated fatty acids and the passage of specific intermediates of biohydrogenation out of the rumen that subsequently reduce milk fat synthesis in the mammary gland.
- Low milk fat tests typically occur as a result of several concurrent diet or management factors rather than as a result of a single factor.
- Fat supplements are commonly fed to increase dietary energy density and support milk production.
- Not all fatty acids are the same: know what fatty acids are in the supplement and what form they are in; interactions with other dietary components are key in determining response.
- Always consider potential effects of fat supplements on dry matter intake and milk production and composition.
- Further work is required to characterize the sources of variation in response to fat supplementation.

## Introduction

Milk components and not milk volume are driving producer milk prices. Therefore, diets that allow for an improvement in milk fat output would potentially be economically advantageous. Equally, low (or reduced) milk fat percentage and yield is also an important economic issue to dairy farms. Improvements in animal genetics can be used to align production with demand in the long term, but does not offer a short to medium term solution. The broad role of nutrition on milk composition is well established and indicates the potential to rapidly respond to changes in milk markets. Recent evidence has increased our understanding of factors affecting milk fat

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synthesis in the mammary gland that should allow the development of nutritional management systems that allow strategic changes in milk composition. Lock and Shingfield (2004) provide a comprehensive review of the impact of nutrition on milk fat and protein. Therefore, the emphasis of the current paper is on recent developments concerning causes of dietary induced milk fat depression (MFD), practical solutions to alleviating low milk fat tests, and opportunities to improve milk fat through dietary fat supplementation.

## ■ Milk Fat Depression

Fat is typically the most variable component in milk, and is affected by many physiological and environmental factors. The available evidence indicates that MFD is due to changes in rumen biohydrogenation of unsaturated fatty acids and the passage of specific intermediates of biohydrogenation out of the rumen (e.g. *trans*-10, *cis*-12 CLA) that subsequently reduce milk fat synthesis in the mammary gland by altering expression of genes involved in fat synthesis. Our recent review on MFD and milk fat synthesis provides further information on this biology (Bauman et al., 2011). Although we have a good understanding of the effect of specific biohydrogenation intermediates in the mammary gland, there is limited information regarding dietary factors that promote their formation in the rumen. A generalized scheme of rumen biohydrogenation of linoleic acid under normal conditions and during diet-induced MFD is shown in Figure 1. Troubleshooting milk fat issues on dairy farms remains one of the more challenging tasks within overall nutritional management of dairy cows. A better understanding of the effect of different diets and specific dietary components on rumen biohydrogenation will allow for the development of nutrition strategies that can diminish the significant financial losses associated with MFD (Lock, 2010). The following sections indicate key areas that should be considered when troubleshooting MFD issues on farm.

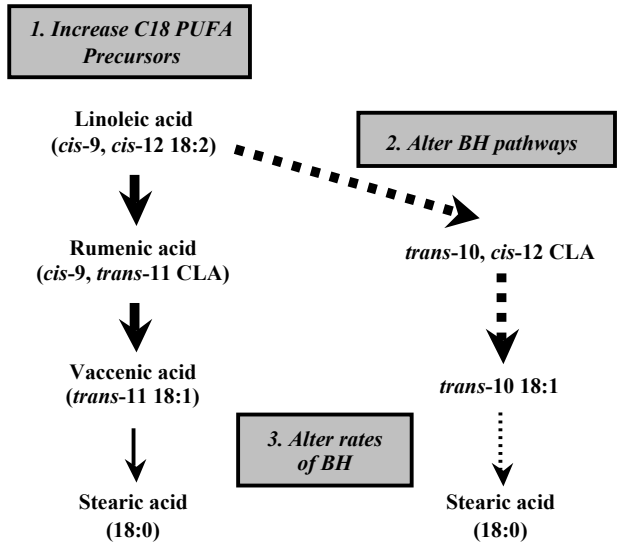


**Figure 1. Generalized scheme of ruminal biohydrogenation of linoleic acid under normal conditions (left side) and during diet-induced milk fat depression (dotted lines, right side). The grey boxes highlight three potential means by which dietary components can increase the risk of milk fat depression (Lock, 2010). PUFA = polyunsatured fatty acids; BH = biohydrogenation.**

## Alteration of the Rumen Environment

Factors that alter the rumen environment are traditionally first considered when troubleshooting MFD on dairy farms. Low rumen pH is a key change in the rumen environment that may lead to flux of fatty acids through alternate pathways of ruminal biohydrogenation. Although data are limited, changes in rumen pH are most likely associated with MFD because they cause a change in the bacterial population favouring those that have alternative biohydrogenation pathways. A common misconception, however, is that acidosis is a prerequisite for MFD to occur. This is not the case and in most situations rumen health appears excellent and there are no overt signs of ruminal acidosis.

Careful consideration should be given to the fermentation rate of starch sources when troubleshooting MFD issues. Carbohydrate fermentability in the rumen is an important factor that can result in changes in biohydrogenation pathways and specific intermediates. For example, a number of studies have reported an effect of corn processing method on risk of MFD. No single factor, however, tends to result in low milk fat and an example of the impact of some

of these dietary interactions is highlighted in Table 1; this study fed diets containing high moisture and dry ground corn at either a high or low starch concentration (Oba and Allen, 2003). At the low starch level there was no significant effect of grain processing on milk fat parameters, whereas at the high starch level high moisture corn significantly reduced milk fat yield by 15% compared to dry ground corn. Additionally, cows consuming diets that contain corn silage as the only or major forage source appear to be more susceptible to MFD when unsaturated fats are supplemented. Partial substitution of corn silage with another forage such as alfalfa has been reported to alleviate this negative effect. For example, it has been shown that replacing half the dietary corn silage with alfalfa silage reversed the negative effect of tallow on milk fat yield (Table 2).

**Table 1. Effect of corn grain processing method and starch intake on milk fat synthesis. Adapted from (Oba and Allen, 2003).**

| | High starch (32% DM) | | Low starch (21% DM) | |
|---|---|---|---|---|
| | High moisture corn | Dry ground corn | High moisture corn | Dry ground corn |
| Milk yield (kg) | 38.8 | 38.4 | 33.4 | 34.3 |
| Milk fat %[1] | 3.05[b] | 3.59[a] | 3.95[a] | 3.73[a] |
| Milk fat yield (kg) | 1.17[b] | 1.35[a] | 1.33[ab] | 1.27[ab] |

[1]Treatment significance ($P < 0.05$) indicated by differences in superscript letters.

**Table 2. Effect of feeding tallow on rumen fermentation and milk fat synthesis in dairy cows fed diets based upon corn silage or alfalfa silage with, or without tallow supplementation. Adapted from Onetti et al. (2004).**

| | Treatment[1] | | |
|---|---|---|---|
| | CS | CST | AST |
| Milk, kg/d | 44.9 | 44.3 | 43.6 |
| Fat, % | 3.12 | 2.68 | 3.32 |
| Fat, kg/d | 1.38 | 1.17 | 1.45 |
| *trans*-10 18:1, % | 0.75 | 2.15 | 0.78 |

[1]CS = 50% corn silage + 50% conc; CST = 50% corn silage + 50% conc + 2% tallow; AST = 25% corn silage + 25% alfalfa silage + 50% conc + 2% tallow.

In some cases during lactation monensin supplementation can result in decreased milk fat percentage and yield (Duffield and Bagg, 2000). It is probable that monensin can affect biohydrogenation rates through altering rumen fermentation and the bacterial species present, thus potentially increasing rumen outflow of biohydrogenation intermediates responsible for causing MFD. These effects are likely the result of interactions with other dietary or management factors that predispose cows to experience MFD. It is important to remember that an increased rumen outflow of biohydrogenation intermediates will not be a problem if typical biohydrogenation pathways are present. However, even if a small proportion of dietary unsaturated fatty acids are undergoing biohydrogenation through pathways that produce *trans*-10, *cis*-12 CLA and related intermediates, monensin can potentially increase the passage of these to the small intestine and increase the risk of MFD. For example, Table 3 highlights the interaction between dietary monensin and soybean oil on milk fat synthesis; while monensin reduced milk fat, the extent of this reduction was dependent on the dietary level of soybean oil (AlZahal et al., 2008).

**Table 3. Effects of 3 levels of soybean oil (SBO; 0, 1.7, or 3.4% of DM) and monensin (MN; 0 vs. 22 g/kg of DM) in the diet on DMI, milk yield, milk fat synthesis, and milk fatty acids. Adapted from AlZahal et al. (2008).**

| | Control (No MN) | | | MN (22 g/kg of DM) | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1.7 | 3.4 | 0 | 1.7 | 3.4 | SEM |
| DMI, kg/d | 21.3 | 20.7 | 20.9 | 20.6 | 21.0 | 21.5 | 0.5 |
| Milk yield, kg/d[1] | 27.5 | 29.5 | 29.4 | 26.9 | 28.9 | 30.1 | 0.75 |
| Milk fat, %[1, 2, 3] | 3.76 | 3.59 | 3.14 | 3.74 | 3.21 | 2.43 | 0.15 |
| Milk fat, kg/d[1, 2] | 1.03 | 1.05 | 0.92 | 0.99 | 0.92 | 0.74 | 0.04 |
| t10 18:1, g/100 g[1, 2, 3] | 0.41 | 0.59 | 1.30 | 0.45 | 0.78 | 2.64 | 0.25 |

[1]Significant linear effect of SBO
[2]Significant linear effect of MN
[3]Significant linear effect of the interaction between MN and SBO

It is probable that other factors can also cause changes in the rumen bacterial population resulting in an increased flow of fatty acids through alternate pathways of ruminal biohydrogenation. For example, we recently reported that spoilage yeasts in silage have the potential to directly impact rumen fermentation; a decrease in NDF digestibility was the most evident change during in vitro fermentation, especially when high levels of spoilage yeasts were present (Santos et al., 2011). Additional issues that warrant further attention include environmental factors (e.g., heat stress), management

issues (e.g., stocking density), and possible dietary components that may aid the maintenance of 'normal' biohydrogenation pathways (e.g., antioxidants, yeast cultures, and live yeast supplements).

## Rumen Unsaturated Fatty Acid Load (RUFAL)

Elevating unsaturated fatty acid concentration in ruminal contents may cause a number of changes in ruminal fermentation characteristics and microbial population distribution. Ruminal changes are the result of the antimicrobial nature of unsaturated fatty acids. Because some bacterial species are more susceptible than others, the result is a microbial shift in the rumen. This microbial shift can redirect the pathways of fatty acid biohydrogenation causing accumulation of CLA isomers linked to MFD (Bauman et al., 2011). Table 4 highlights some important feed sources and their respective fatty acid profiles.

**Table 4. Fatty acid composition of typical feedstuffs (Data from CPM Feed Library).**

| | Fatty Acid (g/100g fatty acids) | | | | | |
|---|---|---|---|---|---|---|
| Feed Name | C14:0 Myristic | C16:0 Palmitic | C18:0 Stearic | C18:1 Oleic | C18:2 Linoleic | C18:3 Linolenic |
| Corn Silage | 0.46 | 17.83 | 2.42 | 19.24 | 47.74 | 8.25 |
| Alfalfa Silage | 0.66 | 18.81 | 3.35 | 2.05 | 15.91 | 38.71 |
| Grass Hay | 0.43 | 16.44 | 1.33 | 2.53 | 23.38 | 49.90 |
| Corn Grain | 2.33 | 13.21 | 1.99 | 24.09 | 55.70 | 1.62 |
| Tallow (Beef) | 3.00 | 24.43 | 17.92 | 41.62 | 1.09 | 0.53 |
| Soybean Oil | 0.11 | 10.83 | 3.89 | 22.82 | 53.75 | 8.23 |
| Corn Distillers | 0.14 | 14.05 | 2.39 | 24.57 | 56.11 | 1.68 |
| Cottonseed | 0.69 | 23.91 | 2.33 | 15.24 | 56.48 | 0.19 |

Since various fatty acids can trigger a number of changes in rumen lipid metabolism the feeding of supplemental fat can be challenging. In general, as you increase the degree of unsaturation of supplemental fat (Table 5) and/or the availability of the fatty acids present (e.g., extruded vs. roasted oilseeds), the chances of MFD occurring will increase. This will not happen in all cases but will depend on interactions between the supplemental fat and the basal diet. Furthermore, with the increased availability of corn byproducts (e.g., corn

distillers' grains) an additional important consideration is their fat content because they can contain a considerable amount of lipid that is predominately linoleic acid (Table 4). The fat content of corn distillers' grains is highly variable and this degree of variation can significantly alter the dietary supply of unsaturated fatty acids to the dairy cow, thereby increasing the risk of MFD. For example, we recently analyzed 20 individual samples of corn distillers' grains with total fatty acid content ranging from 10% to 18% DM; little to no variation was observed in the fatty acid profile of these samples.

Given that the specific fatty acids that cause MFD are intermediates produced during rumen biohydrogenation of PUFA, it is logical that the amount and/or concentration of unsaturated fatty acids may be related to the amount of the key biohydrogenation intermediates that are produced. Linoleic acid is typically the major dietary fatty acid, particularly when corn silage comprises the majority of the forage base in the ration and oilseeds are the major source of added dietary fat. Estimates of linoleic acid intake indicate that in these situations linoleic acid intake can approach and even exceed 400 to 500 g/d. Therefore, it would appear that typical rations have more than enough substrate as linoleic acid to meet the required presence of PUFA for MFD to occur if rumen fermentation and biohydrogenation pathways are altered. In some circumstances, it would appear that an increase in unsaturated load from increasing oleic acid supply (e.g., the tallow treatment in Table 2 or MUFA treatment in Table 5) is sufficient to alter biohydrogenation pathways to favor the production of *trans*-10, *cis*-12 CLA and related intermediates from PUFA already in the diet. This was shown recently in a study that examined the effect of feeding increasing levels of oleic and linoleic acid both independently and together (He et al., 2012); while dietary C18:1 depressed milk fat synthesis, it was less potent than C18:2 (Table 6). As defined, RUFAL accounts for intakes of unsaturated fatty acids from all feed ingredients rather than fatty acid intake coming only from fat supplements. RUFAL can be calculated as the sum of the three primary unsaturated fatty acids consumed by dairy cows, namely oleic, linoleic, and linolenic acids. It is proposed that RUFAL is a better indicator of fermentation disruption in the rumen and risk of MFD rather than relying just on the percentage of fat added to the diet or only dietary linoleic acid supply.

**Table 5. The effect of rumen-inert fats containing mostly saturated fatty acids (SFA), mostly monounsaturated fatty acids (MUFA), or mostly polyunsaturated fatty acids (PUFA) on dry matter intake (DMI), milk yield and milk fat synthesis in midlactation dairy cows. Adapted from Relling and Reynolds (2007).**

| | Diet | | | | $P^1$ |
|---|---|---|---|---|---|
| | Control | SFA | MUFA | PUFA | |
| DMI, kg/d | 23.8 | 23.1 | 22.1 | 22.0 | 0.12 |
| Milk, kg/d | 36.9 | 37.3 | 35.8 | 34.8 | 0.44 |
| Fat, % | 3.37 | 3.86 | 3.32 | 2.61 | 0.03 |
| Fat, g/d | 1,249 | 1,436 | 1,184 | 911 | 0.02 |

[1]Probability comparing the difference between saturated and unsaturated fat supplements (SFA vs. MUFA and PUFA).

**Table 6. Effect of dietary fat blend enriched in oleic or linoleic acid on milk fat depression. Adapted from He et al. (2012).**

| | Fat Blend Treatment[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | No Fat | LOLL | LOML | LOHL | MOLL | MOML | HOLL |
| DMI, kg/d[2] | $23.8^{ab}$ | $24.1^{a}$ | $23.3^{ab}$ | $22.6^{b}$ | $23.9^{ab}$ | $23.5^{ab}$ | $23.5^{ab}$ |
| Milk, kg/d | $33.7^{abc}$ | $35.8^{a}$ | $34.0^{ab}$ | $30.6^{c}$ | $35.2^{ab}$ | $32.5^{bc}$ | $33.6^{abc}$ |
| Fat, % | $3.50^{a}$ | $3.17^{b}$ | $2.54^{de}$ | $2.47^{e}$ | $2.88^{c}$ | $2.46^{e}$ | $2.76^{cd}$ |
| Fat, kg/d | $1.17^{a}$ | $1.13^{a}$ | $0.84^{cd}$ | $0.74^{d}$ | $0.98^{b}$ | $0.79^{d}$ | $0.91^{bc}$ |

[1]No fat: without fat blend; LOLL: low C18:1, low C18:2; LOML: low C18:1, medium C18:2; LOHL: low C18:1, high C18:2; MOLL: medium C18:1, low C18:2; MOML: medium C18:1, medium C18:2; HOLL: high C18:1, low C18:2.
[2]Treatment significance ($P < 0.05$) indicated by differences in superscript letters.

Finally, it is important to remember that the forages in the basal diet also make a significant contribution to the supply of dietary fatty acids and substrates available for milk fat synthesis. In spite of the low lipid content of forages, grass silage for example, can account for proportionately 0.58 (Lock and Garnsworthy, 2002) and 0.67 (Offer, et al., 1999) of total fatty acid intake. Careful consideration should be given to possible variation in the total fatty acid concentration of forages and by-products when formulating diets and establishing possible risk factors for MFD.

## ■ Increasing Milk Fat through the Use of Supplemental Fat

Lipids in milk are primarily in the form of triacylglycerides (98%) with phospholipids and sterols accounting for 1.0 and 0.5% of total lipids, respectively. Bovine milk is extremely complex and contains about 400 fatty acids, a large proportion of which are derived from lipid metabolism in the rumen (Jensen, 2002). Substrates for de novo synthesis are derived from ruminal fiber digestion and dietary lipids supply preformed fatty acids for direct incorporation into milk fat. Microbial synthesis of branched and odd-chained number fatty acids in the rumen and absorption of biohydrogenation intermediates also contribute to the diversity of fatty acids secreted in milk fat. Under typical conditions, about half of the fatty acids in milk are synthesized de novo, 40 to 45% originate from fatty acids in the diet, and less than 10% are derived from mobilisation of adipose tissue (Palmquist and Jenkins, 1980). However, nutrition can substantially alter the balance between mammary de novo fatty acid synthesis and uptake of preformed fatty acids.

In general, replacing grass silage with whole crop cereal silages has little effect on milk content, while switching to corn silage typically causes a small decrease in milk fat content but causes an overall increase in milk fat secretion. However, the addition of fat to the diet to increase dietary energy content can have variable effects on the concentration and yield of milk fat. This is evident in a recent meta-analysis examining the effect of fat supplementation to diets of dairy cows on milk production and milk components (Rabiee et al., 2012). In general milk production and milk fat % and yield increased, DMI and milk protein % decreased, and milk protein yield was not affected by fat supplementation. There was a wide range of responses (~5 standard deviations) for all variables, indicating varied and marked biological effect of the different fats (Rabiee et al., 2012).

Changes in response to different fat supplements are dependent on lipid inclusion rate, degree of unsaturation and physical form of the supplemental fat. Feeding fat supplements often reduces milk fat content as a result of negative effects on ruminal organic matter digestion associated with decreases in intake and also changes in ruminal biohydrogenation (see previous section). This is particularly evident for unsaturated fatty acids that have the potential to affect the growth of some groups of rumen bacteria (Maia et al., 2007). On the other hand, saturated fatty acids (e.g., palmitic [C16:0] and stearic [C18:0] acids) are considered to be inert in the rumen and have not been implicated in MFD. Total milk fat yield as well as fat percentage is often increased when saturated fatty acid supplements are fed. Christensen et al. (1994) compared the effects of abomasal infusion of saturated long chain fatty acids and unsaturated long chain fatty acids (high oleic canola oil, soybean oil, and sunflower oil) and found that saturated fatty acid infusion

increased milk fat yield as compared to the unsaturated fat treatments. These findings are similar to those of Relling and Reynolds (2007) who reported an increase in milk fat percentage and yield as a result of feeding saturated fatty acids compared to a polyunsaturated (Ca-salts of soybean fatty acids) and monounsaturated (Ca-salts of palm fatty acid distillate) fat treatments; furthermore the saturated fatty acid treatment increased milk fat compared to the non-fat supplemented control treatment (Table 5).

There is limited evidence indicating that specific saturated fatty acids are more or less effective at increasing milk fat. Steele and co-workers in the 1960's performed a series of studies using relatively pure sources of palmitic, oleic, and stearic acids and their findings suggest that palmitic acid supplementation induces a higher milk fat response (concentration and yield) as compared to oleic and stearic acids supplementation (e.g., Steele and Moore, 1968). More recent work from Enjalbert et al (1998) suggests that the uptake efficiency of the mammary gland is higher for palmitic acid than for oleic and stearic acids. In a recent study we found that feeding an 85% palmitic acid fat supplement (2% dietary DM) improved milk fat concentration and yield by 8% as well as efficiency of feed conversion into milk compared to a non-fat supplemented diet (Lock et al., 2011).

In addition, the composition of the basal diet is an important determinant of milk fat responses to lipid supplements. In high producing dairy cows an interaction was observed between forage:concentrate ratio and response to supplemental saturated fatty acids (Weiss and Pinos-Rodriguez, 2009). In high-forage diets increased energy intake from supplemental saturated fatty acids was directed mostly to body reserves, whereas in low-forage diets the increased energy intake from the supplemental saturated fatty acids was directed mostly to milk production. Using lower producing cows, Grum et al. (1996) compared diets with different forage:concentrate ratios either without or with added saturated fatty acids. At both forage:concentrate levels supplemental saturated fatty acids increased milk fat concentration and yield (Table 7). Interestingly, fat supplementation had opposing effects on DMI when supplemented in the low or high forage:concentrate diets (Table 7). Clearly, further work is required to characterize the impact of different fatty acids on production responses across different diet types and different levels of production.

**Table 7. Production responses of dairy cows fed increased energy from saturated fatty acids or concentrate. Adapted from Grum et al. (1996).**

| | Treatment[1] | | | | |
|---|---|---|---|---|---|
| Variable | LC | LC + F | HC | HC + F | SEM |
| NDF, % DM | 32.8 | 33.6 | 27.5 | 28.4 | |
| FA, % DM | 2.8 | 5.7 | 2.5 | 5.1 | |
| DMI, kg/d[4] | 19.2 | 20.7 | 20.2 | 19.4 | 0.4 |
| Milk, kg/d | 27.3 | 29.4 | 28.3 | 27.8 | 1.1 |
| Fat, %[2, 3, 5] | 3.52 | 3.83 | 2.98 | 3.33 | 0.11 |
| Fat, kg/d[2, 3, 5] | 0.96 | 1.11 | 0.83 | 0.91 | 0.06 |
| 4% FCM, kg/d[3, 5] | 25.3 | 28.5 | 23.7 | 24.8 | 1.4 |
| Protein, kg/d | 0.85 | 0.87 | 0.92 | 0.88 | 0.05 |

[1]LC: low (45%) concentrate and no supplemental fat; LC + F: low concentrate plus 3% DM supplemental fat; HC: high (70%) concentrate and no supplemental fat; HC + F: high concentrate plus 3% DM supplemental fat. Diets LC + F and HC were isoenergetic (1.7 Mcal/kg).

[2]Significant effect of fat supplementation.

[3]Significant effect of concentrate.

[4]Significant effect of the interaction between fat supplementation and concentrate.

[5]Comparison of equal energy density treatments (LC + F vs. HC).

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