# Implications of Fat-Feeding Practices for Lactating Dairy Cows – Effects on Milk Fat

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## Take Home Messages

- Feeding a variety of fat sources (e.g. oil seeds, tallow, yellow grease, fish oil, and ruminally inert fats) can increase milk yield of dairy cows if managed well.
- Milk fat depression is thought to be caused by a reduced synthesis of fatty acids by the mammary gland due to the formation of trans fatty acids synthesized by ruminal microbes in a more acidic ruminal environment in the presence of mono- and/or polyunsaturated fatty acids.
- Cows consuming diets that contain corn silage as the only or major forage source are susceptible to milk fat depression. Partial substitution of corn silage with another forage such as alfalfa may alleviate this negative effect by making the rumen less acidic.
- It is not necessary to wait until cows have calved in order to initiate fat supplementation.

## Introduction

Supplementing cows with fat can have several beneficial effects. It usually increases the energy density of the diet when starch or fiber is replaced with fatty acids. If milk production is increased, then feed efficiency may be improved which usually translates into more profit. Less heat may be produced in the rumen during digestion of fat-supplemented diets as fatty acids are not digested in the rumen. Less heat produced during digestion would help cows during heat stress conditions. Also palatability of the diet might be improved and feed particle separation may be reduced. As a result, fat inclusion can be a good choice for diet formulators.

Dietary supplementation of fat also can change the concentration of fat in milk, its daily yield, and its fatty acid composition. What happens in the rumen during microbial fermentation of feed and metabolism of fats as well as the synthesis and incorporation of fats into milk by the mammary gland make predicting of these relationships difficult. Some fat sources will be reviewed as to their effects on milk fat, how these effects might occur, and what can be done through diet formulation to help control these effects.

## ■ Sources and Descriptions of Fats

Choices of fats for feeding to dairy cows are extensive and include oilseeds (fed whole, rolled, ground, roasted, extruded), rendered fats such as tallow and yellow grease, vegetable oils, blends of animal and vegetable oils, marine oils, and fats that have been modified to reduce their metabolism by ruminal microbes such as calcium salts of fatty acids and prilled fats. Each fat source is composed of different fatty acids and those of selected fats are shown in Table 1. Each fatty acid can be described easily by listing how many carbons make up the length of the molecule and then how many double bonds occur in each carbon chain. Palmitic acid is a 16-carbon long molecule with zero double bonds, thus C16:0. The carbon chains that contain zero double bonds are classified as saturated fatty acids whereas those containing one or more double bonds are classified as unsaturated fatty acids. Thus fat sources such as the oilseeds are considered highly unsaturated whereas tallow is considered moderately unsaturated. This is important because the degree of unsaturation influences microbial metabolism in the rumen and thus milk fat. Due to time and space limitations, those fat sources that are most commonly fed will be discussed in more detail.

**Table 1. Major fatty acid composition of some fat sources (adapted from Kennelly, 1996).**

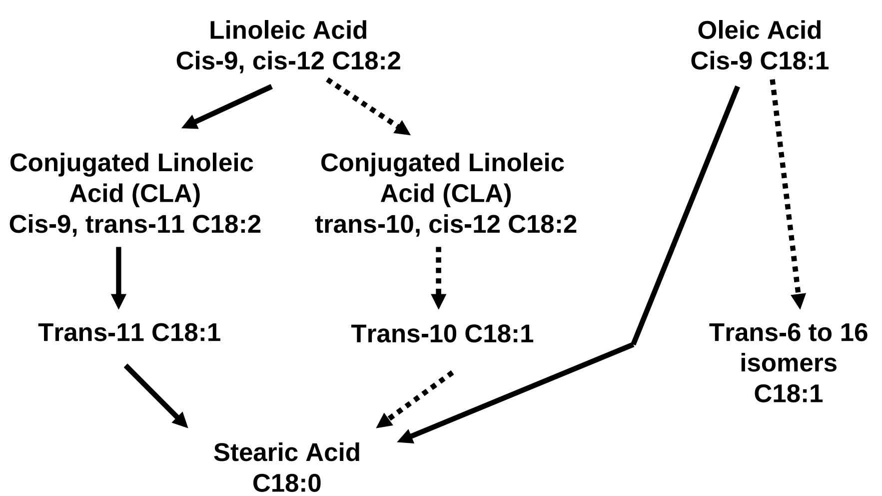
| Fatty acid | C16:0 Palmitic | C18:0 Stearic | C18:1 Oleic | C18:2 Linoleic | C18:3 Linolenic |
|---|---|---|---|---|---|
| Tallow | 26 | 19 | 40 | 5 | 1 |
| Yellow grease | 21 | 11 | 44 | 14 | 3 |
| Booster Fat[1] | 25 | 22 | 45 | 2 | - |
| Megalac; EnerG-II[1] | 51 | 4 | 35 | 8 | - |
| Canola oil | 4 | 2 | 52 | 25 | 13 |
| Cottonseed oil | 25 | 3 | 17 | 54 | - |
| Linseed oil | 5 | 3 | 20 | 16 | 55 |
| Safflower oil | 7 | 2 | 9 | 80 | <1 |
| Soybean oil | 8 | 3 | 24 | 58 | 8 |
| Sunflower oil | 6 | 4 | 20 | 66 | <1 |
| Menhaden fish oil [2] | 17 | 3 | 7 | 1 | 1 |

[1] Commercially prepared, ruminally inert fat sources.
[2] Also contains ~10% C16:1, ~11% C20:5, and 12% C22:6.

## ■ Fate of Fatty Acids in the Rumen

The ruminal microbes will convert unsaturated fats to saturated fats in a sequence of events called biohydrogenation. Some scientists have speculated that this act of biohydrogenation by bacteria is an attempt to protect themselves, as unsaturated fats can be toxic to bacteria, primarily the bacteria that digest fiber. If the feeding of unsaturated fats reduces the numbers or activity of fiber-digesting bacteria in the rumen, then feed intake can decrease, milk production can decrease, and milk fat concentration can decrease. During the process of biohydrogenation of unsaturated fats in the rumen, the conversion to the saturated state may be incomplete. This will result in the synthesis of several forms of fatty acids including some trans fatty acids (Figure 1). Some of the trans fatty acids such as the trans-10, cis-12 conjugated linoleic acid (CLA) and the trans-10 C18:1 can have a tremendous impact on milk fat when they leave the rumen, are absorbed into the blood stream, and are taken up by the mammary gland. These trans fatty acids can be formed by a diverse range of bacteria in the rumen during biohydrogenation of unsaturated fatty acids (Bauman et al., 2000). This will be discussed in more detail later.

**Figure 1. Biohydrogenation of Fatty Acids by Gut Microbes (Bauman and Griinari, 2003; Mosley et al., 2002)**



## ▪ Dietary Fats are used for Milk Fat

Milk is composed of fatty acids of varying chain length. The 4- to 16-carbon long fatty acids found in milk are made by the mammary gland from acetate and butyrate, 2- and 4-carbon long fatty acids respectively, produced by microbes in the rumen. These amount to about 50% of the milk fat. The other 50% of the fat in milk comes directly from fat absorbed from the blood. These fatty acids are primarily 16- to 18-carbon long fatty acids. All of the 18-carbon long fatty acids and about 30% of the 16-carbon long fatty acids come primarily from the diet (Akers, 2002). This fat also can come from the ruminal microbes digested in the small intestine and from body fat reserves that are mobilized mainly during times of negative energy balance. As fat appears in the blood stream during digestive metabolism and body fat mobilization, the mammary gland transfers it into milk fat. It is well established that the more dietary fat consumed, the greater the proportion of the milk fat is made up of the 18-carbon fatty acids and thus a smaller the proportion of the shorter chain fatty acids. For example, when soybeans, cottonseeds, and canola seeds were fed, the proportion of milk fatty acids of less than 14 carbons, of 14 carbons, and of 16 carbons decreased an average of 25, 29, and 20%, respectively, whereas the fatty acids of 18 carbons increased 45% for C18:0, 40% for C18:1, 59% for C18:2, and 11% for C18:3 (Ashes et al., 1997). The reduction in synthesis of the shorter chain fatty acids may be due to a reduction in activity of the key enzymes responsible for milk fat synthesis. Thus more of the dietary fats were incorporated directly into milk fat and fewer fatty acids were synthesized by the mammary gland.

## ▪ Impact of Fats on Dairy Cow Performance

The supplementation of fat in small to moderate amounts to typical diets for lactating dairy cows often increases the production of milk due to the increased energy density of the supplemented diet. An example of this is the work of Weiss and Wyatt (2003). Diets fed were 37.8% corn silage, 7.7% alfalfa hay, 7.2% alfalfa silage, and 47.5% concentrate. Supplemental fat sources were tallow and roasted soybeans fed at 2.35 and 12.3% of dietary DM. Cows fed supplemental fats as tallow and soybeans produced more milk, 37.5 and 36.8 kg/day compared to 35.1 kg/day for cows not fed the fat sources. Across the scientific literature, the effect of supplemental fat sources on milk fat concentration is, however, quite variable. Referring again to Weiss and Wyatt (2003), even though more fat was consumed by cows when fed supplemental fat (1.2, 1.3, and 0.7 kg/day), the milk fat concentration was not increased. Cows fed the control diet and the diet containing soybeans had similar milk fat concentrations of 3.76 and 3.83%. However, the cows fed tallow experienced a reduction in milk fat concentration, dropping to 3.08%. Daily yield of milk fat was 1.33, 1.42, and 1.23 kg for the control, soybean-, and tallow-supplemented cows, respectively. As expected, the milk fat of fat-supplemented cows had a smaller proportion of shorter and a greater proportion of longer chain fatty acids (C18).

In my review of many studies of fat supplementation, it is more common for supplemental fats supplied by oilseeds or rendered fats to have no effect on or to decrease milk fat concentration rather than increase milk fat. However, Palmquist et al. (1993) has published an equation predicting improvement in milk fat concentration based upon 49 studies using a variety of fat sources. Based on his equation, feeding an additional 0.5 kg of fat daily would increase milk fat by 0.18%. The effects of supplementation of selected fat sources on milk fat will be reviewed.

## Tallow

Six studies fed diets of 0 or 2 - 2.5% tallow in corn silage-based diets (40 to 50% of dietary DM) (Table 2). Feeding tallow significantly decreased DMI in 4 of the 6 studies in a range from 0.8 to 1.7 kg/day. This decreased feed intake was accompanied by reduced milk production of 1.6 kg in one study (Onetti et al., 2001). However in two other studies, milk production was increased by 2.1 kg/d (Smith et al., 1993) and 2.3 kg/d (Onetti et al., 2002). In all six studies, milk fat % was significantly depressed from as little as 0.20% to as much as 0.47% units, with the average depression being 0.33% units. Based upon this limited number of studies, what might be expected when tallow is added to corn silage-based diets at 2 to 2.5% of the dietary DM? Assuming a similar response to that shown in Table 2, the efficiency of milk production will be increased (from 1.39 to 1.46 kg of milk per kg of DM intake in these studies) and milk fat% will be decreased by 0.3 percentage units (e.g. from 3.3 to 3.0%).

**Table 2. Effect of feeding tallow on performance of lactating dairy cows fed diets containing 40 to 50% corn silage (DM basis).**

| Reference | % tallow in diet | DM intake, kg/day | Milk, kg/day | Milk fat, % |
|---|---|---|---|---|
| Smith et al., 1993 | 0 | 25.4 | 23.1 | 3.33 |
| | 2.5 | 26.2 | 25.0* | 3.13* |
| Adams et al., 1995 | 0 | 21.8 | 26.7 | 3.65 |
| | 2.5 | 21.4 | 26.5 | 3.35* |
| Onetti et al., 2001 | 0 | 26.3 | 42.3 | 3.30 |
| | 2 | 24.8* | 40.7* | 2.83* |
| Onetti et al., 2002 | 0 | 23.1 | 35.2 | 3.11 |
| | 2 | 22.3* | 37.5* | 2.82* |
| Ruppert et al., 2003 | 0 | 22.6 | 32.3 | 3.18 |
| | 2 | 21.4* | 33.2 | 2.89* |
| Onetti et al., 2004 | 0 | 27.6 | 44.9 | 3.12 |
| | 2 | 25.9* | 44.3 | 2.68* |

* $P \leq 0.05$ (estimated if reference did not report exact comparison).

This negative influence of tallow on milk fat concentration can be eliminated if some or all of the corn silage is replaced with a different forage such as alfalfa hay. When Smith et al. (1993) replace one-fourth of the corn silage with alfalfa hay, tallow no longer depressed milk fat%. Milk fat% was 3.42 vs. 3.47% from cows fed diets of 0 or 2.5% tallow, respectively when diets were 37.5% corn silage and 12.5% alfalfa hay. When alfalfa hay replaced even more of the corn silage (25% corn silage and 25% alfalfa hay), milk fat% tended to be increased by feeding tallow (3.35 vs. 3.70% for cows fed 0 and 2.5% tallow diets, respectively). In a Wisconsin study, replacing 25% or 50% of the corn silage with alfalfa silage did not improve milk fat% when tallow was added to the diets (Onetti et al., 2002). However a later Wisconsin study documented that the milk fat-depressing effect caused by tallow supplementation to corn silage-based diets was alleviated when half of the corn silage was replaced with shortly-chopped alfalfa hay or with alfalfa silage (Onetti et al., 2004). However feeding long-stemmed alfalfa hay was not as effective likely due to cows selecting against the long-stemmed forage. Other forages such as bermudagrass hay and cottonseed hulls also have reversed the milk fat-depressing effect of tallow when partially replacing corn silage (Adams et al., 1995). Feeding tallow at 2.5% of the diet reduced milk fat% from 3.65 to 3.35% when corn silage was the sole dietary forage. Replacing 25% of the corn silage with bermudagrass hay maintained or improved milk fat% from 3.37 to 3.47% when tallow was fed. Likewise, supplementing tallow into corn-silage-based diets that contained some cottonseed hulls did not reduce milk fat % (3.53 vs. 3.60% for cows fed 0 or 2.5% tallow diets, respectively).

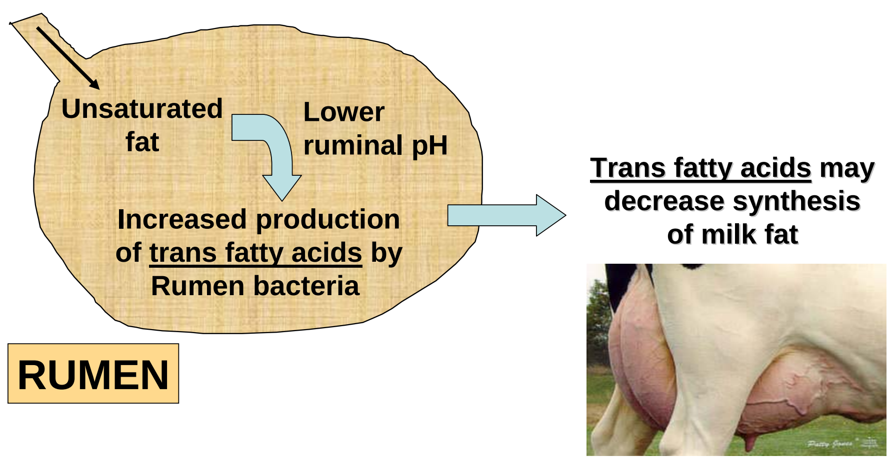
A study from the University of Illinois also indicates that changing the forage in the diet from predominantly corn silage to alfalfa silage can alleviate the depressing effect that tallow can have on milk fat% (Table 3). As tallow increased in the corn silage-based diet from 0 to 2 to 4% (% of dietary DM), milk fat% tended to decrease from 3.18 to 2.89 to 2.70% whereas milk fat% was unchanged when tallow was added to an alfalfa silage-based diet (tallow by forage interaction, $P = 0.12$). The reason for this response was likely due to what was going on in the rumen. Cows fed the corn silage-based diets had a more acidic rumen fluid (average pH of 5.92 vs. 6.04) likely due to the greater intake of nonfiber carbohydrates. As shown in Table 3, the concentration of trans C18:1 fatty acids in milk fat tended to increase to a greater extent when tallow was fed in the corn silage-based diets than in the alfalfa silage-based diets ($P = 0.11$). Therefore the introduction of unsaturated fatty acids (predominantly cis-9 C18:1 in the case of tallow) into a more acidic environment (caused by feeding more corn silage) produced more trans C18:1 fatty acids in milk (Figure 1). Kalscheur et al. (1997) documented that the trans C18:1 fatty acids appear in greater amounts in the small intestine when cows are fed higher grain diets that are not adequately buffered. Therefore cows fed diets that cause a more acidic pH in the ruminal fluid may be more susceptible to the incomplete biohydrogenation of dietary unsaturated fatty acids, thus more trans fatty acids are formed (Figure 2). Feeding diets in which corn silage is the sole or main forage source is likely to result in a more acidic rumen fluid than feeding diets containing alfalfa because alfalfa has 1) greater natural buffering capacity than corn silage and 2) often stimulates greater buffer production via saliva due to greater chewing of longer particle length.

**Table 3. Effect of feeding tallow on selected measurements from lactating dairy cows fed diets based upon corn silage (CS) or alfalfa silage (AS) (Ruppert et al., 2003).**

| Measure | 40% CS : 10% AS | | | 10% CS : 40% AS | | |
|---|---|---|---|---|---|---|
| | 0% tallow | 2% tallow | 4% tallow | 0% tallow | 2% tallow | 4% tallow |
| Milk fat, % [a] | 3.18 | 2.89 | 2.70 | 3.39 | 3.44 | 3.41 |
| Rumen pH [b] | 5.94 | 5.88 | 5.93 | 6.09 | 6.10 | 6.03 |
| Milk trans-C18:1 % of milk fat [c] | 1.45 | 2.95 | 4.86 | 1.19 | 1.89 | 3.05 |

[a] Dietary forage by tallow interaction, $P = 0.12$.
[b] Dietary forage, $P < 0.01$.
[c] Dietary forage by tallow interaction, $P = 0.11$.

**Figure 2. Cows fed high corn silage diets are more susceptible to milk fat depression during fat supplementation**



## Trans Fatty Acids

The trans C18:1 fatty acids are a mixture of several isomers, that is, the single double bond can be located at different carbons along the carbon chain, anywhere from the $6^{th}$ to the $16^{th}$ carbon position (Mosley et al., 2002). Of the trans C18:1 fatty acids, scientists in New York identified the trans-10 C18:1 fatty acid in milk as being most closely associated with milk fat depression caused by feeding an unsaturated fat (corn oil) in a higher grain diet compared to a lower grain diet (Griinari et at., 1998). Onetti et al. (2004) documented that the trans-10 C18:1 fatty acid in milk fat increased most dramatically when milk fat% was depressed by adding tallow to corn silage-based diets and returned to normal levels when alfalfa silage replaced the corn silage.

The major fatty acid in most oil seeds and grains including corn is linoleic acid (C18:2) (Table 1). Linoleic acid can be converted to trans fatty acids in the rumen. Just as there are many isomers of trans C18:1, several isomers of CLA exist. The most common one is cis-9, trans-11 CLA but includes the trans-10, cis-12 form of C18:2. This latter fatty acid can be further converted to trans-10 C18:1 by ruminal microbes (Bauman and Griinari, 2003; Figure 1). As the C18:2 in corn oil fed by Griinari et al. (1998) underwent biohydrogenation in the rumen, more of it was converted to trans-10 C18:1 under the more acidic rumen conditions created by a high grain diet (pH of ~6.4 vs. ~6.1). Ruminal pH is a determinant of microbial populations in the rumen (Russell, 1979). Those ruminal microbes that increase in numbers under more acidic ruminal conditions may possess isomerase enzymes to convert linoleic acid to the trans-10, cis-12 CLA. Trans-C18:1 acids were formed as the major end product of biohydrogenation rather than C18:0 when increased levels of C18:2 were present (Polan et al., 1964). However tallow is generally quite low in C18:2, having cis-C18:1 as the dominant unsaturated fatty acid (Table 1). Typically the trans-11 C18:1 fatty acid is formed during the biohydrogenation process from cis-9, trans-11 CLA. Possibly the isomerization of cis-9 C18:1 in tallow to trans-10 C18:1 is carried out under more acidic conditions in the rumen when fewer fiber-digesters are present. The trans-10 C18:1 and the trans-10,cis-12 CLA leave the rumen with the digesta, are absorbed into the blood from the small intestine, and are taken to the mammary gland where they are incorporated into the milk fat. There is no evidence that the mammary gland can synthesize trans-10 C18:1 and trans-10, cis-12 CLA fatty acids (Piperova et al., 2002). However these trans fatty acids may inhibit the synthesis of the short and medium chain fatty acids by partially inhibiting the enzymes responsible for milk fat synthesis by the mammary gland, thus accounting for the depressed milk fat % due to the feeding of tallow (Bauman and Griinari, 2003). It is these trans fatty acids that may be the cause of the lowered milk fat by tallow supplementation to corn silage-based diets. Other yet unidentified intermediates in addition to trans-10 C18:1 and trans-10, cis-12 CLA may be responsible for milk fat depression (Bauman and Griinari, 2003).

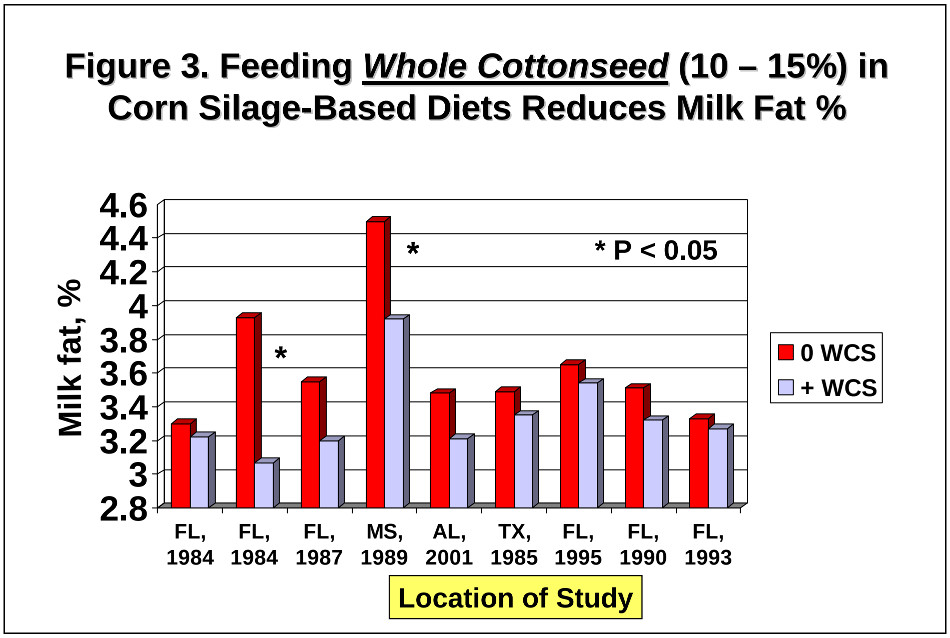
In addition to trans fatty acids being synthesized by the ruminal microbes in the cow, some dietary fat sources may contain trans fatty acids. Some processed vegetable oils can contain trans fatty acids such as recycled restaurant grease (yellow grease) due to the high temperatures reached during the frying process or hydrogenated soybean oil. Wonsil et al. (1994) supplemented a control diet for lactating dairy cows with either no added oil, hydrogenated soybean oil, menhaden oil, or hydrogenated tallow at 3.3% of dietary DM. Intake of trans C18:1 was 0, 69, 0, and 12 g/d for the 4 diets respectively and the amount of trans C18:1 appearing in the small intestine was 37, 152, 163, and 38 g/d. This demonstrates that the trans C18:1 fatty acid was synthesized by microbes in the rumen in all feeding situations but was found in greater amounts when some was fed (soybean oil) and when marine oil was fed (more will be said about marine oil in the next section). The milk fat was depressed in cows fed diets that delivered the most trans C18:1 fatty acids for absorption; that is, 3.26, 2.95, 2.78, and 3.18%, respectively. A commercial calcium salt of primarily (57%) trans C18:1 (BioProducts, Inc.) is being marketed as a fat supplement to decrease milk fat concentration. Feeding a calcium salt form of CLA (BioProducts, Inc.) at a rate of ~150 g/d prepartum and ~225 g/d for 7 weeks postpartum resulted in a drop in milk fat concentration from 3.49 to 2.99% but only a tendency for a decrease in milk fat yield from 1.38 to 1.19 kg/d (Selberg et al., 2004). This product contained ~8% of the CLA as trans-10, cis-12 C18:2 so intake of trans-10, cis-12 CLA was ~20 g/d, indicating its potency to reduce milk fat.

## Marine Oils

The feeding of oils manufactured from salt-water fish in the oil form has depressed milk fat of lactating dairy cows. As intake of fish oil increased from 0 to 75 to 150 to 300 g/day (0%, 0.38%, 0.8%, and 1.8% of dietary DM), milk fat% decreased linearly (3.95, 4.05, 3.31, and 2.88% respectively) and the trans-10 C18:1 fatty acid increased linearly (0.29, 0.46, 1.11, and 4.15% of milk fatty acids) (Arola et al., 2002). Fish oil contains less than 9% C18:1 and C18:2 combined, those fatty acids that are the usual substrates used by ruminal microbes to produce trans-10 C18:1 and trans-10, cis-12 CLA. However, AbuGhazaleh and Jenkins (2004) showed that the C20:5 and C22:6 fatty acids in fish oil increased the trans C18:1 fatty acids and reduced the biohydrogenation of C18:1 and C18:2 in vitro. Therefore fish oil may act as a modifier of ruminal bacteria. On a commercial basis, dairy cows are sometimes fed fish meal. As dietary concentration of fish meal increased in corn silage-based diets (0, 2.6, 5.2, and 7.8% of dietary DM), milk fat concentration decreased linearly (3.5, 3.2, 3.1, and 3.0%, respectively) (Spain et al., 1995). However in their second study when the diets contained a nearly equal mix of corn silage and alfalfa silage, fat concentration and yield were similar (3.8 vs. 3.7% and 1.1 vs. 1.1 kg/d) in milk from cows fed diets containing 0 or 3.8% fish meal (DM basis). Although ruminal fluid pH was not measured by Spain et al. (1995), it is likely that pH was more acidic when alfalfa silage was omitted from the diet and therefore may have created an environment leading to a less complete hydrogenation of unsaturated fatty acids in the rumen; that is, greater trans fatty acid production.

## Whole Cottonseeds

Whole cottonseeds are a commonly fed feedstuff supplying fat, protein, and fiber to dairy cows. About 50% of seeds are processed by oil mills and 50% are fed directly to livestock (National Cottonseed Products Assoc. 1995). About 70% of the fatty acids in cottonseeds are unsaturated. This unsaturated fat can reduce milk fat % just as tallow has done. The milk fat% was numerically depressed by feeding whole cottonseeds (10 to 15% of dietary DM) in all nine studies in which corn silage was the main forage fed but was only significantly lower in two studies (Figure 3). The average depression was 0.29% units. In a longer term study from calving through 17 weeks postpartum, Jersey cows were fed diets of 0 or 12.9% whole cottonseeds in which all of the forage came from corn silage. Over the course of the study, cows fed whole cottonseeds produced milk of significantly lower milk fat% (4.60 vs. 4.88%) (Bertrand et al., 1998). As was the case with tallow, milk fat% responded differently to the feeding of whole cottonseeds if alfalfa hay partially or completely replaces corn silage. Milk fat% was increased by addition of whole cottonseeds to diets when alfalfa hay replaced 25% (3.55 vs. 3.30%) or 50% (3.46 vs. 3.25%) of the corn silage whereas whole cottonseeds had little effect on milk fat% when corn silage was the only forage (3.27 vs. 3.33%) (Smith et al., 1993). In another study, milk fat% was increased by addition of whole cottonseeds to diets when bermudagrass hay replaced 25% of corn silage (3.60 vs. 3.37%) or when cottonseed hulls replaced 25% of corn silage (3.73 vs. 3.53%) whereas whole cottonseeds had little effect on milk fat % when corn silage was the only forage (3.54 vs. 3.65%) (Adams et al., 1995). In this last experiment, alfalfa hay did not have the positive benefit that it did in the Smith et al. (1993) paper. Therefore the inclusion of a second forage such as alfalfa hay, bermudagrass hay, or cottonseed hulls with corn silage should be included in diets containing whole cottonseeds in order to generate a positive milk fat response. Applying the forage lessons learned from feeding tallow, the second forage should help buffer the rumen in order to be effective.




## Other Oil Seeds

In studies in which cows were fed the same diet throughout the experiment, milk fat concentration was unchanged when cows were fed whole or rolled sunflower seeds (7-10% of dietary DM) or rolled safflower seeds (10% of dietary DM) in diets containing at least 50% of the forage as alfalfa (Markus et al., 1996; Stegeman et al., 1992). Feeding regular rolled sunflower seeds high in C18:2 (9% of dietary DM) resulted in a drop in milk fat concentration from 3.14 to 2.43% whereas feeding sunflower seeds high in C18:1 did not affect milk fat concentration (2.92%) (Casper et al., 1988). The trans fatty acid content in milk fat was greatest in cows fed the regular sunflower seeds and the dietary forage was 75% corn silage. Feeding a 50:50 mix of extruded flaxseed and rapeseed (7.6% of dietary DM) in diets in which the main forage was corn silage depressed milk fat concentration from 3.65 to 2.98% but this was reversed when supplemental vitamin E was fed at ~20 times above the NRC recommendation (9616 IU/d) (Focant et al., 1998). However this reversal of milk fat depression by vitamin E was not accompanied by a reversal in the trans C18:1 increase in milk fat caused by feeding the oil seeds, suggesting that the milk fat depression was caused by something other than increased trans C18:1. However the trans-10 C18:1 was not reported. Feeding extruded soybeans (17% of dietary DM) reduced milk fat content by an average of 0.41% units

(3.20 vs. 2.79%) even when dietary forage was at least 25% alfalfa (Kim et al., 1991; Kim et al., 1993). However the daily production of fat was not changed due to an increase in milk production (31.1 vs. 34.1 kg/d) caused by feeding extruded soybeans. Extrusion of canola seeds (8.5% of dietary DM) resulted in a lowered milk fat concentration (3.14 vs. 3.86%) whereas feeding whole or ground canola seeds did not affect milk fat (Bayourthe et al., 2000) in corn silage diets. The feeding of roasted whole or ground soybeans (12-18% of dietary DM) had no effect on milk fat concentration of cows fed diets in which at least 25% of the forage was alfalfa (Faldet and Satter, 1991; Pires et al, 1996; Weiss and Wyatt, 2003).

## Yellow Grease

This fat is derived from the collection and processing of primarily restaurant grease but it can contain dead stock fat. Because restaurants have been using primarily vegetable oils for frying, yellow grease (YG) is primarily vegetable oil and thus has ~2 times more unsaturated fat than does tallow (Table 1). Because these cooking oils are exposed to high temperatures and moisture, they have an elevated maximum free fatty acid level (10 to 25%). When purchasing YG, select ones that have lower free fatty acid levels and contain antioxidants. Lactating dairy cows were fed corn silage-based diets of 0 or 5% YG (Jenkins and Jenny, 1989). Digestibility of dietary fiber (ADF) was reduced in cows consuming YG (21.6 vs. 31.6%). As a result, dry matter intake was reduced from 50.5 to 45.2 lb/d. Milk production, however, remained unchanged (69.4 and 70.5 lb/d for cows fed YG or control diet respectively) thus efficiency of milk production was improved. Milk fat % was depressed from 3.50 to 2.83% by feeding YG. This negative effect on feed intake and milk fat % may have been minimized if the feeding rate would have been reduced from 5% to 2%. Including YG at 2% of dietary DM in diets containing 45% alfalfa hay increased milk yield 2.5 kg/day and fat yield 60 g/day and did not affect milk fat % (Avila et al., 2000). In this same study, scientists substituted YG for tallow in order to examine how changing the degree of saturation affected cow performance. In these alfalfa hay-based diets, yield of milk (2.5 kg) and fat were increased without changing milk fat%. Onetti et al. (2001) also reported that tallow and choice white grease had the same effect on cow performance fed at 2 and 4% of dietary DM.

## Calcium Salts of Palm Oil (CSPO)

This product is prepared by reacting palm oil with sodium hydroxide and water by heating and then precipitating calcium salts using calcium chloride ($CaCl_2$). Unsaturated fatty acids prepared in this way are less “reactive” in the rumen and so negatively affect microbial fermentation to a lesser degree than untreated unsaturated fats (Chalupa et al., 1986). The acid conditions of the abomasum split the calcium from the fatty acids so that the fats are absorbed for metabolism in the small intestine. A review by Chilliard et al. (2001)

concluded from studying 29 different groups that cows fed an average of 0.6 kg/day of CSPO produced significantly more milk, an additional 0.9 kg/day, with no change in milk fat% compared to cows not fed CSPO. This was across several experiments and types of diets.

## ■ How Much Fat Can Be Fed?

As concentration of fat increases in the diet, negative effects of fat can be increased. When choice white grease was fed at 0, 2 or 4% of dietary DM in corn silage-based diets, milk fat% (3.30, 2.93, and 2.85%) and yield (1.39, 1.21, and 1.08%) decreased (Onetti et al, 2001). Tom Jenkins at Clemson University has developed some fat-feeding guidelines based upon the fiber concentration of the diet and the proportion of the unsaturated fatty acids in the fat supplement (Jenkins, 1993). The higher the fiber concentration of the diet, the more fat can be included in the diet. The greater the proportion of unsaturated fatty acids in the fat supplement, the less fat can be included in the diet because of the effect these unsaturated fats have on trans fatty acid production in the rumen. Cows fed diets containing more fiber usually have less acidic rumens and therefore fewer trans fatty acids are produced and milk fat depression is minimized. Two equations exist for estimating the maximum amount of supplementary fat inclusion in a ration: one using the NDF and a second using the ADF concentration of the diets. The current equations do not distinguish between diets that contain corn silage or alfalfa as the sole forage species.

Maximum dietary concentration of supplemental fat =

(6 x % dietary ADF) ÷ (% of unsaturated fatty acids as a % of total fatty acids in the fat supplement ÷ % of total fatty acids in fat supplement) x 100% and

(4 x % dietary NDF) ÷ (% of unsaturated fatty acids as a % of total fatty acids in the fat supplement ÷ % of total fatty acids in fat supplement) x 100%.

The unsaturated fatty acids considered are generally C18:1, C18:2, and C18:3. For tallow shown in Table 1, these add up to 47.1%. Tallow is considered to be 100% fatty acids. Therefore, a diet that contains the minimum ADF concentration of 19% may have a maximum dietary concentration of tallow of 2.4% [(6 x 19) ÷ (47.1%) ÷ (100%) x (100%)] without resulting in a milk fat depression. Using the NDF values from the corn silage-based diets from references cited in Table 1, no milk fat depression would be expected if tallow was fed at less than 2.6% (Onetti et al., 2001), 2.9% (Onetti et al., 2002), 2.8% (Ruppert et al., 2003), 2.9% (Adams et al., 1995), and 3.1% (Smith et al., 1993). However, milk fat depression was observed when tallow was fed at 2 to 2.5% of diet DM indicating that the equations may need to be adjusted if corn silage is the sole forage source in the diet. Equations that would have maximized tallow to <2 to 2.5% of dietary DM in the previous references have the initial coefficients reduced as follows:

(4.5 x % dietary ADF) ÷ (% of unsaturated fatty acids as a % of total fatty acids in the fat supplement ÷ % of total fatty acids in fat supplement) x 100% and

(2.5 x % dietary NDF) ÷ (% of unsaturated fatty acids as a % of total fatty acids in the fat supplement ÷ % of total fatty acids in fat supplement) x 100%.

As more studies are conducted with fat supplements in corn silage-based diets, proper equations can be developed.

Using the equation guidelines of Jenkins (1993), maximum feeding of whole cottonseeds is 8.9% when diets are of minimum fiber concentration. Whole cottonseeds are 18% fat with 71% of the fatty acids as unsaturated fatty acids. Therefore the maximum feeding of whole cottonseeds = (6 x 19) ÷ (71) ÷ 18 x 100 = 8.9%. The studies in Figure 3 fed diets of 10 to 15% whole cottonseeds. The pattern of milk fat depression across these corn silage-based studies may have been eliminated if level of dietary cottonseed had been reduced. Palmquist (1984) has recommended that dietary fat intake should not exceed milk fat output in order to prevent milk fat depression.

## ▪ Timing of Initiation of Fat Feeding

Introduction of fat supplements into the diet can occur prior to calving, right at calving, or a few weeks post calving. Studies on this topic have proven that fat feeding can begin at any of these times since positive results were obtained.

### Prepartum Feeding of Fat

Starting to feed fat in the close-up dry period can adjust the cow’s palate and the rumen bacteria to a fat-enriched diet so that feed intake is not reduced during those early days postpartum when minimizing negative energy balance is so important. The postpartum diet can contain additional energy from the fat to support the demands of milk production. At the University of Wisconsin, cows were fed diets of 5% prilled fat (low in unsaturated fatty acids) starting about 17 days prepartum and through 15 weeks postpartum (Skaar et al., 1989). Diets were 50% concentrate and 50% forage with forage being an equal mix of corn silage and alfalfa silage. The fat was introduced into the cow’s diet gradually by increasing the grain feeding gradually over time. The DM intakes were the same for the two groups of cows in the prepartum and postpartum periods. However, those cows fed prilled fat produced 4.3 kg/day more milk (37.3 vs. 41.6 kg/day) with no difference in milk fat%. All of this advantage from feeding prilled fat came during the warm season rather than the cool season. The liver of cows fed supplemental fat tended ($P < 0.15$) to contain more fat at freshening (27.5 vs. 26.1%, DM basis) and at 5 weeks postpartum (28.9 vs. 24.0%, DM basis). This increased liver fat may have been due to increased uptake of dietary fat from the blood stream rather than increased uptake of mobilized body fat because plasma NEFA concentrations were not increased in cows fed prilled fat. This tendency for elevated liver fat in cows fed prilled fat prepartum did not negatively affect cow performance; therefore, prepartum fat feeding proved very successful in this study. Cows fed Megalac-R® (The Arm and Hammer Animal Nutrition Group, Princeton, NJ) prepartum tended to produce more milk (4.7 kg/day) compared to cows started on the fat source at calving or at 28 days in milk (Cullens et al., 2004).

## Feeding Fat at Calving

Some have strategized to wait until calving before feeding a relatively expensive feedstuff like fat so that a marketable product (milk) could be realized to help cover the extra feed costs. At the University of Florida, multiparous cows were fed diets of 0 or 2.2% calcium salts of palm oil (Megalac®, The Arm and Hammer Animal Nutrition Group, Princeton, NJ) starting at calving through 15 weeks postpartum (Garcia-Bojalil et al., 1998). Milk production curves began to separate about 3 weeks postpartum with cows fed Megalac® having a 2.3 kg/day advantage after 13 weeks on trial. At the University of Wisconsin, first calf heifers also produced additional milk of approximately 1.5 kg/day when fed tallow at 2.8% of dietary DM from calving through 150 days postpartum in an alfalfa silage-based diet (Grummer et al., 1995). However the response was not observed until 7 weeks postpartum. Since there is delay from the start of fat supplementation to the point of milk response, some have argued that fat supplementation should be delayed until cows get through the worst part of negative energy balance. This would mean initiating fat supplementation around 4 to 6 weeks postpartum. However, would a positive response in milk production to fat supplementation have a shorter delay using this strategy? This question needs to be addressed in future studies.

## Feeding Fat Starting at 3 to 4 Weeks Postpartum

South Dakota workers summarized five studies in which cows were fed whole seeds (sunflower or extruded soybeans) at levels ranging from 4.2 to 17.5% from weeks 4 through 16 postpartum (Schingoethe and Casper, 1991). Cows fed the seeds produced 2.8% more milk (average increase of ~0.9 kg/day over the 91 days of seed feeding). However there was a delay of 3 to 4 weeks after seed feeding was initiated before a milk response was observed. By the end of the seed feeding period, cows fed seeds were producing 2.5 kg/day more milk (an 8.2% increase). A delay in milk response to supplemental fat was not eliminated when fat supplementation was postponed beyond calving. If cows spend one to three weeks in a “fresh group” as they do on some farms, a small amount of fat could be introduced at this time and then an increase in fat feeding made in the next group into which the cows move.

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