

Milk Fat Depression in Dairy Cows – Influence of Supplemental Fats

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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 if a liquid fat is added to the TMR. 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 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. Due to time and space limitations, those fat sources that are most commonly fed will be discussed in more detail. 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

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is considered moderately unsaturated. This is important because the degree of unsaturation influences microbial metabolism in the rumen and thus milk fat.

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 (isomers) 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.

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 fatty acids make up 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 when supplemental oilseeds were fed.

Milk Fat Depression and Fat Supplementation – The Traditional Theory

For some time, the negative effect of supplemental fats on milk fat concentration was attributed to the fat's reduction on ruminal digestion of dietary fiber. It was proposed that the physical coating of the fiber or of the microbes by fatty acids reduced fermentation by cellulolytic microbes resulting in less acetic acid being produced in the rumen. With less acetic acid being delivered to the mammary gland, less milk fat was synthesized and milk fat concentration was reduced. In addition, forage-digesting bacteria are pH sensitive and their number decrease with increasing acid conditions in the rumen. So this negative effect of supplemental fat on fiber digestion was aggravated when higher grain diets were fed. Interestingly, trans isomers of C18:1 were reported to increase in the milk following the feeding of soybeans, cottonseeds, or cod liver oil in the 1970's (Storry, 1988). It is only recently that scientists have been able to link some of these isomers to milk fat depression and thus caused us to rethink the mechanism causing milk fat depression via fat supplementation. Information on this new theory involving supplemental fat sources will be discussed below.

Effects of Individual Supplemental Fat Sources on Milk Fat

Tallow. Seven studies fed diets of 0 or 2 to 2.5% tallow in corn silage-based diets (38 to 50% of dietary DM) (Table 2). Feeding tallow significantly decreased DMI in 4 of the 7 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 three other studies, milk production was increased by 2.1 kg/d (Smith et al., 1993), 2.3 kg/d (Onetti et al., 2002), and 2.4 kg/d (Weiss and Wyatt, 2003). In all seven studies, milk fat % was significantly depressed from as little as 0.20% to as much as 0.68% units, with the average depression being 0.38% 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 1.42 to 1.49 kg of milk per kg of DM intake in these studies) and milk fat % will be decreased by 0.4 percentage units (e.g. from 3.35 to 2.97%).

This negative influence of tallow on milk fat concentration may 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 (Ruppert et al., 2003) 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 ruminal fluid (average pH of 5.92 vs. 6.04) likely due to the greater intake of starch. 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 ruminal 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 forage. Can these trans fatty acids be affecting synthesis of milk fat?

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 6th to the 16th 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 fat 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 (Grinari et al., 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. Weiss and Wyatt (2003) reported that cows fed tallow experienced a milk fat depression and they also had more than a three fold increase in the concentration of trans-10 C18:1 isomer in their milk fat.

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 linoleic acid can be formed in the rumen called conjugated linoleic acid (CLA). 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). Ruminant 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). AbuGhazaleh et al. (2005) demonstrated using continuous culture techniques that cis-C18:1 was converted to 10 different isomers of trans-C18:1 (trans-6 to trans-16 except trans-8) with the trans-10 isomer in greatest concentration. At a pH of 5.5, the dominant trans isomer was trans-10. In addition, more of the trans-10 isomer was found at a pH of 5.5 than at a pH of 6.5. Interestingly, they reported that more of the trans-10 isomer originated from sources other than cis-C18:1; that is, a significant part of the trans-10 isomer was made from other trans C18:1 isomers. This work provides valuable physiological evidence for the increased production of trans-10 C18:1 isomers from cis-C18:1. Therefore a significant portion of the oleic acid in the form of tallow that was supplemented to the corn silage-based diets fed by Onetti et al. (2001, 2004) and Ruppert et al. (2003) likely was directly or indirectly converted to trans-10 C18:1 in the rumen. 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 (Bauman and Griinari, 2003), thus potentially accounting for the depressed milk fat % due to the feeding of tallow. 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). By partially replacing corn silage with alfalfa (Onetti et al., 2004 and Smith et al., 1993), the ruminal fluid is less acidic and less of the trans-10 isomers are produced so milk fat synthesis is not reduced at the mammary gland.

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 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 (EnerG TR; Virtus Nutrition) is being marketed as a fat supplement to decrease milk fat concentration in markets based on milk fat quotas. Feeding a calcium salt form of CLA (Virtus Nutrition) 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 significantly lower in only 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% (3.30 vs. 3.55%) or 50% (3.25 vs. 3.46%) of the corn silage whereas whole cottonseeds had little effect on milk fat % when corn silage was the only forage (3.33 vs. 3.27%) (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 (3.37 vs. 3.60%) or when cottonseed hulls replaced 25% of corn silage (3.53 vs. 3.73%) whereas whole cottonseeds had little effect on milk fat % when corn silage was the only forage (3.65 vs. 3.54%) (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 practiced when 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 (continuous study), milk fat concentration was unchanged when cows were fed whole or rolled sunflower seeds (7 to 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). Again in continuous studies, the feeding of roasted whole or ground soybeans (12 to 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). Feeding rolled sunflower seeds, typically 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. Extrusion of the oilseeds appears to consistently depress milk fat concentration across a number of oilseed sources. Feeding a 50:50 mix of extruded linseeds and rapeseeds (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. In studies in which cows were fed the same diets throughout, 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. 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 (Kim et al., 1991; Kim et al., 1993). Again 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. Feeding extruded flaxseeds (13% of dietary DM) resulted in a numerical reduction in milk fat % (3.82 vs. 3.56%) in diets of 35% grass silage and 21% corn silage (Gonthier et al., 2005). The trans C18:1 fatty acids were in greater concentration in the plasma and milk fat. The extrusion process of oil seeds likely results in a faster and a greater availability of oil in the rumen than when whole or roasted oil seeds are fed.

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 higher temperatures and moisture, they have a higher maximum free fatty acid level (10 to 25%) and are therefore more likely to turn rancid. When purchasing YG, select ones that have lower free fatty acid levels and contain antioxidants. 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 %. In corn silage-based diets, lactating dairy cows fed YG at 5% of dietary DM had lower digestibility of dietary ADF (21.6 vs. 31.6%) than cows not fed YG, thus contributing to a 2.4 kg drop in DM intake (Jenkins and Jenny, 1989). Although milk production remained unchanged (31.5 and 32.0 kg/d for cows fed YG or control diet respectively) 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%.

Choice White Grease (CWG). This is an animal fat typically composed of a similar fatty acid profile as yellow grease (Table 1). Milk fat % was depressed from 3.5 to 3.0% when cows were fed diets (36% corn silage and 12% alfalfa hay) of 6% CWG (Tackett et al., 1996). Similarly milk fat % was depressed from 3.30 to 2.83% when cows were fed diets (50% corn silage) of 2% CWG (Onetti et al., 2001). In this study, the trans-10 C18:1 isomer but not the trans-10, cis-12 isomer was in greater concentration in milk fat of cows fed the CWG.

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 (CaCl₂). 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. Diets based on corn silage were not examined apart from those based upon a non grain-containing forage.

How Much Supplemental Fat Can Be “Safely” Fed?

What management steps can be taken to prevent milk fat depression when supplemental fats containing unsaturated fatty acids are fed? If a “low” ruminal fluid pH is an important factor contributing to milk fat depression, then those factors that help buffer pH need to be managed. If an unsaturated fat is brought into a ration and the cows respond with lowered milk fat, it may suggest that that group of cows were borderline acidotic to begin with. Certainly the effective fiber supply, a forage’s buffering capacity, and the presence of supplemental buffering and alkalinizing agents should all be considered. Also the amount of fat consumed has an influence. As concentration of fat increases in the diet, negative effects of fat can be increased. As one example, when choice white grease was increased from 0 to 2 to 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 kg/day) decreased (Onetti et al, 2001).

Dr. 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). His equations consider dietary fiber concentration and the degree of unsaturated fatty acids in the supplement. The higher the fiber concentration of the diet, the more fat can be included in the diet. Cows fed diets containing more fiber usually have a less acidic rumen and therefore fewer trans fatty acids are produced and milk fat depression is minimized. 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 can have on trans fatty acid production in the rumen. Two equations exist, one using the NDF and a second using the ADF concentration of the diet. The current equations do not distinguish between diets that contain corn silage or alfalfa as the sole or major forage species.

Maximum dietary concentration of supplemental fat =

$(6 \times \% \text{ dietary ADF}) \div (\% \text{ of unsaturated fatty acids as a \% of total fatty acids in the fat supplement} \div \% \text{ of total fatty acids in fat supplement}) \times 100\%$ and

$(4 \times \% \text{ dietary NDF}) \div (\% \text{ of unsaturated fatty acids as a \% of total fatty acids in the fat supplement} \div \% \text{ of total fatty acids in fat supplement}) \times 100\%$.

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% $[(6 \times 19) \div (47.1\%) \div (100\%) \times (100\%)]$ 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:

$(4.5 \times \% \text{ dietary ADF}) \div (\% \text{ of unsaturated fatty acids as a \% of total fatty acids in the fat supplement} \div \% \text{ of total fatty acids in fat supplement}) \times 100\%$ and

$(2.5 \times \% \text{ dietary NDF}) \div (\% \text{ of unsaturated fatty acids as a \% of total fatty acids in the fat supplement} \div \% \text{ of total fatty acids in fat supplement}) \times 100\%$.

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 = $(6 \times 19) \div (71) \div 18 \times 100 = 8.9\%$. 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.

Summary

- A variety of fat sources have depressed milk fat concentration including tallow (2%), yellow grease (5%), choice white grease (2%), hydrogenated soybean oil (3.3%), extruded oil seeds (17%), and fish oil (0.75%) (dietary DM basis).
- Milk fat depression is thought to be caused by a reduced synthesis of short-chain fatty acids by the mammary gland due to the formation of trans fatty acids (especially trans-10 C18:1 and trans-10, cis-12 CLA) 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 appear to be more susceptible to milk fat depression when unsaturated fats are supplemented. Partial substitution of corn silage with another forage such as alfalfa may alleviate this negative effect by making the rumen less acidic.

Keeping ruminal pH above 6.0 for most of the day will likely minimize the formation of trans isomers by ruminal microbes.

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Table 1. Major fatty acid composition of some fat sources (partially 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
Choice white grease ¹	24	11	48	12	1
Booster Fat ²	25	22	45	2	-
Megalac; EnerG-II ²	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 ³	17	3	7	1	1

¹ Onetti et al., 2001.

² Commercially prepared, partially ruminally inert fat sources (Church and Dwight Co.; Virtus Nutrition).

³ Also contains ~10% C16:1, ~11% C20:5, and 12% C22:6.

Table 2. Effect of feeding tallow on performance of lactating dairy cows fed diets containing 38 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*
Weiss and Wyatt, 2003	0	22.3	35.1	3.76
	2.35	21.9	37.5*	3.08*
Onetti et al., 2004	0	27.6	44.9	3.12
	2	25.9*	44.3	2.68*

* P ≤ 0.05 (estimated if reference did not report exact comparison).

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 1. Proposed schematic for isomerization and biohydrogenation of unsaturated fatty acids by anaerobic gut microbes. Adopted from Harfoot and Hazelwood, 1997; Bauman and Griinari, 2003; Mosley et al, 2002.) Solid and dotted lines represent the major and minor pathways respectively. All compounds may leave the rumen within the digesta. In addition, the trans monoenes may be isomerized to other trans monene isomers by microbial isomerases (Proell et al., 2002). In addition, Destailats et al. (2205) detected minute amounts of cis-9,trans-13,cis-15 C18:3 and of cis-9,trans-13 C18:2 in milk fat, possibly produced in the rumen.

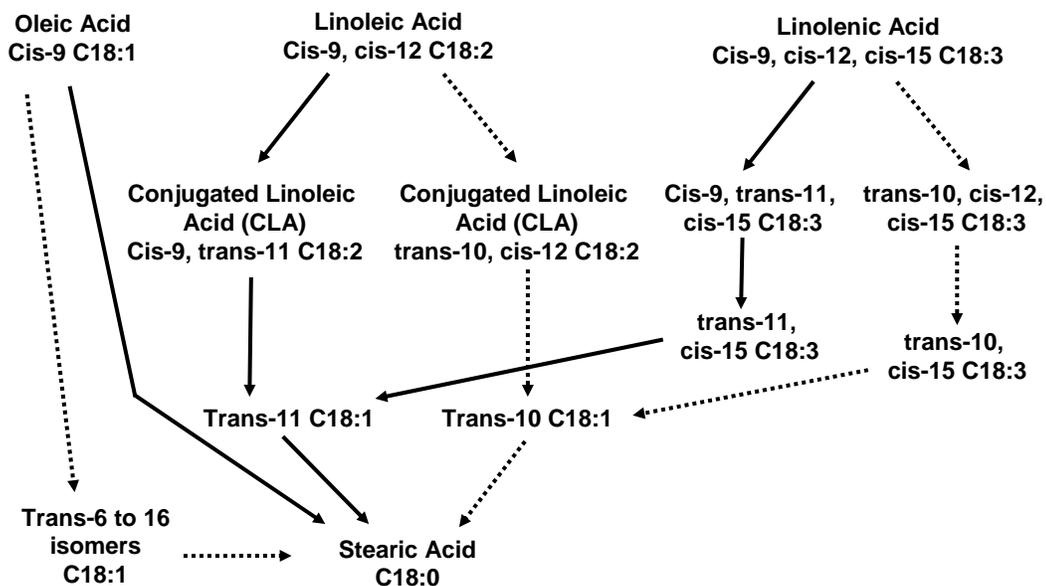


Figure 2. Cows fed high corn silage diets are more susceptible to milk fat depression during fat supplementation

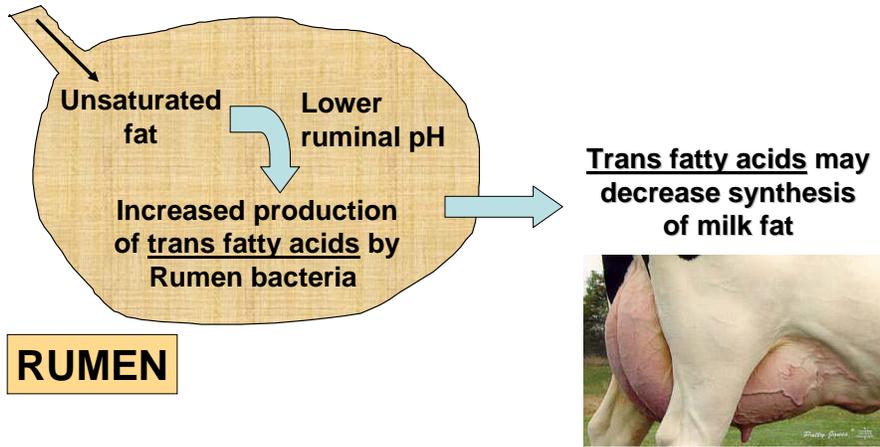


Figure 3. Feeding Whole Cottonseed (10 – 15%) in Corn Silage-Based Diets Reduces Milk Fat %

