Challenges of Meeting Cow Demands for Omega Fatty Acids

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FAT NOMENCLATURE

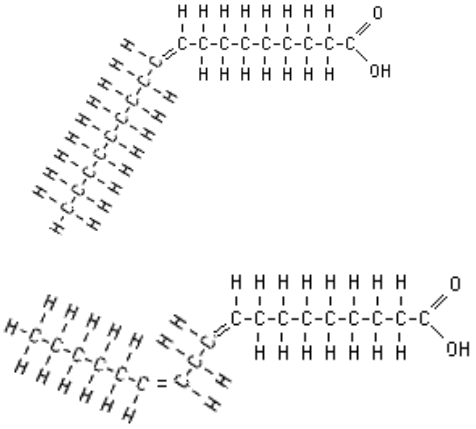
Fatty acids are chains of carbons that end in an acid group, or carboxyl group as it is referred to in biochemistry. Fatty acids vary in the length of the fatty acid chain and the number of double bonds. It is common to abbreviate fatty acids by listing the number of carbons in the chain:number of double bonds (Table 1). An example of a common fatty acid is stearic acid with 18 carbons and no double bonds, or C18:0. Fatty acids, such as stearic acid, are referred to as saturated because all the carbons are holding the maximum number of hydrogens possible, or the fatty acid is "saturated" with hydrogen. Stearic acid is low in plant oils, but present in higher amounts in animal fats, particularly in fats obtained from ruminant species such as beef tallow.

Table 1. Abbreviations of common fatty acids and their typical compositions in tallow and cottonseed.

Abbreviation[a]	Common Name	Tallow	Cottonseed
C14:0	Myristic	3.0	1.0
C16:0	Palmitic	25.0	23.0
C18:0	Stearic	21.5	3.0
C18:1	Oleic	42.0	18.5
C18:2	Linoleic	3.0	52.5
C18:3	Linolenic		

[a]Number of carbons:number of double bonds.
From Rouse (1996)

Figure 1. The structures of oleic and linoleic acids.



Oleic acid and linoleic acid are examples of unsaturated fatty acids containing one or more double bonds (Figure 2). Oleic acid has a single double bond between carbons 9 and 10, and is referred to as a monounsaturated fatty acid. Linoleic acid is a polyunsaturated fatty acid containing two double bonds between carbons 9 and 10, and between carbons 12 and 13.

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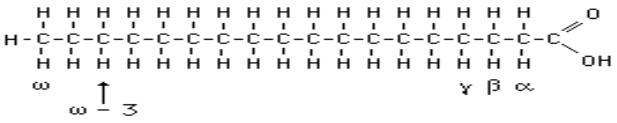
Oleic acid is the predominant fatty acid in animal fats and some plant oils, such as canola oil. Linoleic acid is the predominant fatty acid in many plant oils, including cottonseed oil, soybean oil, and corn oil.

Omega is a system for identifying the location of the terminal double bond in a fatty acyl chain. The omega carbon is the last carbon on the fatty acyl chain, or the one farthest from the carboxyl group (Figure 2). Omega fatty acids contain one or more double bonds, but only the position of the one closest to the omega carbon is given. For an ω-3 fatty acid, there are three carbons between the omega carbon and the closest double bond.

Figure 2. Carbons in a fatty acid chain are identified as α, β, or γ if they are 1, 2, or 3 carbons from the carboxyl group, or ω if it is farthest from the carboxyl group.



Omega fatty acids belong to one of three families, the ω-9, ω-6, or ω-3 family. Each family has a parent fatty acid that is converted to other biologically-active acids within the same omega family (Figure 3). The only parent fatty acid that can be made by body tissues is oleic acid. The ω-6 and ω-3 parent compounds (linoleic and linolenic acids) cannot be synthesized by body tissues and, therefore, must be supplied in the diet. Thus, linoleic and linoleic acids are regarded as essential because they are required for normal tissue function but cannot be synthesized by body tissues.

Figure 3. Parent fatty acids and major metabolites within each of the three omega fatty acid families.

Family Designation	Parent Fatty Acid	Major Metabolites
ω-9	C18:1 ω-9; oleic acid	C20:3 ω-9†; eicostrienoic acid
ω-6	C18:2 ω-6; linoleic acid	C20:4 ω-6; arachidonic acid
ω-3	C18:3 ω-3; linolenic acid	C20:5 ω-3; eicosapentaenoic acid
		C22:6 ω-3; docosahexaenoic acid

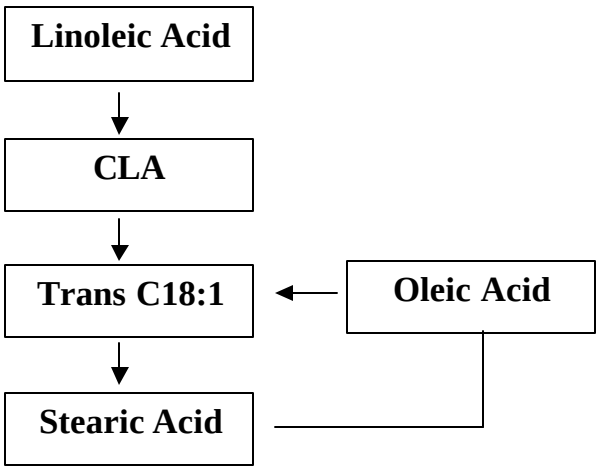
From Gorlin (1988)

A typical total mixed ration of grains and forages generally contains adequate essential fatty acids to meet the needs of the animal. However, the majority of the dietary essential fatty acids are destroyed by microorganisms in the rumen in a process called biohydrogenation.

BIOHYDROGENATION

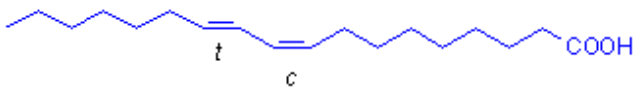
Food consumed by ruminants first passes through the largest of the four stomach compartments or rumen, which acts like a fermentation vat. Countless numbers of bacteria, protozoa, and fungi in the rumen ferment the feed releasing end products that are utilized by the host animal for maintenance and growth of body tissues. The microbial population in the rumen also is responsible for extensive transformation of dietary lipid (Figure 4). Lipid transformations include lipolysis to release free fatty acids from complex plant lipids, and biohydrogenation to convert unsaturated fatty acids in plant matter to more saturated lipid end products.

Figure 4. Major steps in the biohydrogenation of linoleic and oleic acids by ruminal microbes**.**



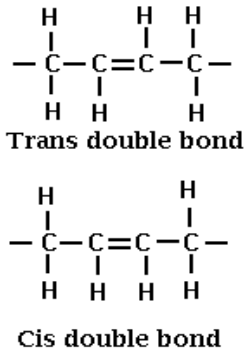
Biohydrogenation of linoleic acid in the rumen begins with its conversion to conjugated linoleic acid (CLA). In this initial step, the number of double bonds remains the same but one of the double bonds is shifted to a new position by microbial enzymes. Normally, the double bonds in linoleic acid are separated by two single bonds, but in CLA, the double bonds are only separated by one single bond (Figure 5). Many types of CLA are produced in the rumen of dairy cows, but a common CLA produced from biohydrogenation of linoleic acid is cis-9, *trans*-11 C18:2.

Figure 5. Basic structure of the most common CLA from ruminal biohydrogenation, the *cis*-9, *trans*-11 C18:2 isomer.



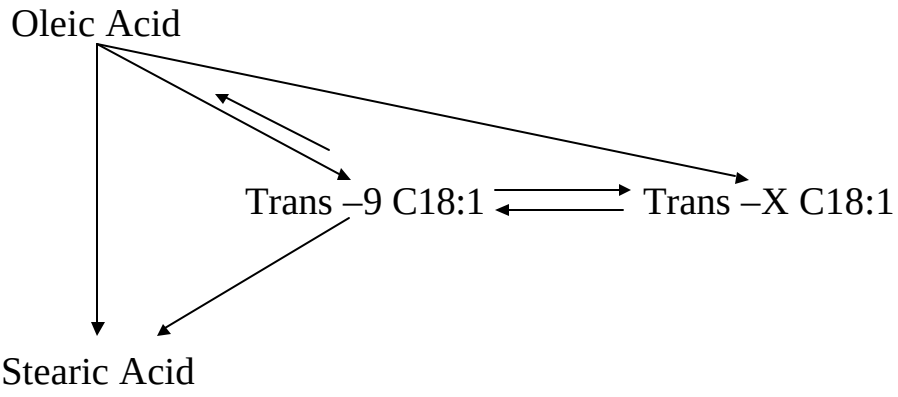
As biohydrogenation progresses, double bonds in the CLA intermediates are then hydrogenated further to *trans* fatty acids having only one double bond. A final hydrogenation step by the ruminal microbes eliminates the last double bond yielding stearic acid as the final end product. *Trans* double bonds only differ from *cis* double bonds in the placement of the hydrogens (Figure 6). The hydrogens are shown on opposite sides of the double bond for *trans* fatty acids, but on the same side of the double bond for *cis* fatty acids. Although the difference in structure between *trans* and *cis* fatty acids appears small, it causes significant differences in their physical and metabolic properties.

Figure 6. Structural differences between *cis* and *trans* fatty acids.



In cows on a typical forage diet, the major *trans* C18:1 present in ruminal contents is *trans*-11 C18:1. Most of the remaining isomers have double bonds distributed equally among carbons 12 through 16 (Bickerstaffe et al., 1972). The exact pathways for the production of these positional isomers are not known. Linoleic and linolenic acids are converted to several *trans* C18:1 and C18:2 intermediates during biohydrogenation. Mosley et al. (2002) recently showed that the biohydrogenation of oleic acid by mixed ruminal microorganisms involves the formation of several positional isomers of *trans* C18:1 rather than only direct biohydrogenation to form stearic acid as previously described. A later study (Proell et al., 2002) at Clemson University showed that a *trans*-9 C18:1 fatty acid isomer was converted to stearic acid but also converted to a number of C18:1 positional *trans* isomers. The conversion of oleic acid to mainly *trans*-9 and *trans*-10 and smaller amounts of *trans*-7, *trans*-8, and *trans*-11 was confirmed in a pure culture of the rumen isolate *Butyrvibrio hungatei* (Vossenberg and Joblin, 2003). Based on the results of these studies, oleic acid is converted to stearic acid as typically shown, but is also converted to *trans* C18:1 intermediates, demonstrating *trans*-to-*trans* and possibly even *trans*-to-*cis* isomerizations (Figure 7).

Figure 7. A proposed scheme of oleic acid biohydrogenation by ruminal microorganisms depicting the major intermediates and end products from ^{13}C tracer studies using GC/MS.



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

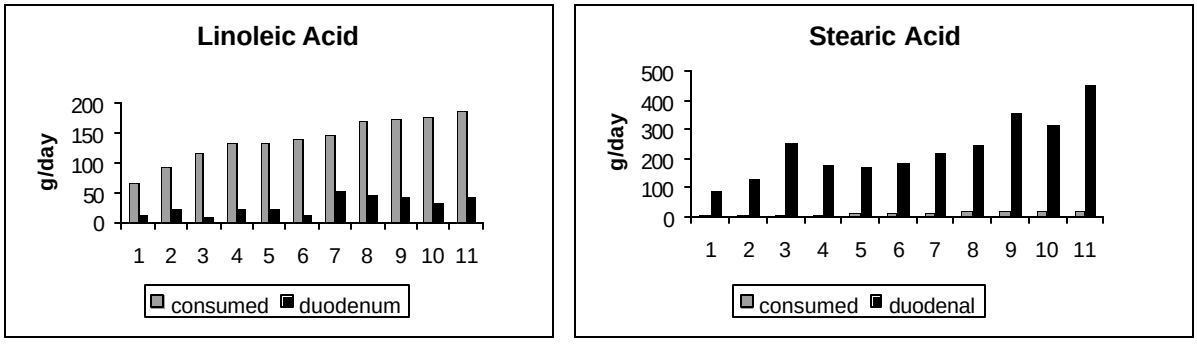
For instance, Gaynor et al. (1994) infused *cis* fat, composed of 65% high oleic sunflower oil and 35% cocoa butter, or *trans* fat, composed of 93% shortening and 7%

corn oil, into the abomasum of lactating dairy cows. Milk yield was not changed, however, milk fat percentage and milk fat yield were lower for the *trans* treatment. Similarly, Romo et al. (1996) infused into the intestines of cattle either a fat mixture high in *cis*-C18:1 isomers or a mixture high in *trans*-C18:1 isomers. Only the *trans*-$C_{18:1}$ treatment resulted in reduced milk fat content. Others followed with similar dairy cattle studies showing marked depressions in milk fat content during abomasal infusion of *trans* fatty acids (Chouinard et al., 1998; Loor and Herbein, 1998).

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

Biohydrogenation in the rumen greatly reduces the quantity of dietary unsaturated fatty acids reaching the small intestine of the cow. Intake of linoleic acid by dairy cows typically ranges from 70 to 200 g/day (Figure 8), with only 10 to 50 g of linoleic acid reaching the small intestine per day. As much as 500 g of stearic acid reaches the small intestines of dairy cows each day, even though just a few grams of stearic acid are consumed. Therefore, stearic acid is the primary fatty acid absorbed in cows regardless of the quantity of unsaturated fatty acids consumed in the diet.

Figure 8. Data from 11 published studies comparing daily intake vs duodenal flow of linoleic acid and stearic acid in lactating dairy cows fed typical diets without added fat.



BENEFITS OF OMEGA FATTY ACIDS

In humans, there is clear evidence that omega fatty acids are essential for normal development and needed to achieve good health throughout life. Early human development is affected by omega fatty acids through their effects on neural growth and later infant development. In later life, the omega fatty acids, especially those of the omega-3 family, protect against atherosclerosis and its related thrombotic complications (Willis and Smith, 1989). Marine omega-3 fatty acids have antithrombotic effects, modify platelet aggregation, decrease vascular adhesiveness, and minimize inflammatory responses in vessel walls (Uauy-Dagach and Valenzuela, 1996). The eicosenoid and leukotriene metabolites originating from the parent omega fatty acids also are associated with beneficial effects on inflammation and immunity (Nettleton, 1995).

Part of the interest in omega fatty acids in dairy cattle is to enhance their concentration in milk for value-added opportunities, and part is to enhance their concentration in body tissues of the cow to enhance production and health. Omega fatty acids in milk are increased to improve manufacturing properties and to increase fatty acid nutraceuticals known to enhance human health. Increasing omega fatty acids in tissues of the cow has potential benefits on reproductive performance, immunity and disease resistance, and positive hormonal shifts.

Manufacturing properties of milk. The hardness of milk fat has long been a concern of the dairy industry. Some applications require reducing hardness such as improving the spreadability of butter. Other applications are geared toward increasing hardness such as producing cheeses more desirable for grating. Hardness is determined by fatty acid composition of the milk fat and the molecular distribution of fatty acids on the triglyceride (Ashes et al., 1997). Processing technologies to alter milk fatty acid composition and distribution are currently being examined, but are hampered by high cost and sometimes complicated, lengthy procedures. An alternative to processing strategies is to utilize feeding, breeding, and environmental factors that influence the composition of milk.

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

A typical fatty acid composition of milk fat is 70-80% saturated and 20-30% unsaturated. Of the unsaturated fatty acids, the majority (>70%) is oleic acid, which is monounsaturated. The ideal milk fatty acid composition according to members of a Milk Fat Round Table discussion sponsored by the Wisconsin Milk Marketing Board

(O'Donnell, 1989) was less than 10% PUFA, up to 8% saturated fatty acids, and the remainder (82%) monounsaturated fatty acids.

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

Reproductive performance. In a few studies, feeding fat to lactating dairy cows has improved reproductive performance implying possible benefits on lifetime production potential. Reported improvements of reproductive performance from added fat include higher conception rates (Schneider et al., 1988; Sklan et al., 1989; Ferguson et al., 1990), increased pregnancy rates (Schneider et al., 1988; Sklan et al., 1991), and reduced open days (Sklan et al., 1991). However, supplemental fat has had little or no benefit on reproductive efficiency in other studies (Carroll et al., 1990; Schingoethe and Casper, 1991).

The mechanism of how fat supplements alter reproductive performance is not clear. Fat may function in one capacity by providing additional energy during early lactation to support improved productive functions, including reproduction. Negative energy balance delays ovulation and the initiation of the first normal luteal phase (Butler et al., 1981). However, recent studies also suggest that the mechanism involves an energy independent response to fat.

When an equal quantity of energy from glucose, saturated animal fat (tallow), or unsaturated fat (yellow grease) were infused into lactating dairy cows via the abomasum, the fat but not carbohydrate decreased plasma estradiol and increased progesterone (Oldick et al., 1997). The study by Oldick et al. (1997) also demonstrated the potential to decrease $PGF_{2\alpha}$ synthesis by supplying elevated concentrations of PUFA. These results were similar to previous reports that intravenous infusion of unsaturated fatty acids from a soy oil emulsion increased plasma $PGF_{2\alpha}$, and number and size of follicles (Lucy et al., 1990, 1991). Ovarian follicular growth was also stimulated more in Brahman x Hereford cattle by fat compared to equal energy from carbohydrate, with a greater effect observed for fats with higher PUFA (Thomas et al., 1997). Hinckley et al. (1996) provided further support of the role of PUFA on reproductive function in ruminants. In their study, dispersed bovine luteal cells had a dose-dependent decline in progesterone production and an increase in production of prostaglandin as PUFA in the media increased. More recently, Staples et al. (2000) showed that size of the dominant follicle was greater for Holstein cows fed Ca salts of linoleic acid or fish oil fatty acids compared to those fed calcium salts of

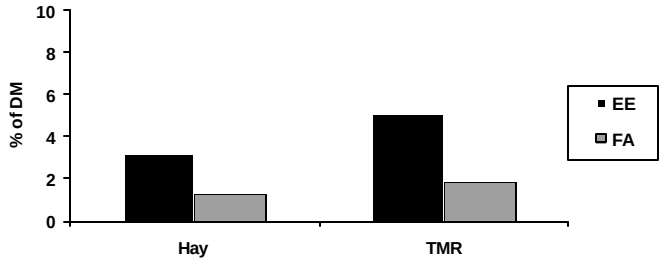
oleic acid. Results such as these continue to demonstrate a reproductive advantage from increased absorption of PUFA compared to other fat sources, such as monounsaturated fats.

FAT SOURCES AND THEIR CHARACTERISTICS

Expressions of Fat Content

Fatty acid content of fat supplements can be diluted by nonfatty acid components that have lower or no energy value. Fat content has traditionally been determined as the ether-extractable component of the feed. When defined in this manner, there can be considerable variation in fatty acid content among feed fats. Among the lowest is the ether extract in grains and forages. In addition to extracting fat, ether also extracts some carbohydrate, vitamins, and pigments. Therefore, fatty acids in corn grain are only 65% of the ether extract, and in alfalfa hay are only 40% of the ether extract (Figure 9) as shown by Palmquist and Jenkins (2002). Because of the problems inherent with ether extract, many laboratories have moved to determining fatty acid content of feeds instead of ether extract.

Figure 9. Ether extract vs fatty acid values for a typical hay and TMR fed to dairy cows.



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

Categories of Fat Sources

A useful way to classify fat supplements for dairy rations is based on their expected rumen response. Terminology varies widely for classifying fat sources according to nutritional effects, but most groupings consider the extent that a fat source depresses digestibility of the basal feed ingredients and the extent that the fat source resists

biohydrogenation. On this basis, fats can be classified as rumen-active, rumen-inert, or protected.

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

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

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

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

PROTECTED FATS

Probably the most widely known fat developed to resist biohydrogenation and increase milk polyunsaturated fatty acid levels was formaldehyde-treated lipid. This product

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

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

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

Fatty amides. Based on low degradation rates of amides by suspended bacterial populations (Steen and Collette, 1989), and the requirement of a free carboxyl group for biohydrogenation by ruminal microbes (Kepler et al., 1970), Fotouhi and Jenkins (1992a) proposed that amides of unsaturated fatty acids would resist biohydrogenation by ruminal microbes. Two in vitro trials demonstrated reduced loss of linoleic acid from ruminal cultures when the unsaturated fatty acid was supplied as an amide rather than as a free acid (Fotouhi and Jenkins, 1992a). In a later study, Fotouhi and Jenkins (1992b) reported that feeding linoleamide reduced the ruminal destruction of linoleic acid compared to feeding unprotected linoleic acid or calcium linoleate.

Amides of other unsaturated fatty acids were fed to ruminants to determine their resistance to biohydrogenation. A secondary amide was synthesized according to Feairheller et al. (1994) from butylamine and soybean oil. Diets containing 5% butylsoyamide, 5% soybean oil, or no added fat were fed to sheep for 32 d. Relative to the control diet, soybean oil increased plasma linoleic acid concentration 22% compared to a 58% increase in plasma linoleic acid from feeding butylsoyamide (Jenkins, 1995). When lactating Holstein cows were fed 3.5% added fat, linoleic acid concentration in milk averaged 3.60, 4.77, and 6.28% for the control, soybean oil, and butylsoyamide supplements, respectively (Jenkins et al., 1996).

Alkanolamides and substituted bisamides were also fed to sheep to determine their ability to increase unsaturated fatty acids in plasma (Jenkins and Thies, 1997). Fatty amides were prepared by reacting soybean oil with either ethanolamine or ethylenediamine to form N-hydroxyethylsoyamide and N,N'-ethylene *bis*-soyamide, respectively. Voluntary consumption of feed by sheep was severely reduced when it contained the bis amide resulting in the elimination of this treatment. Soybean oil added to the diet did not change plasma linoleic acid concentration. However, compared to the control diet, linoleic acid increased 35 and 113% in plasma and plasma triglycerides when sheep were fed the alkanolamide.

A number of studies also were conducted to examine the resistance of primary amides to ruminal biohydrogenation and their ability to enhance unsaturation in blood and milk. Oleamide added to ruminal in vitro cultures reduced the disappearance rate of oleic acid and maintained higher concentrations of this monounsaturated fatty acid at all incubation times (Reeves et al., 1998). When fed to lactating Holstein cows, oleamide increased oleic acid concentration in milk to 48.2% compared to 23.2% for a control diet and 35.1% for a diet containing added canola oil (Jenkins, 1998). Oleamide also increased milk oleic acid concentration when fed to lactating Holsteins at 1, 2, 3, 4, or 5% of the ration (Jenkins, 1999), or when fed to lactating Jersey cows at 3.5% of the ration (Jenkins, 2000).

Lundy et al. (2003) evaluated the ruminal biohydrogenation of oleic and linoleic acids in three forms; soybean oil, calcium salts of soybean oil, and amides of soybean oil. This was the first study examining the ruminal biohydrogenation of amides of unsaturated fatty acids in vivo. Omasal samples were taken from lactating Holstein cows to measure postruminal fatty acid flow and calculate the extent of biohydrogenation. Either the calcium salts or the

amides forms of the soybean oil did not appreciably reduce the biohydrogenation of linoleic acid. Calcium salts also had little effect on biohydrogenation of oleic acid, but the biohydrogenation of oleic acid was markedly depressed by the amides. The effectiveness of calcium salts or amides in resisting biohydrogenation appears to vary with individual fatty acids and perhaps the fatty acid composition of the fat source.

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