Variations in milk lipids

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Structure

Fats (if solid at room temperature) and oils (if liquid) are in the class of compounds known as lipids. Around 95-98% of the lipids in milk are comprised of triacylglycerols, which are abbreviated TG and better known as triglycerides (McGibbon & Taylor, 2006) (Figure 1).

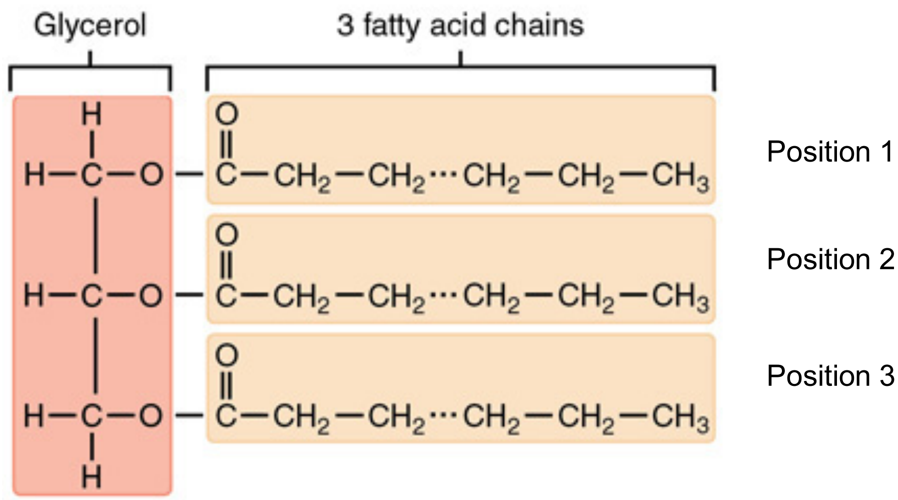

Figure 1. A triglyceride molecule, showing three fatty acids attached to a glycerol backbone.

TG are composed of a glycerol backbone with three fatty acid (FA) molecules attached. TG in milk contain 26-54 carbon atoms with a myriad of possible arrangements of FA on the backbone (Jensen, 2002). The typical FA profiles of cow, goat, and sheep milk are shown in Table 1.The abbreviations correspond to the number of carbon atoms in the molecule and the number of double bonds it has, separated by a colon. Note that roughly half of the FA in milk is comprised of palmitic (16:0) and oleic (18:1) acids. The *cis* and *trans* designations refer to whether the hydrogen atoms along the double bond are on the same side or on opposite sides. Oleic and vaccenic acids both contain 18 carbon atoms with one double bond, but the atoms are arranged differently. Elaidic acid (18:1 *trans*-9), identified as the primary *trans*-fat in hydrogenated fat, is found in miniscule amounts in milk and is not shown. CLA, conjugated linoleic acid, comprises a class of nearly 30 similar FA; the predominant one in milk is rumenic acid, abbreviated as 18:2 *cis*-9, *trans*-11. Humans convert vaccenic acid to rumenic acid. The double bonds in CLA are closer together than in α-linoleic acid.

FA are saturated if they do not contain a double bond (they are saturated with hydrogen atoms) and are unsaturated if they contain at least one double bond. Monounsaturated fatty acids (MUFA) contain one double bond and polyunsaturated fatty acids (PUFA) contain more. Some structures are shown in Figure 2.

Table 1. Principal fatty acids in milk of cows, goats, and sheep, in grams of fatty acid per 100 g of fat (Chouinard et al., 1999; Park et al., 2007).

Fatty acid		Concentration (g/100 g)		
Common name	Abbreviation	Cow	Goat	Sheep
Butyric	4:0	4.2	2.2	3.5
Caproic	6:0	2.2	2.4	2.9
Caprylic	8:0	1.2	2.7	2.6
Capric	10:0	2.7	10.0	7.8
Lauric	12:0	3.1	4.0	4.4
Myristic	14:0	11.1	9.8	10.4
Pentadecanoic	15:0	1.2	0.7	1.0
Palmitic	16:0	27.0	28.2	25.9
Palmitoleic	16:1	1.5	1.6	1.0
Margaric	17:0	0.6	0.7	0.6
Stearic	18:0	11.0	8.9	9.6
Oleic	18:1 *cis*-9	23.9	19.3	21.1
Vaccenic	18:1 *trans*-11	1.9	0.7	1.0
α-Linoleic	18:2 *cis*-9, *cis*-12	2.5	3.2	3.2
Rumenic	18:2 *cis*-9, *trans*-11	0.7	0.7	0.7
Linolenic	18:3	0.4	0.4	0.8

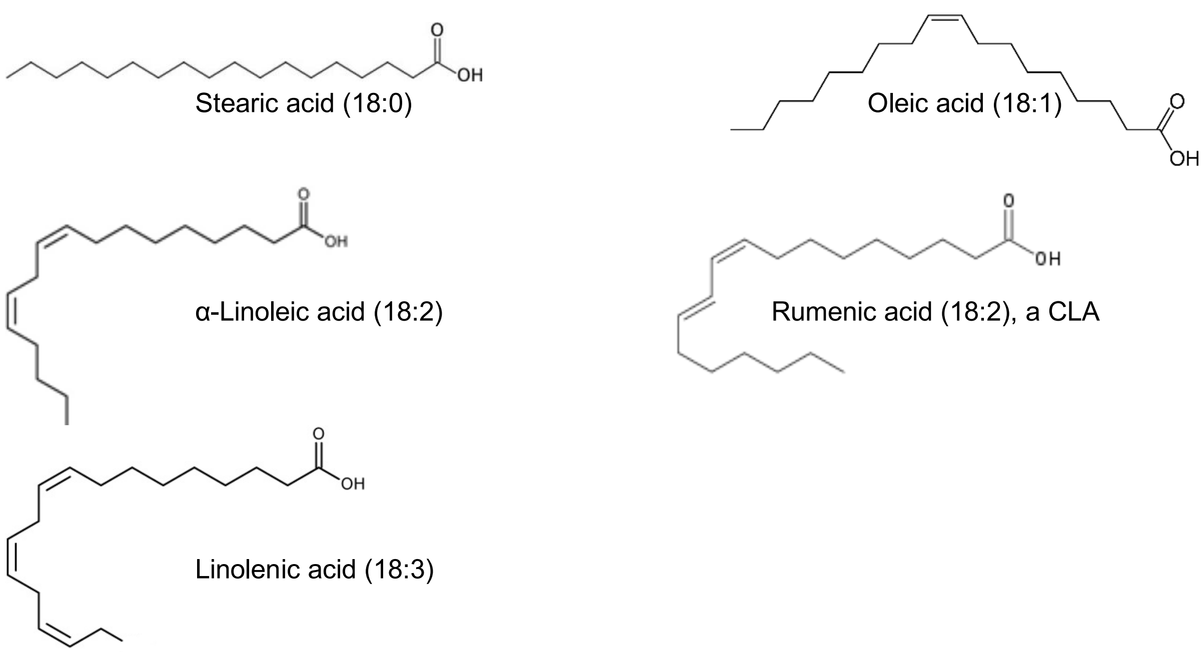

Fig. 2. Skeletal structures of major 18-carbon fatty acids found in milk.

FA and TG in milk are assembled in the mammary gland and are derived from feed and from microbial activity in the rumen of the animal. Variations occur because of species, diet, season, health of the animal, stage of lactation, and other factors. The mammary gland in ruminants synthesizes FA containing an even number of carbons from 4 to 14, along with some 16:0. The remaining 16:0 and the longer FA arise from dietary lipids and breakdown of TG in adipose tissue. Bacterial flora in the rumen synthesize the relatively small numbers of FA with an odd number of carbons. FA may be desaturated in the mammary gland to form unsaturated acids (Månsson, 2008).

The positioning of FA on the TG molecule is not random: nearly all of 4:0, 6:0, and 8:0 are found at position 1, most of the 14:0 and 16:0 occur in position 2, and most of the FA containing 18 carbons are located at the positions 1 and 3 (Blasi et al., 2008). TG in milk from goats and sheep appear to be similar to bovine TG in this regard (Park et al., 2007). FA may be broken away from the backbone by activity of lipase enzymes, thus becoming free fatty acids (FFA). When we consume dairy products, lipases in the mouth and stomach preferentially attack the TG molecule at position 3 (Williams 2000). Therefore, the shorter and longer FA are much more likely to become FFA in the digestive system than the medium-size FA.

Milkfat floats in milk in the form of globules surrounded by a membrane composed of two-thirds lipid and one quarter protein. Most of the lipid in the milkfat globule membrane consists of TG, but some 40% is phospholipid (Fong et al., 2007), a molecule that is similar to a TG except that a phosphate group is attached to the glycerol backbone instead of the third FA. The phosphate groups, which are aligned on the outside of the membrane, are water-soluble and the FA, which point toward the globule, are not. This emulsification prevents globules from coalescing in the fluid portion of the milk and also protects their contents from the action of lipases. Milkfat also contains a small amount of mono- and diglycerides, which have only one or two FA, as well as fat-soluble vitamins (A, D, E, and K), sterols (such as cholesterol), and FFA.

Saturated and Unsaturated Fatty Acids

Dairy fats account for around 21% of the saturated fat intake in the US, but there is no consistent evidence that milkfat levels are associated with an increased risk of cardiovascular disease, coronary heart disease, or stroke (Huth and Park, 2012). Detailed metabolic studies have shown that short-chain and medium-chain FA have minimal effect on plasma LDL and cholesterol levels, only 12:0, 14:0, and 16:0 contribute to higher levels, and 18:0 is considered neutral (Williams 2000). It is not clear whether these effects are due to TG structure, the FA themselves, or some other factor (Mensink, 2005).

MUFA do not appear to influence inflammatory effects in the body, but various aldehydes produced in the oxidation of PUFA, as well as sugars, are known to initiate or advance inflammation, cancer, asthma, type 2 diabetes, and atherosclerosis (Lawrence, 2013). Saturated fats alone might not be responsible for many of the adverse health effects with which they have been associated, but oxidation of PUFA may be the cause of any association that have been found (Lawrence, 2013).

CLA and Omega-3 Fatty Acids

Dairy products contribute about 75% of the total CLA in the human diet. CLA has been identified as a factor against cancer, obesity, diabetes, and atherosclerosis, while helping with modulation of the immune system and bone growth (Lock and Bauman, 2004). A study in our laboratory of milk from adjacent farms, one with cows on pasture and other with cows fed conventionally, revealed that grazing increased the rumenic acid content in milk by 29-36% (Tunick et al., 2016); a nation-wide study of conventional and organic milk from 14 processors showed an 18% increase (Benbrook et al., 2013).

Much research has been directed toward omega-3 FA, which contain a double bond located three carbon atoms from the end farthest from the glycerol backbone. The omega-3 FA of note in milk is α-linolenic acid (18:3); it and linolenic acid (18:2, an omega-6 FA) serve as precursors to other FA that the body requires, namely EPA (20:5) and DHA (22:6). In fact, 18:2 and 18:3 are regarded as essential FA since the body needs them and must obtain them from the diet (Simopoulos, 2006). Our comparison of two farms indicated that milk from pasture-fed cows contained 28-56% more 18:3 than milk from the adjacent conventional farm (Tunick et al., 2016). A nation-wide survey of milk revealed that organic milk averaged 60% more 18:3 than conventional milk (Benbrook et al., 2013).

Omega-6 FA cannot be converted to omega-3 FA in the body since mammals lack the enzyme required. Humans used to consume the two in about equal amounts, but in today's Western diets the ratio is around 16 to 1 (Simopoulos, 2006). In milk, the ratio is within the recommended 4 to 1.

Trans-Fatty Acids

Trans-FA have been linked to coronary heart disease, but the harmful types of these (especially elaidic acid, 18:1 *trans*-9) are found in very low levels in milk (Mozaffarian et al., 2006). Vaccenic acid (18:1 *trans*-11) is a *trans*-FA that occurs in milk, but it is a precursor of rumenic acid (the main CLA in milk) and is considered beneficial (Park et al., 2007).

Flavor and Mouthfeel

People do not consume dairy products simply because of the health aspects – they also enjoy the flavor. TG do not contribute to flavor because their large size makes them nonvolatile. In contrast, short- and medium-chain FA (containing up to 12 carbon atoms) are volatile, have low perception thresholds (we can detect them at parts-per-million concentrations), and are responsible for some of the characteristic flavors of dairy products (Curioni and Bosset, 2002). Goat and sheep milk contain higher levels of short- and medium-chain FA than cow milk, resulting in stronger cheese flavors. Branched-chain FA come from breakdown of proteins instead of lipids and are also noted components of goat and sheep milk cheeses. FFA are precursors of other compounds that result from action of lipases (Curioni and Bosset, 2002), and lipids serve as solvents for these and other compounds that provide flavors.

Mouthfeel, which results from physical stimulation of receptors in the mouth, is also an important part of the eating experience. Milkfat melts just below body temperature (35°C) and exhibits gradual and complete melting in the mouth. It is perceived to have smooth mouthfeel and imparts a desirable cooling sensation in the mouth as it melts. Perceived aroma is related not only to volatile compounds in the nose but also to sensations of taste and mouthfeel (de Roos, 2006). Studies using TG containing 8:0 and 10:0 have shown that lipid deposition on the tongue and other oral surfaces is related to sensory perception (Pivk et al., 2008).

Summary

The FA in milkfat have different lengths, levels of saturation, and molecular arrangements. They also have some effects on human health, although the influence of saturated fats appears to have been overstated. CLA and omega-3 FA found in dairy products are essential to health and are increased in milk from grass-fed animals.

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