Report

Fatty acids in bovine milk fat

Helena Lindmark Månsson

Swedish Dairy Association, Lund, Sweden

Abstract

Milk fat contains approximately 400 different fatty acid, which make it the most complex of all natural fats. The milk fatty acids are derived almost equally from two sources, the feed and the microbial activity in the rumen of the cow and the lipids in bovine milk are mainly present in globules as an oil-in-water emulsion. Almost 70% of the fat in Swedish milk is saturated of which around 11% comprises short-chain fatty acids, almost half of which is butyric acid. Approximately 25% of the fatty acids in milk are mono-unsaturated and 2.3% are poly-unsaturated with omega-6/omega-3 ratio around 2.3. Approximately 2.7% are trans fatty acids.

Keywords: *milk fat*; *fatty acid composition*; *bovine*

Milk composition

Today, not only the nutritional value of milk but also other physiological properties of milk components have attracted interest (1). Bovine milk contains approximately 87% water, 4.6% lactose, 3.4% protein, 4.2% fat, 0.8% minerals and 0.1% vitamins (2). The composition of milk continuously undergoes changes depending on e.g. breeding, feeding strategies, management of the cow, lactation stage and season (2–4).

Milk fat

The lipids in bovine milk are mainly present in globules as an oil-in-water emulsion (5). These fat droplets are formed by the endoplasmic reticulum in the epithelial cells in the alveoli and coated with a surface material of proteins and polar lipids. When secreted, they are enveloped with the plasma membrane of the cell. Membrane-associated materials can comprise 2–6% of the globule mass (6, 7). The composition and structure of the milk fat globule membrane (MFGM) is not known in detail but it is mainly composed of polar lipids and membrane-bound and associated proteins. The lipid fraction comprising approximately 30% of the membrane material consists of lipids such as phospholipids (25%), cerebrosides (3%) and cholesterol (2%). The remaining 70% of the membrane material are proteins, many of them being enzymes (8). The milk fat consists mainly of triglycerides, approximately 98%, while other milk lipids are diacylglycerol (about 2% of the lipid fraction), cholesterol (less than 0.5%), phospholipids (about 1%) and free fatty acids (FFA) (about 0.1) (9). In addition, there are trace amounts of ether lipids, hydrocarbons, fat-soluble vitamins, flavour compounds and compounds introduced by the feed (10). The size of the milk fat globule (MFG) increases with increasing fat content in the milk probably because of a limitation in production of MFGM (11). The number of MFG in milk is approximately 10^{10} per mL with a total area of 700 cm^2 per mL of milk (4). The size of the MFG has crucial influence on the stability and technological properties of milk. Milk lipid globules are resistant to pancreatic lipolysis in the small intestine unless they are first exposed to gastric lipolysis (12).

Origin of milk fatty acids

The milk fatty acids are derived almost equally from two sources, the feed and the microbial activity in the rumen of the cow (10). The fatty acid synthesising system in the mammary gland of the cow produces fatty acids with even number of carbons of 4–16 carbons in length and accounts for approximately 60 and 45% of the fatty acids on a molar and weight basis, respectively (13). This *de novo* synthesis in the mammary gland is of the 4:0–14:0 acids together with about half of the 16:0 from acetate and β-hydroxybutyrate. Acetate and butyric acid are generated in the rumen by fermentation of feed components. The butyric acid is converted to β-hydroxybutyrate during absorption through the rumen epithelium. Bovine fat contains certain fatty acids with odd number of carbons, such as pentadecanoic acid (15:0) and heptadecanoic acid (17:0). These two fatty acids are synthesised by the bacterial flora in the rumen (14). The remaining 16:0 and the long-chain fatty acids originate from dietary lipids and from lipolysis of adipose tissue triacylglycerols (10). Medium- and long-chain fatty acids, but mainly 18:0, may be desaturated in the mammary gland to form the corresponding monosaturated acids.

Fatty acids are not randomly esterified at the three positions of the triacylglycerol molecule (5). The short-chain acids butyric (4:0) and caproic (6:0) are esterified

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almost entirely at *sn*-3. Medium-chain fatty acids (8:0–14:0) as well as 16:0 are preferentially esterified at positions *sn*-1 and *sn*-2. Stearic acid (18:0) is selectively placed at position *sn*-1, whereas oleic acid (18:1) shows preference for positions *sn*-1 and *sn*-3.

When consumed by humans, milk triacylglycerols are lipolysed by lingual lipases in the mouth and by both lingual and gastric lipase in the stomach (10). The lipases preferentially hydrolyse *sn*-3 position fatty acids, and therefore selectively releases the shorter acids. The result is that 4:0–10:0 pass through the stomach wall in decreasing quantities as the molecular weight increases, enter the portal vein, and are transported to the liver where they are oxidised. About 25–40% of the triacylglycerols are digested in the stomach (15).

Fatty acid composition

Milk fat triacylglycerols are synthesised from more than 400 different fatty acids, which makes milk fat the most complex of all natural fats (9, 10, 15). Nearly all of these acids are present in trace quantities and only about 15 acids at the 1% level or higher. Many factors are associated with the variations in the amount and fatty acid composition of bovine milk lipids (15, 16). They may be of animal origin, i.e. related to genetics (breed and selection), stage of lactation, mastitis and ruminal fermentation, or they may be feed-related factors, i.e. related to fibre and energy intake, dietary fats, and seasonal and regional effects. The gross composition of milk fat in Swedish dairy milk 2001 was 69.4% saturated fatty acids and 30.6% unsaturated fatty acids (Lindmark-Månsson, 2001). The content of saturated fatty acids is lowest in the summer when the cows are grazing, and highest in the winter due to indoor feeding. The content of the unsaturated fatty acids shows the opposite pattern with the highest amount in the summer. The fatty acid composition of Swedish milk fat is given in Table 1.

The saturated fatty acids present in milk accounts for approximately 70% by weight (5). The most important fatty acid from a quantitative viewpoint is palmitic acid (16:0), which accounts for approximately 30% by weight of the total fatty acids. Myristic acid (14:0) and stearic acid (18:0) make up 11 and 12% by weight, respectively. Of the saturated fatty acids, 10.9% are short-chain fatty acids (C4:0–C10:0). The amounts of butyric acid (4:0) and caproic acid (6:0) on a yearly average are 4.4 and 2.4% by weight of the total fatty acids, respectively, in Swedish dairy milk (2). These amounts are higher when their proportions are expressed as molar percentages, approximately 10 and 5%, respectively (5).

Approximately 25% of the fatty acids in milk are mono-unsaturated with oleic acid (18:1) accounting for 23.8% by weight of the total fatty acids in Swedish dairy milk. Poly-unsaturated fatty acids constitute about 2.3% by weight of the total fatty acids and the main poly-unsaturated fatty acids are linoleic acid (18:2) and α-linolenic acid (18:3) accounting for 1.6 and 0.7% by weight of the total fatty acids. The ratio between omega-6 and omega-3 fatty acids in Swedish milk fat was 2.3:1 in 2001 (2). Milk and meat from ruminants can be

Table 1. Fatty acid composition expressed as percent by weight of total fatty acids in Swedish dairy milk in 2001, given as weighted means with standard deviations (SD) and as the minimum and maximum weighted means. The estimation of the weighted mean values was based on the proportion of milk delivered to each dairy or dairy company at each sampling occasion (seven dairies at four sampling occasions during 2001). The lowest and highest values observed and *p*-values for geographical and seasonal variation are also given

Fatty acid	Weighted mean 2001	SD	Lowest value observed	Highest value observed	Seasonal variation
4:0	4.4	0.1	4.0	5.1	n.s.
6:0	2.4	0.1	2.1	2.9	n.s.
8:0	1.4	0.1	1.2	1.9	n.s.
10:0	2.7	0.2	2.4	3.5	*
12:0	3.3	0.2	3.0	4.1	**
14:0	10.9	0.5	10.0	12.1	***
15:0	0.9	0.0	0.8	1.1	n.s.
16:0	30.6	0.9	28.7	34.1	**
17:0	0.4	0.0	0.4	0.5	**
18:0	12.2	0.4	10.3	13.3	n.s.
20:0	0.2	0.0	0.2	0.2	n.s.
Saturated fatty acids total	*69.4*	*1.7*	*67.1*	*74.4*	***
10:1	0.3	0.0	0.2	0.4	n.s.
14:1	0.8	0.4	0.4	1.3	**
16:1	1.0	0.0	0.9	1.8	n.s.
17:1	0.1	0.0	<0.1	0.3	n.s.
18:1	22.8	1.0	19.7	24.7	***
Mono-unsaturated faty acids, cis, total	*25.0*	*1.0*	*22.2*	*26.7*	**
18:2	1.6	0.1	1.4	1.8	n.s.
18:3	0.7	0.0	0.6	0.9	**
Poly-unsaturated fatty acids, cis, total	*2.3*	*0.1*	*2.0*	*2.5*	n.s.
16:1t	0.4	0.1	0.3	0.4	***
18:1t	2.1	0.7	2.0	3.3	***
18:2t	0.2	0.0	0.1	0.5	n.s.
Trans fatty acids total	*2.7*	*0.7*	*0.6*	*3.9*	***
CLA	0.4	0.1	0.3	0.5	***

n.s.: Not significant; *$p<0.05$; **$p<0.01$; ***$p<0.001$.

an important source of omega-3 fatty acids in the human diet, as is the case in France, where animal products account for about 40% of the intake (17).

Approximately 2.7% of the fatty acids in milk are trans fatty acids with one or more trans-double bonds (18). The main trans 18:1 isomer is vaccenic acid (VA), (18:1, 11t), but trans double bounds in position 4–16 is also observed in low concentrations in milk fat (5). VA constitutes approximately 2.7% of the total fatty acid content and varies with season. Milk fat contains also conjugated linoleic acid (CLA), with many different isomers including rumenic acid (RA) (cis-9, trans-11 CLA) which predominates (75–90% of total CLA) (18). The majority of RA in the milk fat is synthesised endogenously, in the mammary gland through the action of mammary Δ-desaturase on VA (19). Thus both VA and RA are present in milk and dairy products, generally in the ration of about 1:3 (20). VA has a double role in metabolism because it is both a trans fatty acid and a precursor for 9c, 11t-CLA. A small amount of the CLA originates from biohydrogenation of unsaturated fatty acids by rumen bacteria. Animal studies and new human data have confirmed the bioconversion of VA into CLA (21, 22). Bovine milk, milk products and bovine meat are the main dietary sources of the RA (23). Milk content of 9c, 11t-CLA varies considerably, but in Swedish milk fat it constitutes about 0.4% of the fat fraction.

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Helena Lindmark Månsson
Swedish Dairy Association, Ideon Science Park,
SE-223 70, Lund, Sweden
E-mail: helena.lindmark-mansson@svenskmjolk.se