MEGALAC®

Technical Bulletin

Richard Kirkland

Dietary fatty acids : Effects on milk fat and dairy products.

Milk fat is a complex mix of fatty acids which contribute to and influence the properties of manufactured dairy products. Despite dairy diets containing only five primary fatty acids, as a result of ruminal biohydrogenation, milk fat can contain over 400 different fatty acids, each with its own characteristics and physical attributes.

1. Origin of milk fat

Milk fat is composed of fatty acids originating from two main sources : *de novo*-synthesised and dietary origin, with the balance supplied by fat released from body reserves.

i) *De novo* synthesis – fat manufactured in the udder from acetate and butyrate resulting from digestion of fibre in the rumen. This accounts primarily for the short- and medium-chain fatty acids of 4 to 14 carbons and about half of the palmitic acid (C16:0) in milk fat.

ii) Dietary fat – direct supply of fat from the diet accounts for the other half of the C16:0, as well as the 18-carbon (and above) fatty acids in milk fat (e.g. stearic acid, C18:0; oleic acid, C18:1; linoleic acid, C18:2). Approximately 50% of milk fat originates from dietary fat.

A varying proportion of milk fat will arise from mobilisation of body reserves; a higher proportion originates from this source in early lactation than in later stages of lactation when cows are in positive energy balance.

2. Structure of milk fat

Milk fat exists primarily (typically around 95%) in the form of triglycerides in which three individual fatty acids are esterified to glycerol. The positions occupied by these fatty acids are numbered relative to their stereospecificity, or stereo-specific numbering (*sn*), as *sn*-1, *sn*-2 and *sn*-3 (Figure 1) (Karupaiah and Sundram, 2007).

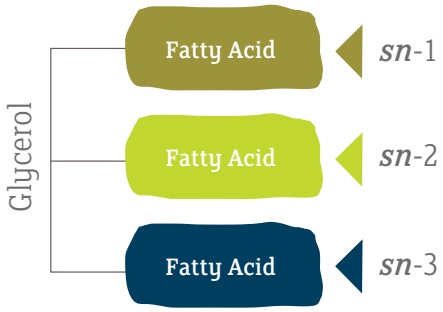

Figure 1: Structure of milk fat triglycerides

2.1 Milk fat globules

Milk fatty acids are almost never secreted in their free form, but in the form of milk fat globules. These globules have a triglyceride core covered with three layers of phospholipids and proteins derived from the cellular membranes of the mammary gland (Argov-Argaman, 2019). Size and stability of globules are influenced by many factors and have important effects on milk fat properties, including sensory characteristics, when used in processing and manufacture of dairy products.

3. Fatty acids in milk fat

Given the nature of milk fat synthesis it's no surprise that milk fatty acid profile varies, though as a general guideline approx. 70% of milk fat is composed of saturated fatty acids (SFA) with the remainder composed of mono-unsaturated fatty acids (MUFA) and poly-unsaturated fatty acids (PUFA).

Primary fatty acids in milk fat, melting points and concentration range are presented in Table 1.

Table 1: Primary fatty acids in milk fat (from Jensen, 2002)

Fatty acid	Name	Average range (wt %)	Melting point (°C)	Category
C4:0	Butyric	2-5	-7.9	SFA
C6:0	Caproic	1-5	-3.4	SFA
C8:0	Caprylic	1-3	16.7	SFA
C10:0	Capric	2-5	31.6	SFA
C12:0	Lauric	2-3	43.8	SFA
C14:0	Myristic	8-14	54.4	SFA
C16:0	Palmitic	22-35	63	SFA
C18:0	Stearic	9-14	70	SFA
C18:1	Oleic	20-30	13	USFA
C18:2	Linoleic	1-3	-5	USFA (omega-6)
C18:3	Linolenic	0.5-2	-11	USFA (omega-3)

Concentration of individual fatty acids vary considerably, with major variation in the proportion of the two primary fatty acids, palmitic and oleic.

4. Factors affecting fatty acid profile of milk fat

The fatty acid profile of milk produced is influenced by many factors including season, type of forage, stage of lactation, breed and specific dietary fat supplementation.

4.1 Seasonal effect

An example of seasonal variation (European origin) is presented in Figure 2, showing how butter manufactured from summer milk (June) is typically lower in SFA and higher in unsaturated fatty acid (USFA) than the winter-manufactured butter, with particular effects on C16:0 (lower) and C18:1 (higher). Milk fatty acid profile will therefore vary considerably throughout the year on typical herds grazing through summer with housing through the winter months.

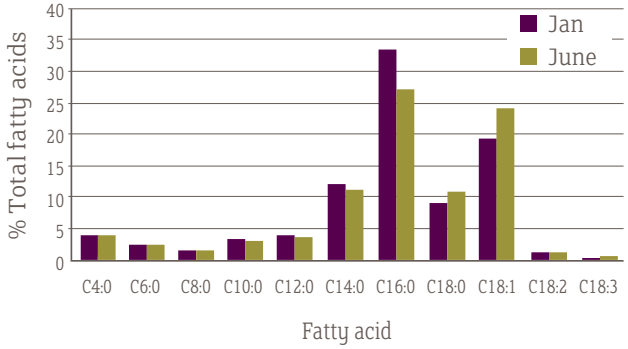

Figure 2: Fatty acid profile of French butters collected in winter and summer (adapted from Jensen, 2002)

4.2 Forage source

Seasonal effects largely reflect changes in forage source, reducing plentiful summer supplies of highly-unsaturated fatty acids from grazed grass with ensiled forages and other ingredients.

Table 2 demonstrates the effect on the major milk fatty acids by increasing proportion of fresh grass at the expense of maize silage; increasing proportion of fresh grass resulted in a linear reduction in C16:0 and total SFA in milk, countered by linear increases in both MUFA and PUFA. These data indicate the considerable variability in milk fatty acid profile that can result from changes in dietary forage source throughout a lactation, such as when transitioning between winter and summer diets.

Table 2: Effect of replacing maize silage with fresh grass on milk fatty acid profile (Couvreur *et al.*, 2006)

Milk production	% Fresh-cut grass (G) : maize silage (M) in forage				Linear effect
	0G : 100M	30G : 70M	60G : 40M	100G : 0M	
Milk yield (kg/d)	23.7	24.8	26.1	25.8	*
Milk fat (%)	4.28	4.39	4.09	4.01	NS
Fatty acids (% total fatty acids)					
C4:0 to C14:0	28.4	27.9	28.5	26.2	*
C16:0	31.0	28.4	26.8	24.1	***
C18:1	19.4	20.4	19.4	21.1	NS
SFA	71.8	69.8	68.4	64.7	***
MUFA	25.9	27.5	28.1	31.2	***
PUFA	2.81	2.94	3.87	4.52	***
C16:0 / C18:1#	1.41	1.21	1.09	0.86	***

Spreadability index (indicator of butter hardness)

4.3 Stage of lactation

Milk fatty acid profile changes considerably throughout a lactation cycle (Barbano *et al.*, 2017) (Figure 3). Early lactation cows in negative energy balance mobilise fatty acids from adipose which are incorporated into milk fat, resulting in inhibition of acetyl-CoA carboxylase and consequently *de novo* synthesis of shorter chain fatty acids (with the exception of C4:0). With increasing positive energy balance through lactation, the contribution of long chain preformed fatty acids is reduced.

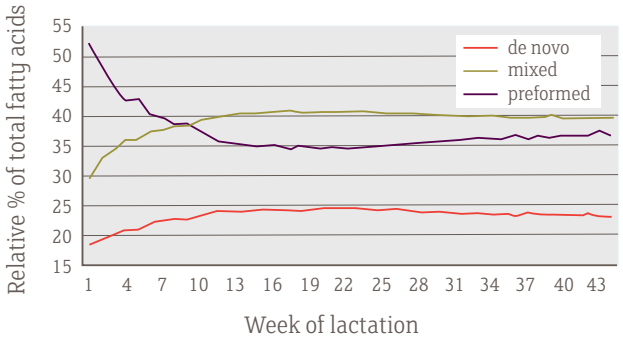

Figure 3: Contribution of *de novo*, pre-formed and mixed (C16:0, C16:1) fatty acids through lactation (Barbano *et al.*, 2017)

Milk collected from farms will therefore vary according to stage of lactation of a particular herd which may influence processability and milk fat functionality for manufacturing and product quality attributes.

VOLAC WILMAR
FEED INGREDIENTS

MEGALAC®
More milk, better fertility

4.4 Breed

Milk fatty acid profile differs between breeds. As presented in Table 3, Jersey cows typically produce milk with higher *de novo*-synthesised fatty acids, C16:0 and overall SFA, and lower MUFA and PUFA than that of Holsteins. Processability of milk and properties of dairy products manufactured may therefore be influenced by the genetic background of the supplying herd.

Table 3: Milk fatty acid profiles of Danish Holstein and Danish Jersey milks (% of fatty acids) (Hein *et al.*, 2018)

Fatty acids	Breed #	
	Holstein	Jersey
C14:0	11.07[a]	11.49[b]
C16:0	29.25[a]	31.45[b]
C18:0	11.23[a]	11.15[b]
C18:1	24.85[a]	21.60[b]
SFA	67.46[a]	72.08[b]
MUFA	28.48[a]	24.38[b]
PUFA	4.06[a]	3.55[b]
Short chain fatty acids	11.14[a]	12.13[b]

Values in the same row with different superscripts are significantly different (P < 0.05)

4.5 Rumen-protected fat supplements

Rumen-protected fats have been added to dairy rations for several decades, primarily as concentrated sources of energy. However, with increased understanding of the role of specific fatty acids in nutrition and metabolism, supplements with contrasting fatty acid profile are often targeted for particular applications.

The most common source of rumen-protected fat supplements used in dairy diets are those based on fractions of palm oil, reflecting the abundance of palm by-products from other sectors. Primary products used in the dairy industry are :

i) high melting point derivatives which remain solid at rumen temperature (high palmitic and/or stearic products)

ii) calcium salt supplements, in which fatty acids have been converted to a rumen-insoluble form

Typical fatty acid profiles of the four main categories of palm-based fat supplements are presented in Table 4.

Table 4: Typical fatty acid profile of primary palm-based fat supplements offered to dairy cows

Fatty acids		% of total fatty acids (typical)			
		Calcium salts	'High-C16'	Hydrogenated	Triglyceride-based
Myristic	C14:0	1.5	-	-	2
Palmitic	C16:0	48.0	>80	48	77
Stearic	C18:0	5.0	2-5	43	6
Oleic	C18:1	36.0	5-10	6	12
Linoleic	C18:2	9.0	-	-	2

As presented in Table 4, C16:0, C18:0 and *cis*-9 C18:1 are the most abundant fatty acids in palm supplements used in dairy diets; coincidentally, similar to the major fatty acids in milk fat (Table 1).

4.5.1 Why are palm-based fatty acid supplements used

The most common palm-based supplements used are the calcium salt and 'high-C16' variants. Aside from an additional energy supply, each type has specific attributes for dairy nutrition.

- Calcium salts – these are the largest category used in the dairy industry and enable delivery of C18:1 to the small intestine for absorption. Key benefits include :
  - i) increase total dietary fat digestibility
  - ii) improve fertility through enhanced egg development
  - iii) influence partitioning of nutrients between milk and body tissue (promote adipose deposition)
- 'High-C16' – these are particularly effective in stimulating milk fat synthesis, though data indicate effects on nutrient partitioning whereby nutrients are prioritized to milk production, particularly milk fat, at the expense of body tissue reserves.

4.5.2 Effect of palm-based supplements on milk fatty acids

In a study by Michigan State University (USA), de Souza and Lock (2019) evaluated the effect of supplementing fresh cow diets (days 1-24 of lactation) with a palmitic-based fat product (85.1% C16:0; 1.5% of diet DM). As presented in Table 5, cows offered the 'high-C16' supplement produced milk with significantly higher milk fat % and concentration of C16:0 fatty acids. However, no significant effects on *de novo*-synthesised and preformed long chain fatty acids were recorded.

Table 5: Milk fatty acid profile from cows offered a Control or 'high-C16' supplement (de Souza and Lock, 2019)

	Diet		SEM	Significance
	Control	'High-C16'		
Milk yield (kg/d)	47.2	48.6	1.05	NS
Milk fat (%)	4.48	4.89	0.13	*
Fatty acids (% total fatty acids)				
C4:0	3.68	3.58	0.06	NS
C6:0	1.76	1.62	0.06	NS
C8:0	0.84	0.75	0.04	NS
C10:0	1.63	1.46	0.12	NS
C12:0	1.69	1.55	0.13	NS
C14:0	7.01	6.47	0.33	NS
C16:0	28.6	32.4	0.35	**
C18:0	13.1	12.8	0.25	NS
C18:1 *cis*-9	29.3	27.9	0.82	NS

In further work, de Souza *et al.* (2021) evaluated production effects of supplementing fresh cow diets (days 1-24 of lactation) with palm-based supplements containing different ratios of C16:0 and C18:1 (in rumen-protected, calcium salt form). As presented in Table 6, milk fat % was highest with the 80% C16:0 supplement treatment, which also recorded the highest concentration of C16:0 in milk. Increasing proportion of C18:1 in the fat supplement from 10% to 30% reduced concentration of C16:0.

Table 6: Fatty acid profile of milk from cows offered palm-based fatty acid supplements (de Souza *et al.*, 2021)

	Ratio of C16:0 to C18:1 in fat supplement				SEM	Linear#
	Control	80:10	70:20	60:30		
Milk yield (kg/d)	46.5	48.6	48.8	49.7	1.39	NS
Milk fat (%)	4.06	4.45	4.26	4.21	0.12	NS
Fatty acids (% total fatty acids)						
C4:0	3.20	3.40	3.27	3.35	0.09	NS
C6:0	1.74	1.73	1.64	1.77	0.09	NS
C8:0	0.90	0.85	0.79	0.88	0.06	NS
C10:0	1.99	1.78	1.66	1.87	0.18	NS
C12:0	2.12	1.88	1.75	1.97	0.19	NS
C14:0	8.27	7.64	7.27	7.81	0.46	NS
C16:0	30.1	35.0	33.1	33.1	0.60	*
C18:0	11.2	10.8	11.9	11.8	0.33	*
C18:1 *cis*-9	29.3	26.9	28.3	27.6	1.20	NS

Linear effect of *cis*-9 C18:1 inclusion in supplemental fat

In a study at the University of Reading (UK), the effects on milk fatty acid profile of supplementing post-peak dairy cows with 'high-C16' or Megalac calcium salt fat variants (at 2.5% of diet DM) were evaluated. Results are presented in Table 7. Neither C16:0 or total SFA in milk were significantly altered by inclusion of the 'high-C16' supplement. Differences in individual fatty acid concentrations in milk from cows offered Megalac did not reach statistical significance, but total SFA were significantly lower than the non-fat-supplemented Control and 'high-C16' groups.

Table 7: Milk fatty acid profile of cows offered palm-based fat supplements (Kliem *et al.*, 2012)

	Diet offered			SEM	Sig #
	Control	'High-C16'	Megalac		
Milk yield (kg/d)	35.0	36.4	38.7	5.08	NS
Milk fatty acid profile (% total fatty acids)					
C12:0	4.54	3.97	3.56	0.422	NS
C14:0	12.1	11.1	10.6	0.70	NS
C16:0	30.9	32.7	30.5	1.60	NS
C18:1 *cis*-9	13.7	14.8	16.2	0.89	NS
Sum SFA	70.4[a]	69.5[a]	66.9[b]	0.80	*
Sum MUFA	17.5	18.5	19.8	0.80	NS
Sum PUFA	2.57	2.55	2.71	0.166	NS

Values in the same row with different superscripts are significantly different (P < 0.05)

In earlier work at Ohio State University (USA), progressive increases in palm-based calcium salt inclusion in dairy diets were evaluated (Palmquist *et al.*, 1993) (Figure 4). This work demonstrated that increasing supplementation of Megalac from 250 through 500 and 750 g/cow/d progressively reduced *de novo*-synthesised SFA, concomitantly increasing C18:1 USFA by up to 17% relative to the Control diet.

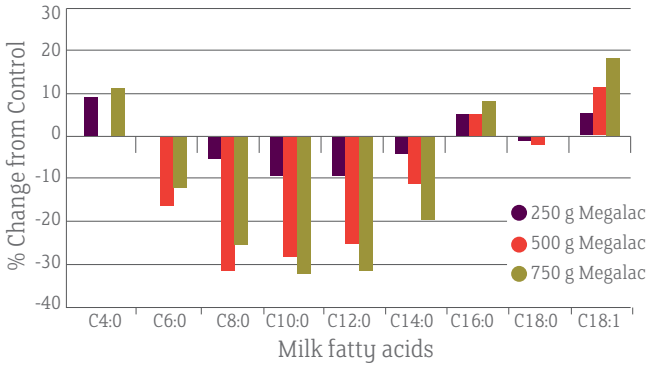

Figure 4: Effect of Megalac on milk fatty acid profile (change relative to Control milk) (Palmquist *et al.*, 1993)

More-recently, dos Santos Neto *et al.* (2021a) reported meta-analyses data on effects of supplementation of dairy diets with calcium salts of palm fatty acids (Table 8). Notable findings include the large range in individual fatty acid concentrations recorded in the studies and the near-5-fold increase in C18:1 compared with C16:0 in milk fat in response to calcium salt supplementation.

Table 8: Range of fatty acid concentrations in milk from Control (non-fat-supplemented) diets and response of milk fatty acids to supplementation with calcium salts of palm fatty acids (adapted from dos Santos Neto *et al.*, 2021a)

Milk fatty acid (% total FA)	Value (Control diets)			
	N #	Mean	Min	Max
C16:0	15	31.3	23.6	45.6
C18:0	14	10.0	7.24	17.8
C18:1	11	21.3	14.9	27.1
C18:2	14	3.38	1.95	5.83
Difference (Calcium salt - Control)				
	N #	Mean	*P*-value	
Milk yield (kg/d)	100 (31)	1.53	<0.01	
Milk fat (%)	107 (31)	0.03	0.43	
Milk fatty acids (% total FA)				
C16:0	32 (9)	1.02	0.05	
C18:0	30 (8)	0.25	0.40	
C18:1	22 (8)	4.81	<0.01	
C18:2	30 (8)	0.01	0.90	

Number of treatment means (number of studies)

These same authors (dos Santos Neto *et al.*, 2021b) also conducted a meta-analyses on effects of offering 'high-C16' supplements (>80% C16:0) or supplements with a mix of C16:0 and C18:0 (sum >80%) fatty acids on milk fatty acid profile (Table 9). These data demonstrate a significant increase in concentration of C16:0 in milk through 'high-C16' supplementation, though effects on other long chain fatty acids were relatively small.

Table 9 : Milk production and fatty acid concentrations in milk from Control (non-fat-supplemented) and fat-supplemented diets (adapted from dos Santos Neto *et al.*, 2021b)

	Fat supplement type				SEM	Significance ##
Milk production	N #	Control	C16:0 / C18:0 mix	'High-C16'		
Milk yield (kg/d)	95 (31)	37.8^{b}	39.0^{a}	39.4^{a}	1.36	<0.01
Milk fat (%)	93 (30)	3.61^{b}	3.61^{b}	3.79^{a}	0.09	<0.01
Milk fatty acids (% total FA)						
C16:0	67 (17)	31.7^{b}	32.9^{b}	37.8^{a}	0.79	<0.01
C18:0	67 (17)	9.74^{b}	10.9^{a}	8.74^{c}	0.39	<0.01
C18:1	67 (17)	21.6	22.2	20.7	0.86	0.17
C18:2	61 (16)	3.33^{a}	3.13^{ab}	3.05^{b}	0.25	<0.01

Number of treatment means (number of studies)
Means in the same row with differing superscripts are significantly different (P<0.05)

These data highlight the variability of response in milk production parameters such as milk yield and milk fat %, along with milk fatty acid profile, dependent on fat supplement used. Concentrated C16:0 supplements may increase C16:0 in milk fat to a variable extent but not necessarily lead to an increase in proportion of total high melting point SFA. In contrast, delivering C18:1 to the small intestine from calcium salt supplementation results in elevated concentrations of low melting point C18:1 in milk fat.

Whether these effects from different fat supplements have a specific influence on properties of dairy products manufactured will depend on many factors; the extent of variability in fatty acid profile of basal milk supply was noted previously. Furthermore, regardless of diet the animal is genetically driven to ensure liquid milk is produced such that the effect of any individual supplement on increasing hardness of milk fat and potential influence on manufactured dairy product is necessarily limited.

5. Milk fat functionality

5.1 Spreadability index

Butter hardness can be assessed using the 'spreadability index', calculated as the ratio of C16:0 / C18:1 and hence more easily determined from typical fatty acid profile analyses.

French data reported summer butters (pasture) to be characterised by an average C16:0 / C18:1 ratio of 1.00, compared with winter butters from silage-based diets (C16:0 / C18:1 = 1.50) (Guyonnet, 1989), indicating the significant effect of season on this attribute of dairy products.

Similarly, those data presented in Table 2 highlight the decreasing ratio of C16:0 / C18:1 as proportion of fresh grass in the diet increased. This effect was linked to linear decreases in final melting temperature and solid fat content (see later section) of butter (i.e. softer butter), and perceived in sensory analysis by a linear decrease in firmness in the mouth (Couvreur *et al.*, 2006).

5.2 Milk fat fluidity – fatty acid profile and triglyceride structure

Regardless of diet or fatty acid profile of specific fat supplements offered, regulatory biological mechanisms operate to ensure that milk fat remains fluid at body temperature. In this context, it is not just the individual fatty acids with contrasting melting points (Table 1) that influence properties of milk fat, but also the structure of the milk fat triglycerides, that determine melting point, crystallisation behaviour and rheological properties of milk fat.

Triglyceride structure also influences lipolytic enzyme activity and absorption, and further, the flavour of cheeses (Jensen, 2002). Given the considerable number of different triglycerides, milk fat has a melting range rather than a sharp melting point.

Primary regulatory mechanisms to ensure milk fat fluidity include :

i) altering proportion of *de novo*-synthesised fatty acids of differing melting points in the milk fat triglycerides

ii) specificity in positioning of individual fatty acids on the triglyceride molecule

iii) varying extent of desaturation of high-melting point C18:0 to lower-melting point C18:1 in the mammary gland

In triglyceride assembly, different fatty acids are preferentially esterified at particular stereo-positions (Table 10). Low melting point C4:0 fatty acids predominate at the *sn*-3 position of milk triglycerides as a key parameter to ensure melting point of milk fat is maintained, whereas C16:0 is more-uniformly located between the *sn*-1 and *sn*-2 positions.

Table 10: Milk fat triglyceride composition (calculated by Jensen, 2002)

	Fatty acid								
	C4:0	C6:0	C8:0	C10:0	C12:0	C14:0	C16:0	C18:0	C18:1
Triglyceride stereo-specificity (mole %)									
sn-1	1.6	3.1	10.3	15.2	23.7	27.3	44.1	54.0	37.3
sn-2	0.3	3.9	55.2	56.6	62.9	65.6	45.4	16.2	21.2
sn-3	98.1	93.0	34.5	28.2	13.4	7.1	10.5	29.8	41.5

In contrast to beef tallow which has C16:0 in the *sn*-1 position (C18:1 at *sn*-2), in butter fat, C16:0 is not exclusive to *sn*-1 but occupies *sn*-2 in two-thirds of the triglyceride species (e.g. *sn*-1 palmitic, *sn*-2 palmitic, *sn*-3 oleic).

In manufacture of dairy-based products, knowledge of stereo-specific effects on milk fat functionality can be used to provide desirable qualities. For example, the melting point of chocolate, just below body temperature, can be attributed to C18:0 and C16:0 exclusively at *sn*-1/3 and C18:1 at the *sn*-2 positions (Karupaiah and Sundram, 2007).

This stereo-specificity is particularly important in determining whether preformed fatty acids delivered to the mammary gland stimulate or inhibit *de novo* fatty acid and milk fat triglyceride synthesis.

In cellular studies, C16:0 was demonstrated to stimulate *de novo* fatty acid synthesis and incorporation of butyrate into the *sn*-3 position (Hansen and Knudsen, 1987) which may reflect the essentiality of ensuring milk fat fluidity even when high-melting point fatty acids are included in the diet. The ability of the bovine mammary gland to alternatively use lower melting point fatty acids (C4:0 to C10:0), or C18:1 to maintain milk fat liquidity was noted by Timmen and Patton (1989), with desaturation of C18:0 to C18:1 proceeding as per fluidity-related requirement via the stearoyl-CoA desaturase enzyme (cited by Jensen, 2002).

These data highlight the complexity of milk fat synthesis and the key end point of ensuring liquidity of milk fat through selective incorporation of low melting point fatty acids into triglyceride sites, despite the nature of the dietary fatty acids presented to the mammary gland. The corollary is that even with supplementation of high-melting point saturated fatty acid supplements, such as those with high proportions of C16:0, the mammary gland's biological regulatory mechanisms necessarily restrict the extent of incorporation of these fatty acids into the milk fat triglyceride; else milk fat would be too solid at body temperature.

In summary, in order to ensure liquidity of milk fat most fatty acids are necessarily esterified to triglycerides in combinations which deliver melting points of 39°C or below (cow body temperature). This non-random, selective esterification is directed to produce the required triglycerides regardless of change of dietary fatty acids (Jensen, 2002) and both SFA and USFA are required to elicit desired qualities in manufactured dairy products.

5.3 Solid fat content

Milk fluidity is a key factor determining processing qualities of milk for manufacturing dairy products.

Milk fat is completely liquid at +40°C and completely solid at -40°C and between these temperatures milk fat exists as a mixture of crystals and liquid. Melting point of milk fat, defined as the temperature at which milk fat becomes visually clear and free of crystals, is approx. 32°C to 36°C for 'normal' milk fat. The proportion of crystallised and liquid fat affects the physical properties, consistency and mouth feel of dairy products (Ortiz-Gonzalez *et al*, 2007).

These parameters can be determined as the solid fat content (SFC), a measure of the % of solid milk fat in a sample at a selected temperature, measured using Differential Scanning Calorimetry (DSC). The DSC technique assesses the thermal properties of milk fat at different temperatures through the transition from liquid to crystallisation of fat (Ortiz-Gonzalez *et al*, 2007).

Solid fat content affects milk fat functionality, relating to the melting properties of milk fat in the human mouth, and is one of the key factors contributing to the rheological properties of butter (Fearon, 1988).

Figure 5 demonstrates the effect of temperature on SFC of Emmental cheese; at a temperature of 20°C 38% of the fat is crystallised, while only 3% is similarly crystalised at mouth temperature (37°C).

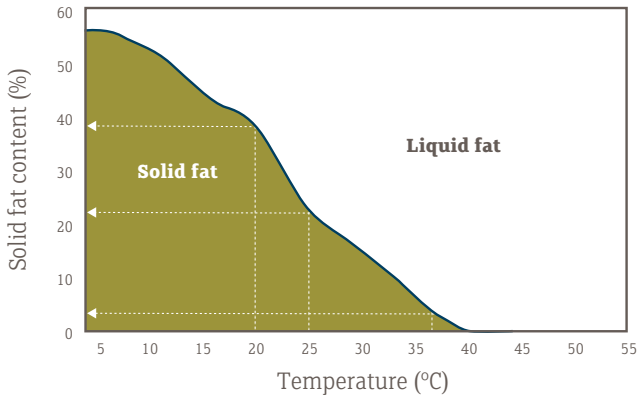

Figure 5: Solid fat content as a function of temperature in Emmental cheese (Lopez *et al*., 2006)

5.3.1 Factors affecting solid fat content

Those factors influencing fatty acid profile and fluidity of milk are key determinants of SFC.

Figure 6 demonstrates how increasing concentration of *cis*-C18:1 in milk fat, via duodenal infusion, reduces SFC of butter (butter is softer). Similarly, these data highlight the effect of temperature; SFC was considerably higher in butter at refrigerator temperature (6°C) compared to 'room' temperature at 18°C.

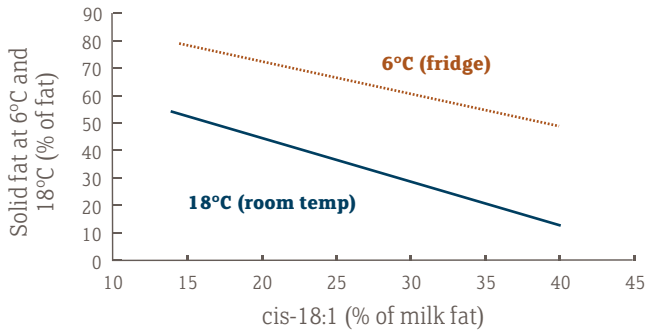

Figure 6: Relationship between milk fat concentration of C18:1 and solid fat in butter at fridge (6°C) and at 'room' temperature (18°C) (Enjalbert *et al*., 2000)

Enjalbert *et al.* (2000) also evaluated the effects of duodenal infusions of palmitic and stearic fatty acids, in addition to oleic effects (Table 11). Oleic infusion increased softness of butter at low temperature but resulted in oily butter at room temperature. In contrast, the authors reported that palmitic infusion increased butter quality at room temperature (less oily butter). Stearic acid had minimal effect relative to Control.

Table 11: Solid fat (%) in butter produced from milk from cows duodenally infused with different fatty acids (Enjalbert *et al.*, 2000)

Temp (°C)	Fatty acid infused #				SEM
	Control	Palmitic	Stearic	Oleic	
-10	95.0^{c}	94.4^{c}	93.9^{c}	75.6^{d}	1.2
0	87.1^{c}	89.2^{c}	84.7^{c}	63.0^{d}	1.7
6	78.8^{c}	81.6^{c}	75.8^{c}	54.0^{d}	1.7
12	69.0^{c}	69.5^{c}	64.7^{c}	33.8^{d}	2.5
18	45.5^{bc}	56.7^{ac}	42.6^{ab}	15.3^{d}	2.2
24	29.2^{bcd}	39.4^{ac}	26.7^{bd}	6.7^{e}	1.8
30	15.1^{d}	25.8^{c}	14.3^{d}	1.2^{e}	0.9

Means in the same row without a common superscript differ (a, b, $P<0.05$; c, d, e, $P<0.01$)

These data indicate that the profile of fatty acids offered can influence the resulting melting properties of dairy products, but significant changes in SFC (decrease or increase) may also reduce quality of butter produced depending on its targeted application and environment where it is used (e.g. ambient temperature).

In further work using abomasal infusion techniques to deliver differing fatty acids to the small intestine, Ortiz-Gonzalez *et al.* (2007) reported significant correlations between individual fatty acids and SFC at different temperatures. A positive correlation was recorded between concentrations of C14:0 and C16:0 fatty acids and increased melting point in milk fat (harder) (Table 12), while C18:2 fatty acids were associated with decreased melting point (softer). Effects of C18:1 *cis*-9 fatty acids were not significant.

Table 12: Correlations among solid fat content (SFC) of butter and fatty acid composition # (Ortiz-Gonzalez *et al.*, 2007)

SFC	Fatty acids in butter								
	C4-C10	C12:0	C14:0	C16:0	C18:0	C18:1 *cis*-9	C18:1 *trans*	C18:2	C18:3
SFC at 5°C	0.038	0.236	0.449	0.653	0.274	-0.123	-0.020	-0.593	-0.578
	NS	NS	**	***	NS	NS	NS	***	***
SFC at 20°C	-0.182	0.133	0.398	0.709	-0.074	0.096	-0.011	-0.595	-0.609
	NS	NS	*	***	NS	NS	NS	***	***

Top number = Pearson correlation coefficient; Bottom number = probability the correlation differs from zero

However, this study noted that whereas increasing concentrations of MUFA and PUFA in milk fat may be beneficial in some applications, data presented indicate that large changes in proportion of unsaturated fatty acids in milk can't be achieved without a negative effect on most of the functional properties of milk fat, in which C16:0 plays a fundamental role.

Hence, the effect of changes in specific fatty acids in milk needs to be considered in the context of the ambient conditions in which the milk fat will be used e.g. higher C18:1 and other unsaturated fatty acids may improve cold-spreadability of butter, but higher C16:0 and other SFA may help functional properties of butter at room or higher temperature environments.

VOLAC WILMAR
FEED INGREDIENTS

Experts in fat nutrition
Volac Wilmar Feed Ingredients is a joint venture which combines the nutritional reputation, global brand and sales network of Volac with the operational raw material logistics and scale of Wilmar.

www.volacwilmar.com

MEGALAC®
More milk, better fertility

002.42

MEGALAC®

Technical Bulletin

Summary

- Basal diet, breed, stage of lactation and season are key factors influencing melting point of milk fat.
- The effect of palm-based fatty acid supplements is influenced by the basal parameters of a herd and by the type of fat supplement offered.
- 'High-C16' supplements may be more-correlated with increased SFC of milk fat, whereas oleic acid-supplying calcium salts may be more-correlated with reduced SFC, though effects on dairy products will vary on target application.
- These effects may enable more-precise nutritional control of manufacturing milk supply depending on requirements for specific milk fat functionality, as basal supply varies throughout the year.
- The range of long chain dietary fatty acids including C16:0 and C18:1 are essential for milk fat functionality in manufactured dairy products.
- The effect on milk fat hardness of fatty acid profile of any fat supplement offered (in particular those with high melting point SFA) is necessarily limited, reflecting the biological regulatory mechanisms in place to ensure the cow produces liquid milk fat.

VOLAC WILMAR
FEED INGREDIENTS

Experts in fat nutrition

Volac Wilmar Feed Ingredients is a joint venture which combines the nutritional reputation, global brand and sales network of Volac with the operational raw material logistics and scale of Wilmar.

www.volacwilmar.com

MEGALAC®
More milk, better fertility

00242