Dietary manipulation of the content and fatty acid composition of milk fat

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The fat content of bovine milk shows considerable seasonal variation. For example, values ranging from 35·6 to 41·2 g/l were recorded in manufacturing dairies in South-west Scotland (Muir *et al.* 1978), the samples being taken from silos containing up to 20 000 l of milk. With individual cows, much more extreme values may be observed, e.g. 20–60 g/l, depending on breed, age, stage of lactation, nutritional status and state of health.

Rather more than 970 g milk fat/kg is composed of triglycerides. Whilst several hundred fatty acids have been identified in these triglycerides, the vast majority are present in such small quantities that for most practical purposes only about twelve need be considered. Again, pronounced seasonal effects in the relative proportions of these fatty acids are observed (Hall, 1970; Muir, 1982).

This review deals with the dietary manipulation of the content, and consequently the fatty acid composition, of milk fat. Basically, this end may be achieved by two methods, namely (a) inclusion of fat in the diet of the cow and (b) changing the ruminal fermentation pattern. The experiments to which reference is made are of the changeover type and are applicable to the immediate post-peak period of lactation.

Inclusion of fat in the diet of the cow

Free fat in hay-based diets. There is a fairly voluminous literature in this area, stretching back some 50 years. The results that have emerged from this considerable input are somewhat contradictory and practical benefits of including fat in the diet have not materialized, despite the recognition that the energy density of fat makes it an appropriate addition to the feed of the high-yielding cow (Storry, 1980). For example, the average incorporation of added fat in dairy cake in the UK is only about 10 g/kg (Clapperton & Steele, 1983). Particular concern is expressed regarding the adverse effects of fat on the digestibility of the other constituents, especially fibre, of the diet (Steele & Moore, 1968). These interactions would be expected to have significant effects on the proportion and yield of milk fat, quantities of obvious economic importance to the farmer.

The classical work of Virtanen (1966), in which synthetic diets were used, established that, if fatty acid intake fell below a limiting value, the output of milk and its constituents fell considerably. Storry *et al.* (1967) suggested that this limitation would not be encountered with natural diets, but in one of our earliest fat-feeding trials we found otherwise. Each component of the diet, by chance, had a fatty acid content at the lower end of the range associated with that component, so that the intake of fatty acid on this basal diet was only about 80 g/d (Banks *et al.*

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1976). The addition of various fats and oils to the basal diet resulted in an increase in milk yield of 25–35%. In a subsequent experiment, in which cows of similar yield potential received a basal diet providing approximately 120 g/d of fatty acid, no such limitation to milk production was observed.

Interestingly, in the case in which fatty acid intake limited milk production, the response in milk fat content to incorporating the different fats and oils was very similar to that observed when fatty acid intake was not limiting (Table 1). Thus, relative to the low-fat basal diet, tallow has little effect on milk fat content, whilst soya-bean oil decreases and the palm oil/palmitic acid mixture increases the fat content. The decrease observed with soya-bean oil is fairly typical of the outcome of feeding unsaturated vegetable oils given in two meals per day. However, when the intact oil seed is given twice per day, or the free oil in a large number of small meals, as shown in Table 2, the effect on the fat content is quite different. In both cases, the fat content is increased marginally, whereas twice daily feeding of the free oil again reduces the content of milk fat. Thus the decrease in milk fat content is due not to the presence of soya-bean oil *per se,* but rather to a potential reaction between the oil and the rumen ecosystem.

The changes in milk fat content observed on offering fat-supplemented diets to dairy cows are a reflection of the changes in output of the different fatty acids from the mammary gland. These acids are derived from two sources, namely (a) *de novo* synthesis within the gland and (b) transfer of preformed acids from the blood. Generally, the acids from 4:0 to 14:1 may be regarded as originating from *de novo* synthesis within the udder, whilst those containing eighteen carbon atoms (C_{18} acids) are supplied preformed by the blood. However, the mammary gland possesses desaturase activity, specific for the conversion of stearic to oleic acid

Table 1. *Fat content (g/l) of milks produced when a low-fat basal diet is supplemented with various fats and oils* (*Banks* et al. 1976)

Diet . . .	Low-fat, basal	Soya-bean oil	Palm oil/ palmitic acid	Tallow
Milk fat	44·0	37·8	49·6	44·7

Table 2. *Fat content (g/l) of milks produced by feeding a low-fat control diet and that diet supplemented with soya-bean oil offered twice per day as the free oil or as crushed soya beans and 24 times per day as the free oil* (*results of Banks* et al. 1980a,b, *reduced to common control treatment*)

	Offered twice per day			Offered at hourly intervals
Diet . . .	Low-fat, basal	Crushed soya-beans	Free soya-bean oil	Free soya-bean oil
Milk fat	41·2	43·7	34·7	42·3

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(Bickerstaffe & Annison, 1968), allowing some modification of the C_{18} supply. The C_{16} fatty acids are derived from both synthesis and from the blood but the relative contributions of the two sources are not generally known.

The fatty acid profiles of the milk fats obtained by offering soya-bean oil and soya beans twice per day and soya-bean oil 24 times per day are shown in Table 3. Inevitably, the proportion of short-chain fatty acids (SCFA), i.e. 6:0–14:1, must decline as the content of C_{18} acids, derived from the diet, increases. However, even when fatty acid output is expressed in terms of yield, a decrease in the SCFA fraction is observed following the inclusion of fats in the diet. The origin of this decrease, whether it lies at a ruminal or mammary gland level, is the subject of some dispute (Moore & Steele, 1968). On the one hand, Storry *et al.* (1969) showed that intravenous infusion of various triglycerides did not decrease the yield in milk of SCFA, suggesting that the effect observed on feeding was mediated at the ruminal level. On the other hand, the ability to manipulate the levels of intermediate metabolites in milk by including fat in the diet (Faulkner, 1981; Faulkner & Clapperton, 1981) argues that suppression of synthesis occurs at the mammary gland level. The two pieces of evidence are mutually irreconcilable.

We have observed (Banks *et al.* 1983) that when depression of synthesis of SCFA is expressed in relative terms as a function of the amount of added dietary fat, expressed as g per l milk, the values tend to scatter about the two lines shown in Fig. 1. Line (a) is obtained with hay-based diets supplemented with unsaturated oils given twice-daily. Line (b) is obtained with hay-based diets and saturated fats offered twice per day, unsaturated fats offered at hourly intervals and silage-based diets with both saturated and unsaturated fats given twice-daily. A number of literature values, including some derived from experiments in which protected fats were given, also scatter about line (b). One interpretation of Fig. 1 is that line (a) represents the effects of both ruminal and intramammary suppression, whilst line (b) is dominated by the latter factor.

Table 3. *Fatty acid content (g/kg total fatty acids) of milk fats produced from feeding a low-fat control diet and that diet supplemented with soya-bean oil, offered twice per day as the free oil or as crushed soya beans and 24 times per day as the free oil (Banks* et al. 1980a,b)

	Offered twice per day			Offered at hourly intervals
Diet . . . Fatty acid	Low-fat, basal	Crushed soya-beans	Free soya-bean oil	Free soya-bean oil
Σ(6:0–14:1)	251	179	146	131
16:0+16:1	397	314	262	225
18:0	94	168	188	221
18:1	229	300	357	380
18:2+18:3	29	39	47	43

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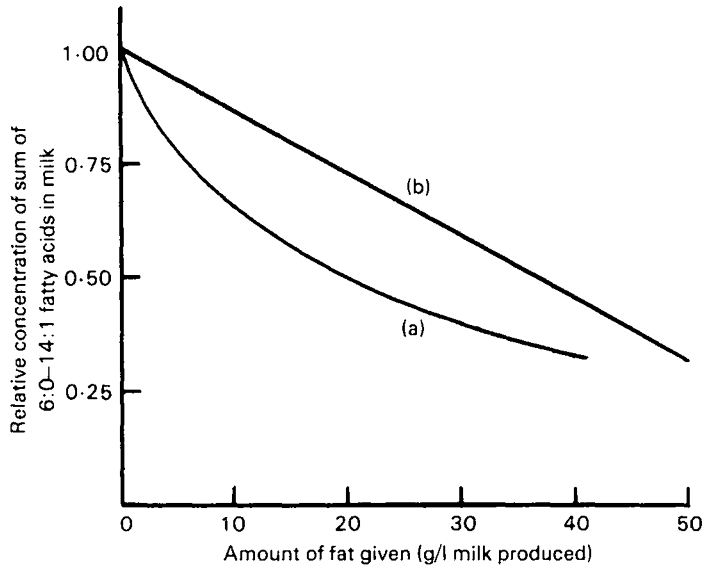

Fig. 1. Relative change in the cumulative concentration of fatty acids from 6:0 to 14:1 as a function of the amount of dietary fat given per l of milk produced. Line (a) is obtained with hay-based diets supplemented with unsaturated oils given twice-daily. Line (b) is obtained with hay-based diets and saturated fats offered twice per day, unsaturated fats offered at hourly intervals and silage-based diets with both saturated and unsaturated fats given twice-daily.

Changes in fatty acid composition are accompanied by altered melting spectra of the milk fats (Banks *et al.* 1976*a*, 1980*a*). The effect of feeding oils rich in C_{18} fatty acids is to elevate the content of 18:1 in the milk fat and therefore to produce more molten material at low temperature. Conversely, by using a feed rich in C_{16} fatty acids, the 16:0 content of the milk fat is increased and, at a given temperature, more material is solid. These changes in melting spectrum are reflected in the rheological properties of butters made from the milk fats, as shown in Table 4.

Table 4. *Extruder thrust values and stand-up properties for commercial and experimental butters* (*Banks & Kelly*, 1978; *W. Banks, unpublished results*)

	Temperature (°)	Commercial butter (summer) 1	2	Experimental butter: Standard winter diet	Winter diet + soya-bean oil	Winter diet + palm oil
Extruder thrust values (*g*)	5	2000	1850	3200	1050	4000
	10	375	380	1540	390	2200
Stand-up properties (% original height)	15	100	100	100	100	100
	25	96	97	100	98	100

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Thrust values were measured using a FIRA/NIRD extruder. As the value decreases, the butter becomes more spreadable, e.g. up to approximately 1000 *g*, butter would be regarded as fairly easy to spread whilst at 2500 *g* it would be regarded as difficult to spread (Prentice, 1954). Thus the butter obtained by supplementing the cow's diet with soya-bean oil is considerably easier to spread than even the best of summer butter. The two commercial samples in Table 4 gave the lowest values in a year-long survey of the butters available from local supermarkets. The mean thrust recorded in this study was 2850 *g* at 5°. In terms of stand-up properties, i.e. the relative change in height of a plug of butter stored at the given temperature for 120 min, all the butters performed adequately over the temperature range of interest.

Free fat in diets based on grass silage. Statistics demonstrate quite clearly that silage is replacing hay as the main winter forage for dairy cows. Few manipulative experiments have been reported in the case of silage, but a somewhat similar picture to that described above for hay-based diets emerges (Banks *et al.* 1980*b*). However, there are minor, but interesting differences. On a silage-based, low-fat control diet the proportion of SCFA in the milk fat is lower than on the corresponding hay-based diet and the relative decrease occasioned by supplementing that diet with fat is much less than with a hay-based diet. For that reason, both tallow and palm oil/palmitic acid tend to increase the fat content, whilst soya-bean oil has little effect. We noted earlier that twice-daily feeding of soya-bean oil against a silage background changed the concentration of SCFA in such a way that, in Fig. 1, the points scattered about line (b), whereas in the corresponding hay-based experiment they scattered about line (a). This difference in behaviour is consistent with the observation that the intake of silage is associated with fairly stable conditions in the rumen (Thomas *et al.* 1980). However, animals receiving silage and an unsaturated vegetable oil may occasionally exhibit the low-fat-milk syndrome (Davis & Brown, 1970), so caution is necessary if such oils are to be offered.

The changes in fatty acid composition consequent upon feeding the different types of fat or oil are similar to those observed with hay-based diets. Therefore, the physical properties of milk fat from silage-fed animals can be manipulated in the same way as described earlier, with consequent effects on the spreadability of butter made from that milk fat.

Protected fat in the diet. By encapsulating fat within a coating of protein which is then cross-linked by exposure to formaldehyde, a particle which is resistant to ruminal action can be produced. In the more acidic conditions of the abomasum, the cross-link is destroyed and the component fat and protein can then be digested in the normal manner. This technique of protecting lipid against ruminal activity or, conversely, of protecting ruminal activity against the presence of lipid was developed by Australian workers (Scott *et al.* 1970), principally to allow the production of meat and dairy products containing substantial quantities of polyunsaturated fatty acids, e.g. the linoleic acid content of milk fat can be increased to any value up to approximately 35% (Fogerty & Johnson, 1980). This change in fatty acid composition can be accompanied by an increased yield of milk fat, achieved by an increase in milk yield, fat content, or both. Storry *et al.* (1974) suggest that the increase in fat content arises from the fact that the rumen is protected against the presence of lipid and consequently there is no decline in the output of acids synthesized *de novo* in the mammary gland. Whilst this observation is in accord with those obtained in model studies, in which triglycerides were infused intravenously (Storry *et al.* 1969), it is not in accord with our own (unpublished) work, inasmuch as we have detected changes in the concentrations of the *de novo*-synthesized acids with accompanying changes in the concentration of milk citrate. The former result could arguably be due to incomplete protection of the fat allowing interference with rumen function, but the observed increase in citrate content suggests that the presence of preformed, long-chain fatty acids in the mammary gland suppresses *de novo* synthesis. Thus we again return to the two irreconcilable pieces of evidence regarding the level at which suppression of *de novo* synthesis of SCFA in milk fat is mediated.

The presence of a large proportion of linoleic acid in the milk fat alters the melting spectrum, increasing the proportion that is liquid at low temperature (Morrison & Hawke, 1979). Consequently, butter made from such milk fat has good spreadability at refrigeration temperatures, but this is accompanied by oiling off at 20° in those samples containing more than 15% linoleic acid (Wood *et al.* 1975). Taste panel studies showed the acceptability of linoleate-rich butter to be equal to that of commercial tub margarines, but both were considered inferior to conventional butter (Buchanan & Rogers, 1973). It is usually necessary to add antioxidants to linoleate-rich milk immediately after milking.

It is also possible to feed protected saturated fats (for a review, see Storry *et al.* 1980*a*), but the main application in this instance is to increase the intake of dietary energy, and its efficiency of use for milk production (Storry *et al.* 1980*b*), in the high-yielding dairy cow. This type of supplement generally invokes the same type of response in terms of yield of milk fat as do the protected polyunsaturated fats. However, one interesting exception is provided by protected hydrogenated soya-bean oil which decreases the fat content (Astrup *et al.* 1975). We have recently compared free, hydrogenated soya-bean oil with its protected counterpart as supplements for the dairy cow and have found that the protected oil does decrease the milk fat content. No satisfactory explanation for this phenomenon is yet available.

Manipulation of rumen fermentation

It is generally accepted that those diets containing a substantial proportion of long-fibred forage will produce a milk having a high-fat content, whilst those rich in concentrates produce less milk fat. The former diet produces a ruminal fermentation pattern dominated by acetate (acetate:propionate $\simeq 3\cdot3$) and the latter diet a pattern in which the proportion of propionate increases (acetate:propionate $\simeq 1$). However, equally low values for the fat content can be achieved by adding highly

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unsaturated vegetable oils to a high-fibre diet, and in this case the accompanying change in rumen fermentation pattern may be quite small (Davis & Brown, 1970). Thus the direct association of acetate (or propionate) with these extremes of milk fat contents is not generally valid.

We deal here only with the extremely low milk fat contents that can be achieved, either by feeding a high-concentrate diet or a normal diet supplemented with considerable quantities of polyunsaturated vegetable oils. This state is referred to as the 'low-fat-milk syndrome'. It is characterized by a fairly distinctive fatty acid composition, the dominant features of which are an enhanced content of C_{18} polyunsaturated and monounsaturated acids, with decreases in the 16:0 and, more markedly, in the 18:0 fatty acids (Clapperton *et al.* 1980). In milk fats derived from normal diets, a linear relation exists between the proportions of 18:0 and 18:1 fatty acids (Banks *et al.* 1974). In the case of the low-fat-milk syndrome, this relation is not found (Banks *et al.* 1976*b*). The ability to define the normal state is useful in that we have noted that the fat content may decline by up to 8 g/l milk and the relationship remains, whilst at decreases of 10 g/l milk or greater the relationship disappears, i.e. it is possible to decrease the milk fat content substantially without invoking the low-fat-milk syndrome.

As might be expected of a milk fat in which approximately 50% of the fatty acids are unsaturated, the product of the low-fat-milk syndrome has a high proportion of material that is molten at low temperatures. Hence, it gives rise to butter that has good spreadability when taken from the refrigerator. It does, however, suffer from a loss of stand-up properties at 20° and above (Banks & Kelly, 1978).

Conclusions

There exists considerable scope to produce butters having a range of properties. Since the necessary manipulation is carried out purely by dietary means, the product conforms to the strictest legal definition of butter. The main difficulty lies in convincing the farmers, and the Milk Marketing Boards, that any extra production cost is justified. However, butter consumption in the UK is currently declining at 10% per annum. It would appear reasonable to conclude, therefore, that if butter is to occupy only the top 15–20% of the market, it will have to be presented as the premium spread. The market image, involving packaging and spreadability, must be suitable for a premium product.

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