Milk composition—manufacturing properties

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Over the last 20 years there have been significant changes in the pattern of milk utilization in the UK. For example, in 1960, only 27% of a total production of 9·7 billion l of milk was used in the manufacture of dairy products. In contrast, 15·2 billion l of milk were produced in 1982 and of this total 49% was utilized in the liquid market (Anon., 1982). The remaining 7·8 billion l of milk were converted into a comparatively narrow range of milk-based foods. The relative importance of various manufactured products is shown in Table 1. There is a clear distinction between Scotland and England and Wales, for in Scotland cheese production—principally of the Cheddar variety—is the most important manufacturing operation with smaller, but relatively equal, amounts of milk being converted to butter and to evaporated milk. However, in England and Wales butter production predominates with cheese manufacture assuming lesser importance. Comparatively little milk is processed to condensed milk. Notwithstanding these regional differences, throughout the UK a small but significant proportion of the milk supply is manufactured into fresh cream products.

Because the ascendancy of the manufacturing sector of the UK dairy industry is recent, comparatively little attention has been paid to the relation between milk composition and either the efficiency of the manufacturing process or the quality of the end-product. Furthermore, it is difficult to translate results obtained abroad into a UK framework because of differences in breed of cow, lactational pattern and nutritional practice. In the UK, the nutrition of the cow is the major determinant of milk composition since, unlike the Irish Republic and New Zealand, the continuing policy of encouraging milk production in winter has resulted in a fairly even supply of milk throughout the year. The ratio, peak:trough production in the UK in 1982 was 1·4:1·0.

Table 1. *The relative importance of various manufactured dairy products* (1981–82) (*Anon.,* 1982)

	Percentage of total milk sales converted into manufactured products	
Product	Scotland	England and Wales
Butter	13·1	25·3
Cheese	20·9	15·0
Condensed milk	11·2	2·2
Fresh cream	5·6	6·4
Whole milk powder	<0·1	1·4
Others	0·1	0·1

This paper considers the key compositional factors influencing the manufacture of Cheddar cheese, full-cream evaporated milk, butter and whipped cream and examines the feasibility of tailoring milk composition to an 'ideal' for the manufacturing sector of the UK dairy industry. Against this background, it may be possible to devise an acceptable and unified nutritional strategy for the national dairy herd.

Cheddar cheese

The relation between cheese yield and quality and milk composition has been more extensively investigated than that for any other dairy product. The principles which determine cheese yield were clearly elucidated by Van Slyke & Price (1927) and, despite changes in manufacturing practice, still hold true. (For more up-to-date studies on cheese yield and milk composition the reader is referred to Olson (1977), Lundstedt (1979), Banks *et al.* (1981), and for modern cheesemaking practice to Scott (1981).) Cheese yield is determined first by the composition of the raw milk and thereafter by the efficiency of the cheesemaking process.

The seasonal variation in milk composition, in particular the changes in protein plus fat, and cheese yield are shown in Fig. 1. The results were obtained in recent experiments in which milk was converted into cheese on a pilot scale (360 l) under a scientifically-controlled cheesemaking protocol. As expected, there was a correlation between the fat plus protein content of the milk (the yield potential) and cheese yield although the curves are not co-incident. The divergency of the curves is, in part, due to seasonal variation in the proportion of casein in the total protein (cf. Muir *et al.* 1978) but it also reflects differences in efficiency of recovery of milk fat and protein.

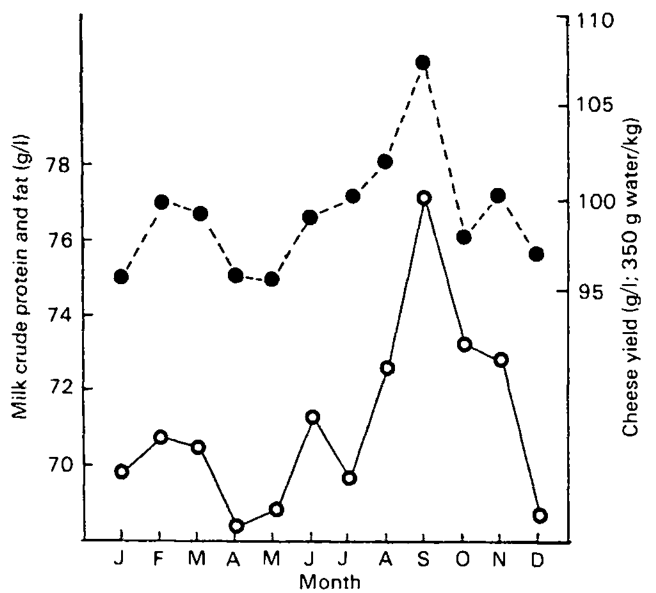

Fig. 1. Seasonal changes in milk crude protein and fat (○) and cheese yield (●).

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The efficiency of cheesemaking has been studied within two large plants in South-west Scotland by Banks *et al.* (1981). We found that there were seasonal trends in the efficiency of incorporation of fat and protein in cheese but that these were overshadowed by variations resulting from different methods of manufacture between the factories. Although the compositional factors responsible for the seasonal variations in efficiency were not pin-pointed, it was noted that the casein:fat value in milk influenced efficiency. In addition, there was more variation in this ratio in milk in South-west Scotland (Muir *et al.* 1978) than has been noted for the UK as a whole (Harding & Royal, 1974). Furthermore, there is also evidence that suggests that cheese *quality* is improved by careful adjustment of the casein:fat value (Chapman, 1974; Scott, 1977): for Cheddar cheese, the optimum value is 0·7.

The effect of standardizing milk composition to this value on the efficiency of the cheesemaking process was examined in detail for a complete season (Fig. 2). There was an increase in efficiency of cheese production—tending to increase with yield potential—when the crude protein:fat value was 0·9 (this value is almost equivalent to a casein:fat value of 0·7). The average increase in efficiency was between 1 and 2% which, although small, is worth several million pounds sterling to the UK dairy industry.

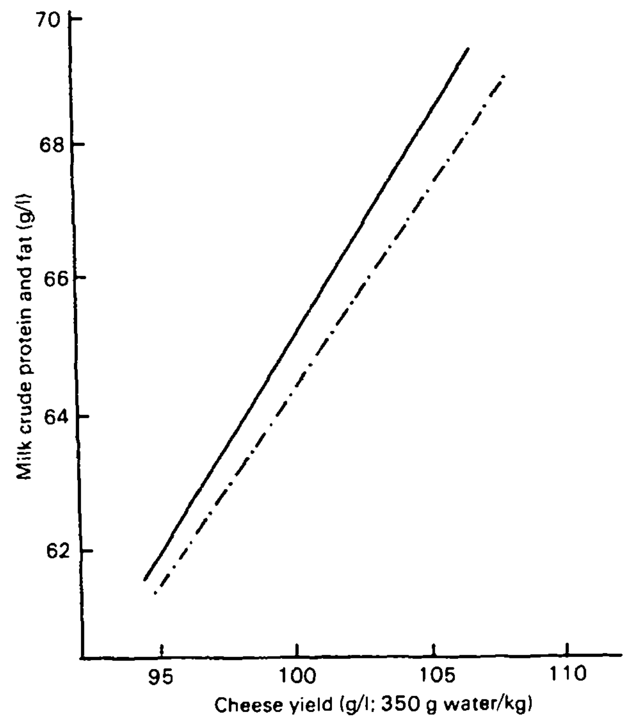

Fig. 2. The effect of standardizing the ratio, crude protein:fat on the efficiency of cheesemaking. (———) Natural, seasonal composition; (—·—·—) standardized composition (crude protein:fat = 0·9).

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The grade scores for both seasonal and standardized milk are also shown (Fig. 3). The grade score includes assessment of flavour, texture, colour and finish and showed no clear seasonal pattern. Nevertheless, standardization of the casein:fat value brought about an improvement in grade in 9 out of 12 months. The improvements in grade score were almost equally divided between improvements in texture, as found for example by Chapman (1974), and improvements in aroma and flavour.

These results show that on average the composition of milk in Scotland is not perfect for the production of Cheddar cheese. The 'ideal' milk would have a casein:fat value of 0·7 and, to maximize yield, as high a fat level as possible. For the present average fat levels, a modest over-all increase in casein content of 50 g/l would suffice, but in the winter months (November–March) when average fat levels are high an increase of at least 120 g/l in casein content would be required.

Full-cream evaporated milk

Home sales of full-cream evaporated milk have shown a steady fall for many years but this decline has been compensated by a growth in the export market to Africa, South and Central America and to Arabia. For this reason, production of evaporated milk is an important sector of the manufacturing industry in Scotland. Two main problems related to seasonal factors are of commercial concern. First, difficulty is encountered in sterilizing concentrated milk. This is at first sight not surprising since the concentrate will not naturally withstand heat sterilization.

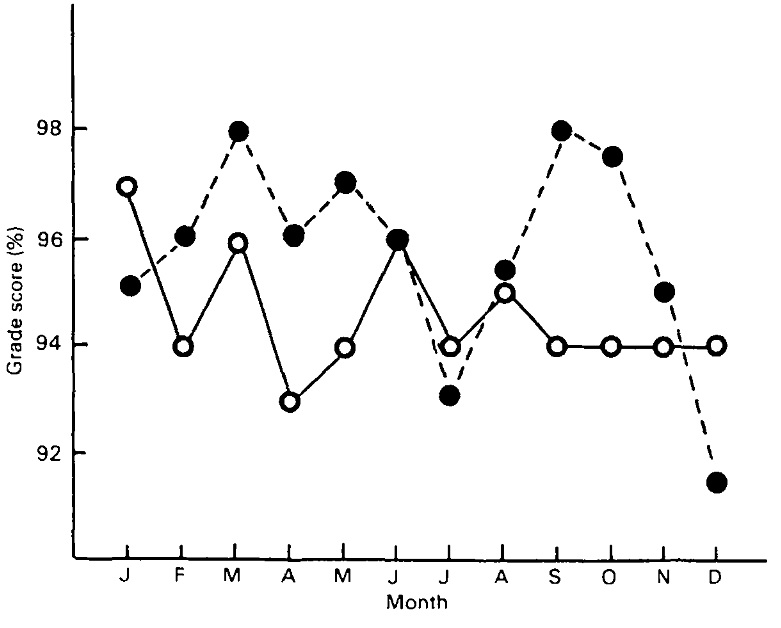

Fig. 3. Seasonal changes in grade score of Cheddar cheese. (○) Natural composition; (●) standardized composition (crude protein:fat = 0·9).

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However, over the last 70 years empirical solutions to this problem have been devised. Unfortunately, these technological manipulations cannot always compensate for extreme changes in milk composition and heat-stable concentrate cannot be produced.

Second, sterile concentrates are not always stable on prolonged storage. Samples produced in December–April show more frequent and extensive fat separation than do corresponding samples made in September–October. This defect is not completely understood and no commercially-acceptable solution has been devised.

The manufacturing sequence for production of evaporated milk is shown in Fig. 4. The order of the processing steps is critical and reversal of certain operations can result in destabilization (Sweetsur & Muir, 1982*b*). The initial process of standardization is carried out for economic reasons. The appropriate legal standard stipulates that full-cream evaporated milk shall contain at least 90 g fat/kg and 310 g total solids/kg. When the fat:total solids value in the raw milk is adjusted to 0·29, the appropriate standard is satisfied after concentration to 310 g total solids/kg. This step would not be carried out if butterfat were less expensive than milk solids-not-fat. The standardized milk is then stabilized by addition of simple phosphate salts and subjected to a forewarming treatment. The effect of forewarming is incompletely understood and it is clear that different treatments can have very different effects (Webb & Bell, 1942; Sweetsur & Muir, 1981, 1982*c*). Nevertheless, after concentration and homogenization (necessary to prevent fat separation during storage), the concentrate will usually withstand sterilization at 120° for 4–6 min ($F_0 = 4$–6).

Our own studies have focused on the compositional factors responsible for the seasonal instability and technological solutions to the problem. For example, Sweetsur & Muir (1982*a*) found a highly significant relation ($P<0.001$) between

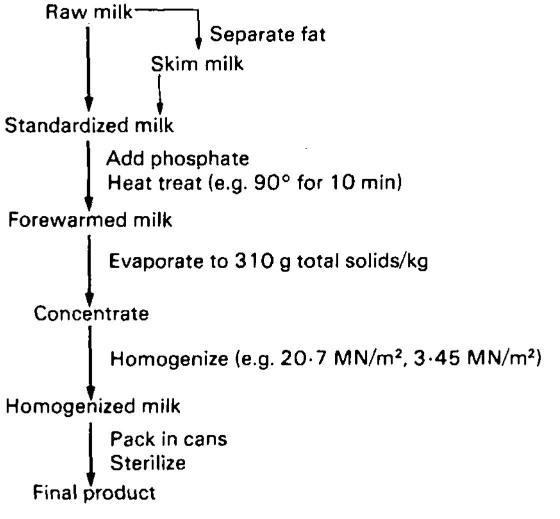

Fig. 4. The manufacturing sequence for production of full-cream evaporated milk.

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Table 2. *The effect of season on the heat stability of homogenized milk concentrate* (310 *g total solids/l*)

Sample . . .	Maximum potential heat stability at 120° (min) May	February
Control milk concentrate	15·5	16·5
Homogenized at:		
20·7 MN/m^2	17·0	8·0
31·05 MN/m^2	12·5	2·0

the heat stability of concentrated skim milk and the citrate and soluble calcium concentrations. In milk, citrate and soluble Ca are highly correlated (Holt & Muir, 1979), probably for simple physicochemical reasons. Thus the seasonal variation in heat stability is related to changes in soluble Ca and citrate. These changes in turn are associated with intra-mammary synthesis of short-chain fatty acids (Peaker & Faulkner, 1983).

We have also found that the heat stability of the homogenized concentrate (analogous to full-cream evaporated milk) shows even more pronounced seasonal variation than that of either skim-milk or whole-milk concentrate (Table 2). During May, when citrate and soluble Ca are at their seasonal minima, homogenization has a comparatively small effect on heat stability. In contrast, milk in February is typically much less heat-stable after homogenization (Table 2). Both homogenized milk and concentrate are much more sensitive to destabilization by Ca during heating than are the corresponding skim and whole milks (Muir & Sweetsur, 1982*a*, 1983*a,b*). For example, when comparatively small amounts of soluble Ca (as $CaCl_2$) are added to concentrate, the milk is destabilized by about one-third. However, after homogenization, the concentrate is so unstable that it will not withstand sterilization (Table 3). Such small changes in the soluble Ca level are less than those observed seasonally.

The results of preliminary experiments have shown that heat stability can be changed by dietary manipulations which influence milk citrate and soluble Ca concentrations (J. M. Banks, J. L. Clapperton, D. D. Muir, A. K. Powell and

Table 3. *The effect of calcium chloride addition on the heat stability of concentrated homogenized milk*

Sample . . .	Maximum potential heat stability at 120° (min) Unhomogenized control	Homogenized (20·7 MN/m^2)
No addition	16·0	15·0
Calcium chloride added:		
1 mM/l	14·5	5·0
2 mM/l	11·0	2·0

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A. W. M. Sweetsur, unpublished work). However, we do not wish to imply that the soluble Ca concentration is the sole determinant of the heat stability of homogenized concentrate, for it is difficult to clearly isolate the effects of consequential changes in other milk components brought about by dietary manipulation. Nevertheless, seasonal variations in mineral equilibria are important and are now more clearly defined than when they were first recognized (e.g. Sommer & Hart, 1926).

Notwithstanding the above description of the probable role played by minerals in determining the ability of concentrated milk to withstand sterilization, more recent work has shown that proteins containing sulphydryl groups are particularly important in homogenized milk systems (Sweetsur & Muir, 1983*b*).

The effect of adding β-lactoglobulin to homogenized concentrated milk is shown in Table 4. A small addition of this protein, rich in sulphydryl groups, significantly reduced heat stability. Conversely, the addition of reagents like *N*-ethylmaleimide and copper ions (factors known to block sulphydryl-group interactions) resulted in large improvements in heat stability. There is a seasonal variation in the ratio, β-lactoglobulin:casein (e.g. Muir *et al.* 1978) but this appears to be related to lactational rather than dietary factors. The manipulation of milk protein content and composition is reviewed by Thomas (1983).

Only circumstantial evidence is available to explain the second seasonally-related problem of evaporated milk—that of fat separation. Over several years of commercial experience it has been found that evaporated milk produced in the autumn is less prone to fat separation during storage than that produced at any other time. The principal compositional factor likely to be responsible is the concentration of protein, for in August and September the protein level is at its seasonal peak (Muir *et al.* 1978). It is widely recognized that emulsion stability is dependent on the ratio, surfactant:fat and, in evaporated milk, the newly formed fat surface formed during homogenization is stabilized by protein, mainly casein (Mulder & Walstra, 1974). Thus it is probable that the seasonal variation in long-term stability of the evaporated milk is associated with seasonal variations in protein content.

Table 4. *The effect of* β*-lactoglobulin,* N*-ethylmaleimide and copper addition on heat stability of concentrated homogenized milk* (310 *g total solids/l*)

Additive	Maximum potential heat stability (min): Control milk*	Maximum potential heat stability (min): Milk + additive*
β-Lactoglobulin (500 ppm)†	16·5	9·5
N-ethylmaleimide (376 ppm)‡	3·0	26·0
Copper ions (2 ppm)‡	6·0	21·0

*All samples were homogenized at 20·7 MN/m².
Measured at: †120°, ‡110°.

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In summary, the ideal raw material composition for successful production of evaporated milk would involve low levels of soluble Ca and a high concentration of casein. Furthermore, the protein:casein value would be low.

Unfortunately, the compositional requirements are less well substantiated than in the case of cheese milk and may require revision in the light of new knowledge.

Butter

A great deal of attention has been focused on improvement of the properties of butter and this topic is discussed in detail by Banks *et al.* (1983). Perfect butter has a natural yellow colour, subtle flavour and spreads from the refrigerator. Each of these properties is controlled, at least in part, by the diet of the cow and 'spreadable' butter can be achieved by at least three types of dietary manipulation which result in a fat of low melting point: by feeding protected polyunsaturated acids (Buchanan & Rogers, 1973), by manipulating the supply of pre-formed fatty acids (particularly the C_{18} group) to the mammary gland (Banks *et al.* 1976, 1980) and by inducing the low-milk-fat syndrome (Banks & Kelly, 1978; Clapperton *et al.* 1980).

Not only have the dietary factors required to produce soft butter been identified but the required changes in manufacturing practice have also been investigated. For example, there has been full-scale production of soft butter in Australia (Buchanan & Rogers, 1973): the product, although spreadable, was unsuccessful because of susceptibility to oxidation. Such problems are not pronounced in soft butter rich in mono-unsaturated fatty acids, but these products have not yet been commercially exploited.

The UK dairy industry has yet to be convinced of the marketing potential of improving butter quality. Meanwhile, butter sales continue to decline at an alarming rate.

Whipping cream

In 3 out of 5 years, seasonal problems occur in the production of pasteurized cream which will produce a stable foam when whipped. The period of instability occurs in late May or early June and is associated with low-milk-fat concentrations (e.g. Clapperton *et al.* 1980) but the problem has not been investigated in detail. In recent years detailed studies on the whipping properties of dairy cream have been undertaken at the Hannah Research Institute (HRI) but space does not permit a detailed report. However, the effect of changing fat composition on whipping properties will be considered briefly.

When cream is whipped in a domestic mixer under carefully standardized conditions, air is rapidly incorporated to produce a foam. After a few minutes of continuous whipping, a maximum 'in volume' expansion occurs and the foam then collapses to form butter granules. Typical whipping time–overrun profiles for pasteurized dairy cream, standardized at 360 and 400 g butterfat/kg, are shown in Fig. 5. The curves characterize only the initial whipping properties of the cream,

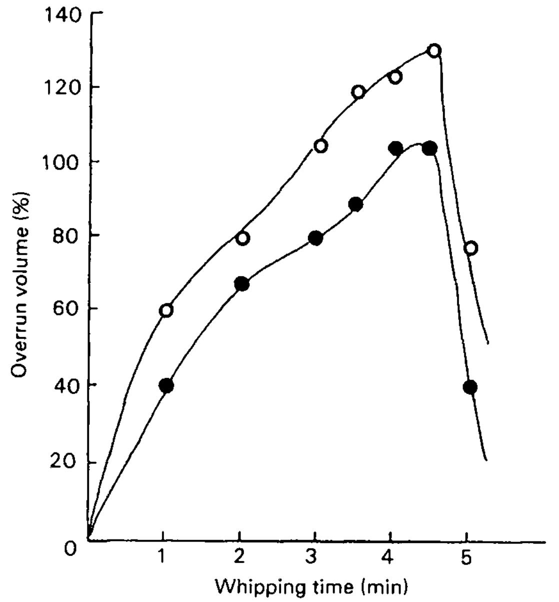

Fig. 5. Whipping time–overrun profiles for cream. (○) 360 g fat/kg; (●) 400 g fat/kg.

for in commercial conditions the physical strength and long-term stability of the foam are equally important. For example, an important use for whipped cream is as cake filling and occasional collapse of cream filling has resulted in significant financial loss to many dairy companies. In the laboratory, the physical strength of the foam can be assessed by a cone penetrometer and long-term stability is conveniently evaluated by measuring serum separation from the whipped cream after storage in the refrigerator for at least 12 h (the standard test used in our work involves storage of the whipped cream at 4° for 18 h).

To demonstrate the effects of milk composition on whipping properties of cream, results are shown from a typical short-term experiment. (Table 5). A basal diet of hay and concentrates was given to a group of four cows for a period of 2 weeks. At the end of the second week, milk was collected for cream manufacture and part of the concentrate ration was replaced on an isoenergetic basis by soya-bean oil. This type of treatment has been shown to result in rapid changes in the fat type (e.g. Banks *et al.* 1980). After 7 d on the test diet, cream was produced from the composite milk and the cows were returned to the control diet. One week later the milk was again converted to cream. The short-term nature of this type of experiment is designed to minimize lactational effects. Only minor changes in mineral balance and no systematic change in protein content were observed as a result of this dietary treatment. However, significant changes in the fat type did result (Table 5). Thus it is fair to suggest that changes in whipping properties of the creams resulting from the dietary manipulation are associated with changes in the milk fat.

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Table 5. *Changes in milk fat composition and properties resulting from adding soya-bean oil (test) to a hay and concentrate (basal) diet for 7 d*

Diet ...	Basal	Test	Basal
Melting properties			
Latent heat of fusion (J/g)	81·6	68·6	78·2
(cal/g)	19·5	16·4	18·7
Liquid fat at 6° (g/kg)	243	432	241
Fatty acid composition (g/kg)			
6:0–14:1	306	241	301
16:0+16:1	467	310	479
18:0+18:1	200	405	198
18:2+18:3	27	44	22
De novo synthesized fat (g/kg)	12·0	9·9	12·6

As a result of soya-bean oil supplementation of the diet, the proportion of oleic acid (18:1) in the milk fat was enhanced and the fat melting point was reduced. In the trial shown, the amount of fat liquid at 6° (refrigerator temperature) increased from 24 g/kg on the control diet to 43 g/kg on the test treatment. The consequence of this change in fat type on whipping properties is shown in Table 6. As a result of lowering the melting point the whipping time was reduced, albeit very slightly, the time to form butter granules was markedly reduced as was the extent of maximum overrun (cf. Fig. 5). More significantly, from a commercial point of view, on the test diet the foam was very soft and serum separation was greatly accentuated. Usually, the defects in poor whipping creams can be reduced by increasing the fat content of the cream from the minimum permitted level of 350 g/kg to 400 g/kg (Muir, 1982). However, when a soft fat is present this action has little effect (Table 6).

Table 6. *Changes in whipping properties of cream resulting from the addition of soya-bean oil (test) to a hay and concentrate (basal) diet for 7 d*

		Diet		
	Fat (g/kg)	Basal	Test	Basal
Whipping time (min)	360	3·5	3·0	3·75
	400	3·0	2·5	3·25
Churning time (min)	360	9·6	4·6	7·6
	400	7·4	4·1	6·3
Maximum overrun (min)	360	147	127	152
	400	130	118	132
Serum separation (min)	360	2·5	8·4	1·0
	400	2·1	11·4	1·0
Firmness (arbitrary units)	360	0·7	<0·2	0·7
	400	0·7	<0·2	0·5

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Clearly, soft milk fat has a deleterious effect on the production of satisfactory whipping cream. This result is consistent with the seasonal observations reported earlier for, in May–June when milk fat levels are particularly low, the milk fat is soft (e.g. Muir, 1982).

Insufficient evidence is available to define more closely the 'ideal' milk for production of whipping cream. Nevertheless, in one important characteristic, that is fat type, the 'ideal' milk is far from that required for the production of perfect butter. Whilst a soft fat will produce butter which spreads from the refrigerator it also produces a whipped cream with major commercial disadvantages.

Ultra-high temperature (UHT) milk and skim milks

Milk, semi-skimmed milk and skim-milk products manufactured by the UHT process in Scotland are becoming an important new outlet for milk. Several problems occur with UHT milk products and are related to both initial heat stability and long-term storage stability. Although some compositional factors which influence the stability of full-cream evaporated milk also affect the heat stability of unconcentrated milk products (see the review by Fox & Morrissey, 1977), there are important differences (Muir & Sweetsur, 1978). For example, we have shown that the urea content of the unconcentrated milk is the principal determinant of the initial heat stability and can account for over 90% of the observed seasonal variation in heat stability (Muir & Sweetsur, 1976, 1977; Holt *et al.* 1978*a*). However, urea has no effect on the heat stability of concentrates unless certain aldehydes and sugars are added (Holt *et al.* 1978*b*) or when high forewarming treatments are applied (Sweetsur & Muir, 1981, 1982*c*). Milk urea level is directly related to blood concentrations (Thomas, 1980) and can readily be changed by dietary manipulation. Recent experiments at HRI have shown that dietary treatments can influence heat stability by means of changes in milk urea level (J. M. Banks, J. L. Clapperton, D. D. Muir, A. K. Powell and A. W. M. Sweetsur, unpublished observations). Therefore we have yet another desirable compositional attribute for milk which may be UHT sterilized—that is, a high urea concentration.

Conclusions

A summary of the relative importance of different compositional factors is shown in Table 7. Without doubt the single most important component in milk from a manufacturing viewpoint is protein. Higher average protein levels would benefit a number of important products and this benefit would be greater if the casein concentration in milk was selectively increased. Changes in either fat level or composition would have different and contradictory effects on individual products and would need to be undertaken with considerable forethought. Lactose in milk is of little importance in manufactured products and may even be an embarrassment. Nevertheless, lactose is an important energy source and there may well be an advantage in reinforcing pasteurized milk for liquid consumption

Table 7. *Summary of the relative importance of compositional factors to quality of some dairy products*

Product	Fat	Protein	Lactose	Minerals
Cheese	+	+++	–	?
Evaporated milk	+	+++	+	+++
Butter	+++	–	–	–
Cream	+++	++	–	?
Ultra-high temperature milk	–	+++	?	+++

–, Not important; +, ++, +++, increasingly important.
?, Ill-defined effects.

with added lactose (e.g. by the technique used by Poulsen *et al.* 1978). The minerals in milk can have profound effects on the stability of products which are sterilized either in cans or by the UHT process. In general, a lowering of the citrate and soluble Ca concentrations would offer a significant advantage to the milk processor.

Notwithstanding the above arguments, the modern milk processor can readily adjust milk composition by technological means. Fat content is easily adjusted by separation of cream, protein:lactose values can be manipulated by ultrafiltration and mineral composition can be changed by ultrafiltration, diafiltration, electrodialysis and ion-exchange. It may well be sensible, in view of the specific needs of individual products, to concentrate dietary treatments on the production of cheap milk and to leave the manipulation of milk composition for each manufactured product to the milk technologist.

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