3

Influences on raw milk quality

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3.1 Introduction

Milk is produced by all mammalian species for feeding their young, and there is a very large range of milk properties across all the species. Some mammals, such as the Tamar wallaby, can even produce milk of different compositions from adjacent mammary glands of the same individual at the same time (Nicholas, 1988). This chapter focuses exclusively on the range of quality (i.e. composition and related milk characteristics) of raw milk from dairying breeds of cattle (*Bos taurus*).

Although many people are persuaded that 'milk is milk' and that is the end of the matter, not all milks are created equal. There is significant variation in milk composition, which creates both problems and opportunities for the dairy industry. At the simplest level, differences in milk produced by different breeds are well recognised and have been used as a market position by some companies (Canada – Jersey Farm; USA – Promised Land Dairy; UK – 'Gold Top' – see Internet URLs at the end of this chapter). Despite thousands of years of domestication and selective breeding of dairy cattle, there is still a wide variation in milk composition from cow to cow. Table 3.1 gives an indication of the scope of variation within the herd of just one country (New Zealand). Much of this variation is evened out by a combination of milk from many animals at the farm level, with further evening out as collections from various farms are accumulated in the milk tanker, and in the silo at the factory, as shown in Fig. 3.1. A major survey of the protein composition of milk at the national level was carried out by the International Dairy Federation in the early 1990s (Higgins *et al.*, 1995). The survey covered 25 milk-producing countries. Annual average protein in the milk varied between countries from 3.00% to 3.55%, with monthly

Table 3.1 Range of composition in milks from individual cows in New Zealand. Data were collected from milk samples from 16 000 Friesian cows, 5800 Jersey cows and 340 Ayrshire cows and were analysed using Fourier Transform infrared spectrometry (S. Petch, unpublished, personal communication)

Component	Breed	Low	High
Milkfat %	Friesian	1.4	8.6
	Jersey	2.0	10.9
	Ayrshire	2.4	6.7
Protein %	Friesian	2.4	5.2
	Jersey	2.8	5.7
	Ayrshire	2.7	5.0
Lactose %	Friesian	3.7	5.7
	Jersey	4.2	5.6
	Ayrshire	4.3	5.4

values ranging from 2.75% to 4.09%. Protein as a percentage of the SNF (solids, non-fat) ranged from 32.7% to 46%, and the ratio of casein to whey protein varied from 3.24 to 5.87. Thus, even with national averages, there is considerable variation.

Variability in milk composition (and hence quality) extends considerably beyond simple breed characteristics. In this chapter, milk characteristics are addressed according to the source of variation, although they could equally well be divided according to where they impact and have economic or other effect. Milk characteristics have an effect at the processing level, on processability and yield, at the product level, in terms of the overt characteristics of the product, and on the consumer, in terms of nutrition and other physiological activity.

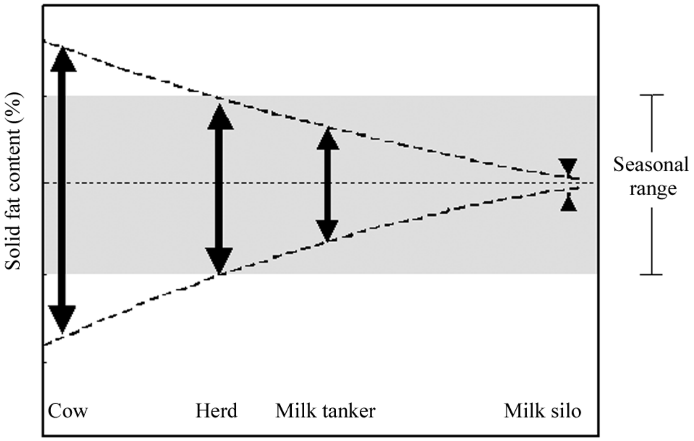

Fig. 3.1 Variation in milk characteristics. Although the example shown relates to butter hardness as measured by solid fat content, the principle is generally applicable. The seasonal range is the variation in milkfat in the silo during a season. Figure courtesy of A.K.H. MacGibbon, Fonterra Research Centre.

Genetic variations, many of which are breed linked, are the predominant source of variation in milk protein (Ng-Kwai-Hang and Grosclaude, 1992) and have a significant effect on milkfat composition and the amount of water in the milk. These are covered in Section 3.2. The second major influence on milk characteristics is the diet of the cow. This has a much greater effect on milkfat than on protein. It is covered in Section 3.3. In Section 3.4, the effects of other aspects of animal husbandry are dealt with. Section 3.5 gives a speculative view of what might happen in the future of milk production.

3.1.1 Economic importance of milk composition

Before discussing variations in milk composition in detail, it is worth considering the importance to the dairy industry of some of the compositional variables. This area has recently been reviewed by Williams (2002) and Hillbrick and Augustin (2002).

The first component of importance is water. Water is not usually directly cited as a compositional variable, but is implicit in the way other components are expressed, as water makes up the bulk volume of milk. Water is important in milk for consumption in its liquid form, as it affects the nutritional value per unit volume; however, in milk for processing, it has other important consequences. In dried products such as milk powders, water must be removed, and there is an energy cost for that removal; in the manufacture of cheese, water creates the bulk of the whey and has either a disposal cost, or a removal cost when other products are created from the whey. Further, water has a cost in transport, storage prior to processing, and size of processing plants in manufacturing. Thus, the ideal milk for most manufacturing purposes would have the highest possible solids content consistent with being able to be expressed from the mammary gland.

Protein is the most valuable component of milk. Within the major proteins, the most important split is between the caseins and the whey proteins. The ratio of casein to total protein is often known as the casein number (Ng-Kwai-Hang and Grosclaude, 1992) and is usually expressed as a percentage. This number defines the amount of cheese or casein that can be made from the protein in the milk, and is usually around 80. If the casein number gets too low (i.e. not enough casein relative to total protein), it can be difficult to make cheese.

Within the casein proteins, the only casein that seems to have a major concentration-dependent effect on processing is κ-casein. The ratio of κ-casein to total casein is an indicator of micelle size (Anema and Creamer, 1993) and relates in turn to curd formation during renneting (Puhan and Jakob, 1994) and stability during milk powder manufacture (Singh and Creamer, 1992).

The composition of milkfat is a very important variable (Hillbrick and Augustin, 2002). In today’s consumer environment, low fat products are valued, and milkfat is often the component that must be removed, for example, in producing half fat and low fat drinking milks. However, fat has a value in its own right, being an essential component in cheese, butter and a range of milkfat-based ingredients. As well as the amount of fat in milk being important, the properties of the fat need consideration. Proper functional behaviour of butter, and to some extent of cheese, depends on the appropriate melting behaviour of the fat. Butter needs sufficient solid fat to maintain shape at room temperature, but sufficient liquid phase to allow it to spread from the refrigerator. In all fats, the consumer requirement is for low levels of saturated fats and higher levels of mono- and polyunsaturated fatty acids. Finally, some specific fat components, such as omega-3 fatty acids and conjugated linoleic acid (CLA), are becoming recognised for their possible health benefits (Gurr, 1995; Hillbrick and Augustin, 2002). CLA is of particular interest because milkfat is one of the main dietary sources of this fatty acid.

Lactose has importance as the bulk phase of milk powders. In most countries, lactose is not considered to be a valued component of milk, although recent changes in the Codex Alimentarius of FAO/WHO, allowing standardisation of the level of protein in milk powders by adding lactose, may change this.

Minerals are not generally considered to be valuable components in milk, with the possible exception of calcium. Milk is an important dietary source of calcium, which is important for bone health and the prevention of osteoporosis. In practice, milk calcium is tightly regulated and the calcium level does not vary greatly, with a calcium to protein ratio in the range from 0.7 to 1.0 mmol/g (Davis *et al.*, 2001). It is a relatively simple matter to fortify drinking milks with calcium from other sources.

3.2 Breed, genetics and milk quality

Differences in composition between milks from different breeds are apparent even at the simplest levels of analysis, and are well known to dairy farmers and the processing industry alike. The Jersey breed, once dominant for commercial milk production in some countries, is known for high levels of fat and protein, and higher overall levels of solids in the milk (i.e. less water); however, it produces more fat relative to the amount of protein. It has been observed that Jersey milk performs better in cheesemaking, but recent work has shown that, if milk is standardised for both fat content and protein content, the cheesemaking properties are indistinguishable between the Jersey and Friesian–Holstein breeds (Auldist *et al.*, 2001). Sensory analysis of ripened Cheddar cheese showed only minor differences, all attributable to slight differences in mineral composition due to the standardisation process (Greenwood *et al.*, 2002).

In New Zealand, the majority of herds are tested at one central laboratory, the National Milk Analysis Centre in Hamilton. Because of a relatively uniform regime of pastoral farming across New Zealand, their results allow a good breed comparison. Compositional data for each of the main dairy breeds in New Zealand are given in Table 3.2.

Recently, it has been noticed that the Friesian breed, the main dairy breed farmed in New Zealand and Australia, has diverged noticeably from the Holstein

Table 3.2 Breed differences in New Zealand milk composition (calculated from Livestock Improvement Corporation, 2001)

Breed	Milk solids %	Protein %	Protein:fat %
Jersey	9.8	4.1	71
Friesian–Jersey cross (F1, F2)	8.7	3.7	75
Friesian	7.9	3.5	79
Ayrshire	7.9	3.6	81

breed of Europe and North America in terms of size of animal, milk volume yield per animal and milk composition, although both had a common origin a little over 100 years ago. The two strains were compared in an extended trial, and first lactation results suggest that the milk from Holsteins is lower in fat, protein and casein concentrations, although the lactation milk yield is higher (Auldist *et al.*, 2000a; Kolver *et al.*, 2002 – see Table 3.6 below for data).

3.2.1 The relationship between breed and genetic polymorphisms

Apart from obvious breed differences, there is a range of well-known genetic polymorphisms of milk proteins. Genetic polymorphism occurs when there is a change to the protein structure, usually as a result of a point mutation in the coding DNA. The resulting proteins are referred to as variants, and are designated by a letter, usually in the order of discovery.

Genetic polymorphism in milk proteins was first described by Aschaffenburg and Drewry (1955), and polymorphic forms, or genetic variants, have been described in the common dairy breeds for all major milk proteins excepting α_{s2}-casein and α-lactalbumin. The distribution of the main genetic variants in the major dairy breeds is given in Table 3.3. Of particular note is the higher level of κ-casein B in the Jersey breed. The β-lactoglobulin A and B variants are more or less evenly distributed in most breeds.

3.2.2 Genetic effects on gross composition

Heritability is a term that describes the proportion of natural variation that can be explained by genetic differences. Heritabilities of milk characteristics have been reported by a number of different authors. Some of these are given in Table 3.4. The values generally explain about half the within-breed variation; however, many of the genes responsible for this variation have yet to be identified. The heritabilities for concentrations of milk components are notably higher than those for production of milk components, reflecting a larger environmental impact on the volume of milk produced.

Fat and protein content in milk are often assumed to be quite tightly linked genetically. The results of a breeding programme over three generations in the Netherlands challenge this assumption. The fixed effect for protein to fat ratio

Table 3.3 Gene frequency of the major genetic variants of the major milk proteins in selected dairy breeds (data from Buchberger, 1995)

Protein/breed	Variant frequency (%)			
α_{s1}-Casein	**A**	**B**	**C**	
Holstein–Friesian, Ayrshire, Brown	Rare	90–99	1–9	
Jersey	Rare	71–89	10–19	
Guernsey	Rare	71–80	20–29	
α_{s2}-Casein	**A**	**D**		
All breeds	100	Rare		
β-Casein	**A1**	**A2**	**A3**	**B**
Holstein–Friesian	46–71	46–70	Rare	1–14
Jersey	3–24	46–70	Rare	30–46
Ayrshire	46–71	20–45	Rare	1–14
Guernsey	3–24	>70	Rare	1–14
Brown	3–24	46–70	Rare	15–29
κ-Casein	**A**	**B**		
Holstein–Friesian, Ayrshire	70–93	7–29		
Jersey	32–49	50–66		
Guernsey, Brown	50–69	30–49		
β-Lactoglobulin	**A**	**B**	**C**	
Most breeds	38–58	42–69	<5	
Ayrshire	5–20	70–88	<5	
α-Lactalbumin	**A**	**B**		
All breeds	Rare	100		

Table 3.4 Heritabilities of milk characteristics

Characteristic	Heritability	Breed	Reference
Protein concentration	0.37	Holstein	Wilcox *et al.*, 1971
	0.56	Jersey	Wilcox *et al.*, 1971
	0.59	Holstein	de Jaeger and Kennedy, 1987
Fat concentration	0.57	Holstein	Wilcox *et al.*, 1971
	0.71	Jersey	Wilcox *et al.*, 1971
	0.61	Holstein	de Jaeger and Kennedy, 1987
Carrier[a]	0.61	Holstein	de Jaeger and Kennedy, 1987
Lactose	0.36	Ayrshire	Robertson *et al.*, 1956
Minerals	0.50	Ayrshire	Robertson *et al.*, 1956
Colour	0.40–0.49	Friesian	Winkelman *et al.*, 1999
	0.17–0.31	Jersey	Winkelman *et al.*, 1999

[a] Carrier is defined by these authors as the sum of all components other than protein and fat.

between selected high fat and low fat lines differed by 5.4%, 8.8% and 12.6% over the three successive generations of selection (Vos and Groen, 1998). This indicates clear potential to breed for changed ratios of protein to fat.

Genetic polymorphisms of the major milk proteins have in many cases been tied to changes in milk composition (Ng-Kwai-Hang *et al.*, 1987; Ng-Kwai-Hang and Grosclaude, 1992; Hill, 1993; Puhan and Jakob, 1994; Hill *et al.*, 1995a, 1995b; Ng-Kwai-Hang, 1997; Ojala *et al.*, 1997; Coulon *et al.*, 1998; Bobe *et al.*, 1999). The clearest example of this is the difference in milk composition between milks containing only the A variant of β-lactoglobulin and milks containing only the B variant. This difference was explored by Hill *et al.* (1995a, 1995b). Briefly, a farm was set up with 200 β-lactoglobulin AA phenotype cows, and 200 β-lactoglobulin BB phenotype cows. The two herds were matched for age, breeding worth and breed composition. The two groups were run as one herd, and milked in a milking shed equipped with dual milk lines and collection vats, so that the milk from each phenotype could be collected separately without disruption to milking practices. The herd was managed as a seasonal supply herd: cows were calved in July/August and were milked through to March/April. The herd was managed in this way for two years, and a variety of experiments was carried out using the milk. Composition data for the milk collected monthly over the two-year period are summarised in Fig. 3.2. The genetic basis for the difference observed in this trial has since been defined, and is a mutation within a consensus binding site for activator protein-2, at position -430 bp upstream from the transcription initiation site for β-lactoglobulin (Lum *et al.*, 1997).

Polymorphism of κ-casein has also been linked to changes in composition. This usually appears as a higher concentration of κ-casein in the milk of BB

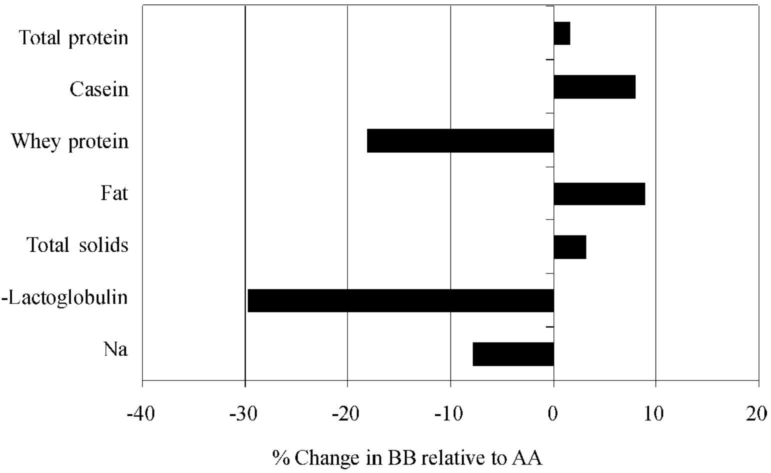

Fig. 3.2 Effect of β-lactoglobulin polymorphism on milk composition. Bars refer to the percentage difference in the composition of the BB milk relative to the AA milk. Results are based on 40 samples of each milk taken over two years. Each herd comprised 200 cows.

phenotype cows, with a consequent overall increase in total casein and cheese yield (Puhan and Jakob, 1994). The consequence of higher levels of κ-casein is a smaller micelle size, leading to better coagulation properties and firmer curd in cheesemaking. The κ-casein variant effect observed in our work was about half the effect seen for β-lactoglobulin. Because κ-casein B is only a small proportion of the gene pool in Holstein cattle, any value of breeding for this variant would probably be offset by the overall loss of genetic gain. The genetic basis for the difference in expression between the A and B forms is unclear: a study of expression in AB animals showed only a modest increase in expressed sequences of mRNA (13%), and no polymorphisms were found in the promoter region. Allele-specific differences in the length of mRNAs suggest that the level of κ-casein may be under a post-translational control (Debeljak *et al.*, 2000). As not all studies have found differential expression of protein or casein between the variants (Dikkeboom *et al.*, 2000), caution is advised concerning breeding specifically for this variant.

A study comparing both β-lactoglobulin and κ-casein polymorphisms with natural variation (Bobe *et al.*, 1999) has concluded that the κ-casein phenotype explains 25% of the phenotypic variation of the κ-casein content and 11% of the variation of α_{s1}-casein, that β-lactoglobulin polymorphism explains 26% of the variation of β-lactoglobulin composition, 4% of the variation of α_{s1}-casein and 6% of the variation of β-casein, and that neither polymorphism explains any variation in total protein. The last observation is consistent with results reported by other authors (Hill, 1993). All other effects were at the 1% level or less. This means that, for practical purposes, these polymorphisms primarily affect the ratio of casein to whey protein (casein number).

3.2.3 Genetic effects on milkfat composition

Although there are undoubtedly important genetic effects on milkfat composition, evidence to date is relatively sparse. The most obvious genetic effects are seen in the differences between butters made from Jersey and Holstein milkfats. Jersey butter is consistently seen to be harder (i.e. higher solid fat content – MacGibbon, 1996) and Jersey milkfat is more yellow than its Friesian or Ayrshire counterpart (Winkelman *et al.*, 1999). The Friesian–Jersey comparison was analysed further by MacGibbon (1996) to identify differences in the fatty acids making up the triglycerides (Table 3.5).

A recently discovered polymorphism of the gene coding for acyl CoA – diacylglycerol acyl transferase (DGAT), an essential enzyme in milkfat synthesis – explains some of the variability in milkfat composition (Grisart *et al.*, 2002). The gene for this has been found on the centromeric end of bovine chromosome 14 and the polymorphism results in a structural change from the highly conserved lysine 232 to alanine in the enzyme. This change has been linked to a change of 0.4% in milkfat proportion. No doubt further genetic polymorphisms that can explain differences in milkfat composition will soon be described.

Table 3.5 Mean solid fat content and fatty acid composition for milkfat from Friesian and Jersey factory supply herds on the same day (MacGibbon, 1996); fatty acids are expressed as g per 100 g fat

Fatty acid	Friesian (*n* = 11)	Jersey (*n* = 8)
C4:0	3.8	3.8
C6:0	2.4	2.5
C8:0	1.3	1.5^{***}
C10:0	2.8	3.4^{***}
C12:0	3.2	3.9^{***}
C14:0	10.7	11.2^{**}
C16:0	29.8	28.7^{*}
C18:0	10.5	12.1^{***}
C18:1	22.1	20.6^{*}
C18:2	1.2	1.3^{*}
C18:2c	1.3	0.9^{***}
C18:3	0.8	1.0^{**}
SFC10	54%	57%

Significance levels are $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

3.2.4 Composition effects on cheese yield and casein yield

The difference in composition between milks from different phenotypes can be used to economic advantage. The difference in composition between β-lactoglobulin AA and BB milks, shown in Fig. 3.2, leads to increased yields of casein and cheese from the same amount of milk protein (Puhan and Jakob, 1994; van den Berg, 1994; Tong *et al.*, 1994; Hill *et al.*, 1995a, 1995b). When milk is paid for on the basis of protein, and used for making cheese or casein, unless there is a very profitable parallel production of a specialised whey protein product, there is considerable economic benefit in using BB milk. This was piloted at the Kaikoura Dairy Co-operative in New Zealand, where the group of farmers supplying the company (which made only cheese) selectively bred for the B variant of β-lactoglobulin (Boland *et al.*, 2000; Boland and Hill, 2001). This company was amalgamated with a larger company before the second cohort of 'BB' cows was in full production, so the final benefits could not be captured.

3.2.5 Chemistry effects – UHT fouling, pre-heater fouling

One of the more dramatic effects attributable to the chemistry of the genetic variants is the impact on heat exchanger fouling in UHT plants (Hill *et al.*, 1997, 2000). In many warm-climate countries, recombined or reconstituted UHT milk is produced using imported milk powders. Following recombining or reconstitution, the milk is UHT treated at 140ºC. Fouling of UHT heat exchangers causes decreased efficiency of operation of the plant and increased

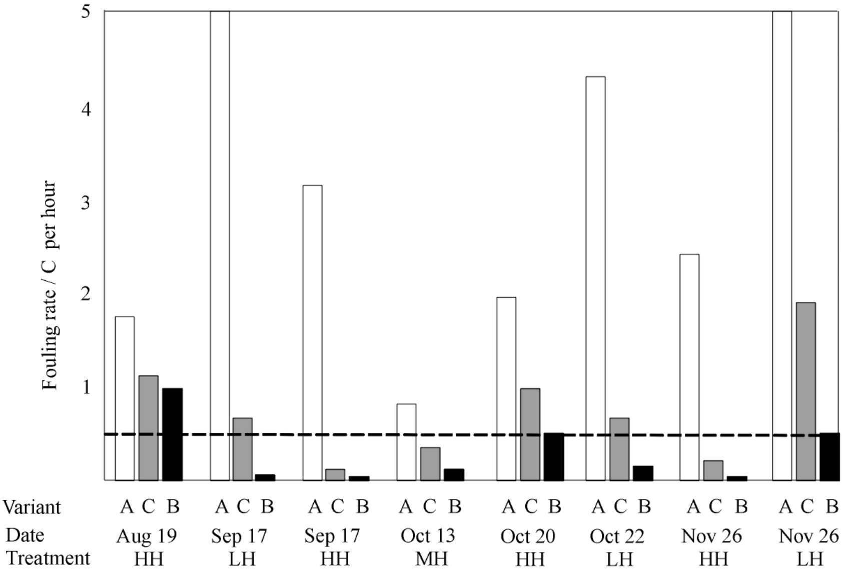

Fig. 3.3 Effect of genetic variant on fouling of UHT plants by reconstituted whole milks. Legend: A, milks containing only β-lactoglobulin AA variant; B, milks containing only β-lactoglobulin BB variant; C, control milk (mixed variants). Treatments during powder manufacture were: HH, 120ºC, 180 s; MH, 95ºC, 20 s; LH, 72ºC, 15 s. Data from Hill *et al.* (1997).

back-pressure through the heat exchanger, and can at worst require premature plant shutdown for cleaning. Milk was collected from the β-lactoglobulin AA and BB cows in the herd described earlier in this chapter, and used to make milk powder. A range of powders was made during the peak of the production season, with different preheat treatments. These powders were then tested for UHT fouling. Typical results are presented in Fig. 3.3. This shows a dramatic difference between the A and B variants in their fouling properties. These results were seen over both years of the trial, for both skim and whole milk powders, and in pre-heater fouling in milk powder manufacture (although to a lesser degree).

Further analysis of the data from these trials shows no relationship between fouling and any compositional differences between the milks (data not shown – see Hill *et al.*, 1997, for details). Thus the difference in fouling behaviour must be attributable to differences in the chemistry of heat effects on the different β-lactoglobulin variants.

A similar genetic-variant-dependent difference in fouling was seen for κ-casein AA and BB, with the BB milk fouling at about twice the rate of the AA milk. A semi-factorial trial with both κ-casein and β-lactoglobulin variants showed the two variant effects to be independent and additive (Hill *et al.*, 2000).

3.3 Cow diet and milk quality

Cow nutrition can have important effects on milk composition. Proteins are relatively unaffected provided the cow has an adequate level of nutrition; however, the milkfat is very considerably affected by diet composition.

3.3.1 Differences between milks from pasture-fed and concentrate-fed cows

There are two quite distinct ways of managing dairy cows, which dictate the way they are fed and consequently affect the characteristics of the milk and dairy products. Pastoral farming, where the cows spend their time outdoors grazing pasture, is practised almost exclusively in New Zealand, most of Australia, and for a large part of the year in Ireland. In contrast, most of the dairy cows in North America and a large part of Europe are housed indoors for most of the time and are fed on concentrates and rations largely based on grains. These differences in feeding affect milk yield and the composition and other qualities of the milk. In a parallel trial, small herds of Friesian and Holstein cows ($n = 27$ or 26) were fed either on pasture or on total mixed rations (TMR). The pasture-fed cows produced milk with higher concentrations of milkfat, whereas the cows fed on TMR produced greater volumes of milk and higher concentrations of lactose (Auldist *et al.*, 2000a; Kolver *et al.*, 2000, 2002). Some data are given in Table 3.6. Milks from pasture-fed and ration-fed cows also show significant differences in fatty acid composition (Palmquist *et al.*, 1993; White *et al.*, 2001; Taylor and MacGibbon, 2002), though these differences are confounded with seasonal effects on milkfat from pasture-fed cows (Taylor and MacGibbon, 2002); they are discussed in Section 3.4.2.

3.3.2 Effect of diet on milkfat composition

Cow diet can have a considerable effect on milkfat composition. Milkfat is composed mostly of triglycerides. The physical properties of milkfat products are largely governed by the chain length and degree of unsaturation of the fatty acids that make up the triglyceride. Nutritional and health benefits are also affected by the positioning of double bonds and regioisomerism (i.e. position in

Table 3.6 Differences in milk composition between cows fed on pasture and total mixed rations (TMR) (data from Kolver *et al.*, 2002)

	NZ Friesian		Holstein	
	Pasture	TMR	Pasture	TMR
Milk yield (kg per cow, full lactation)	5300	7304	5882	10 097
Fat (%)	5.03	4.60	4.28	3.62
Protein (%)	3.74	3.65	3.50	3.54

Table 3.7 Effect of pasture species and season on milkfat composition (20-day rotation) (data from Thomson *et al.*, 2002)

	Ryegrass	Timothy	Standard error of difference (between means) – s.e.d.	Significance
Spring				
Milkfat yield (kg/cow/d)	0.85	0.94	0.05	***
Monounsaturates (%)	22.8	24.9	0.51	***
Polyunsaturates (%)	3.9	4.6	0.17	***
Total unsaturates (%)	26.7	29.5	0.61	***
Autumn				
Milkfat yield (kg/cow/d)	0.52	0.48	0.04	
Monounsaturates (%)	30.8	28.9	0.54	***
Polyunsaturates (%)	6.9	6.1	0.36	*
Total unsaturates (%)	37.7	35.1	0.63	***

Significance levels are $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

the triglyceride) of the fatty acids. In the cow, the fatty acids come from two sources: fatty acids of less than C16 are synthesised *de novo* in the mammary gland, but fatty acids of C18 or longer chain length come from dietary sources. Fatty acids of C16 are derived from both sources (Hawke and Taylor, 1995). Dietary fat is extensively modified by microorganisms in the rumen, so that the fatty acid profile that is received by the cow is the product of diet composition and rumen modification. The most important modification in the rumen is the saturation of polyunsaturated fatty acids. High concentrations of polyunsaturated fatty acids are toxic to some microbial species in the rumen, which carry out desaturation as a detoxifying mechanism.

Feeding of pasture species with different lipid content results in milkfat with different composition. In a comparison between milk from cows grazing ryegrass/white clover pasture and cows grazing timothy/white clover pasture, at two different times of year, the milkfat showed species and season-dependent differences in levels of unsaturated fatty acids (Thomson *et al.*, 2002) as shown in Table 3.7. The changes in milkfat composition are as much a consequence of the amount of plant lipid as of the composition of that lipid. When the rumen is presented with a high level of polyunsaturated fat, its capacity to desaturate is limited so that more unsaturated fatty acids, particularly C18:1, are available to the cow for milkfat synthesis.

CLA has been identified as an important health-promoting component of milkfat with anti-cancer properties (Parodi, 1994, 2001; Gurr, 1995). Milkfat from pasture-fed cows contains relatively high levels of this fatty acid, of the order of 1% (MacGibbon *et al.*, 2001), in contrast to milkfat from grain-fed animals which typically contains about 0.4–0.5% (Chin *et al.*, 1992; White *et al.*, 2001). At least one company in the US has converted to pasture feeding and makes a marketing position based on the (relatively) high level of CLA in its cheese ('Northern Meadows' cheese from Full Circle Farms – see the URL at the end of this chapter). There is a wide variation in the level of CLA from milk of individual pasture-fed cows and between herds. A recent New Zealand study across 44 herds found a herd-to-herd range from 0.8% to 2.2% on a single day, and a seasonal variation from 0.8% in early spring to 1.4% in autumn for the overall average (MacGibbon *et al.*, 2001). It is now recognised that some of the CLA comes directly from production in the rumen, but that the majority arises from desaturation of trans-11 linoleic acid (vaccenic acid) in the mammary gland (Palmquist, 2001). Thus, the level of CLA in the milkfat will be a function of the availability of substrate and the activity of stearoyl-CoA Δ-9 desaturase.

3.3.3 Modification of composition by dietary supplements

Both the relative amount and the composition of milkfat can be modified by dietary supplements. A full discussion of this area is beyond the scope of this chapter, and the reader is referred to the recent reviews of Bauman and Griinari (2001) and Chilliard *et al.* (2000).

Nutritional manipulation of milkfat concentration has been reviewed by a number of authors, including Sutton (1989), Kennelly (1993), Murphy (2000) and Bauman and Griinari (2001). Milkfat concentration is depressed to a small extent when grazing cows are fed concentrates; however, an excess of readily fermentable carbohydrate in the diet, leading to an acidic condition in the rumen, will give a more dramatic decrease in milkfat concentration, so-called 'low milkfat syndrome' (Sutton, 1989; Stockdale *et al.*, 2001). This condition has been known for over 100 years. It is probably not sustainable and may impact adversely on the cow's health. Under acidic conditions, the rumen metabolism changes to produce higher concentrations of propionic acid and *trans* C18:1 (Holmes *et al.*, 2002, pp. 356–357). It has recently been proposed that low milkfat syndrome is largely due to the formation of *trans*-10, *cis*-12 CLA in the rumen (Bauman and Griinari, 2001).

Reductions in milkfat concentration have been achieved by feeding a wide range of supplements, including fat (Palmquist *et al.*, 1993; Beaulieu and Palmquist, 1995), fish oils (Chilliard and Doreau, 1997; Keady and Mayne, 2000), and oleamide (Jenkins, 1999). Many of these act in a similar way, reducing the level of short- and medium-chain fatty acids and increasing C18:1 fatty acid, suggesting a suppression of *de novo* fatty acid synthesis.

A more dramatic reduction in milkfat production can be achieved by feeding CLA (Loor and Herbein, 1998). To be effective, rumen desaturation must be avoided, so ruminal protection or rumen bypass must be used. A reduction of milkfat percentage by up to half has been demonstrated by direct infusion of CLA into the abomasum (Chouinard *et al.*, 1999; Kraft *et al.*, 2000). CLA exists as a number of isomeric forms. The common form in animal fat is the *cis*-9, *trans*-11 isomer. It has recently been identified that the other most common isomer in synthetic CLA, the *trans*-10, *cis*-12 isomer, is responsible for milkfat

Table 3.8 Yield and characteristics of fatty acids in milkfat produced by cows fed 2 kg oilseed per cow per day that was unprotected crushed seed (Canola 1) or protected against ruminal biohydrogenation by two different processes (Canola 2 and Canola 3). The control sample was from grass-fed cows (data from Thomson *et al.*, 2002)

	Control	Canola 1	Canola 2	Canola 3
Milkfat yield (kg/cow/d)	0.53^{a}	0.56^{a}	0.50^{a}	0.58^{a}
Monounsaturates (%)	32.4^{a}	38.4^{b}	42.0^{c}	$39.5b^{b}$
Polyunsaturates (%)	6.3^{a}	6.1^{a}	6.8^{a}	$10.6b^{b}$
Total unsaturates (%)	38.7^{a}	44.5^{b}	49.0^{c}	50.0^{c}

^{abc} Means within fatty acid groups having superscripts with common letters are not significantly different ($p < 0.001$).

reduction (Baumgard *et al.*, 1999). It has been suggested that this isomer operates through down-regulation of expression of the stearoyl CoA Δ-9 desaturase gene (Choi *et al.*, 2000), although the mechanism is unclear.

Milkfat composition can be modified by feeding a wide variety of supplements. For a comprehensive review of this area, see Chilliard *et al.* (2000). Of particular interest is the feeding of oilseed, or ruminally protected oilseed (Ashes *et al.*, 1992, 1997; Murphy *et al.*, 1995; Chilliard *et al.*, 2000; Murphy, 2000). Feeding ruminally protected Canola can modify the level of unsaturation of milkfat and hence the perceived healthiness (Ashes *et al.*, 1992, 1997), and the level of solid fat content and thus the spreadability of butter (Thomson *et al.*, 2002). Data from some recent trials are shown in Table 3.8.

3.4 Other aspects of animal husbandry and milk quality

3.4.1 Colostrum

Colostrum is the secretion produced over the first few days after parturition. The components of colostrum are synthesised in the mammary gland over several days prior to parturition. Colostrum is rich in special nutrients for the newborn calf, in particular a high level of immunoglobulins, believed to confer significant passive immunity against gut pathogens, and a range of growth factors. In addition, the milk has a higher level of β-carotene, imparting an intense yellow colour, and a high level of somatic cells. A summary of the main differences in composition is given in Table 3.9.

Recently there has been a lot of commercial interest in colostrum because of its elevated levels of bioactives, especially growth factors, and there is a wide range of literature supporting the health benefits of colostrum (Scammell, 2001). At least nine companies are known to be producing specialist colostrum products in Europe, the US, Australia and New Zealand, with production in 2001 estimated at 600 tonnes. The price for colostrum powder is estimated to be about \$25 000/tonne, more than 10 times that of normal milk powders (Scammell, 2001).

Table 3.9 Comparison of bulk components and bioactive protein components of normal milk and colostrum (data from Holmes *et al.*, 2002, p. 350 and papers cited therein for bulk components, and from Scammell, 2001, for bioactives)

Component	Colostrum	Normal milk
Total protein (%)	8–21	3–4.8
Casein (%)	3–6	2.6–3.8
Fat (%)	3–11	3–6
Carotene (ppm)	50–300	1
Somatic cells (per ml)	$1\text{–}2 \times 10^6$	$2\text{–}30 \times 10^4$
Total immunoglobulins (%)	3–15	0.02–0.1
IgA (%)	0.32–0.62	0.01
IgG1 (%)	4.8–8.7	0.04
IgG2 (%)	0.16–0.29	0.005
IgM (%)	0.37–0.61	0.005
IGF-1 (ppm)[a]	0.1–2	0.025
IGF-2 (ppm)[a]	0.1–2	0.002
TGF-B (ppm)[a]	20–40	0.002
EGF (ppm)[a]	4–8	0.002
Lactoferrin (g/l)	1.5–2	0.1
Lysozyme (ppm)	0.1–0.7	0.1–0.3
Lactoperoxidase (ppm)	30	20

[a] Abbreviations for growth factors: IGF: insulin-like growth factor; TGF: transforming growth factor; EGF: epidermal growth factor.

3.4.2 Seasonal effects in pastoral farming

Variations in milk characteristics during the season are well known for cows that are farmed in seasonally calving, pasture-based dairying systems. This is due largely to the combined effects of the lactation cycle of the cow and seasonal effects on the composition of the pasture, which in turn impact on milk composition. Similar variation is not normally seen to such an extent in herds housed indoors and fed concentrate, because their feed supply is constant and calving is usually staggered throughout the year. Typical seasonal variation in milk composition is shown in Fig. 3.4.

Seasonal variation was studied by Auldist *et al.* (1998) by running parallel small herds (about 20 cows each) that were calved at three-monthly intervals. Concentrations of major milk components, including total protein, casein and fat, increased as a function of the stage of lactation; however, other factors of importance for the processor, including protein to fat ratio, casein to whey protein ratio and solid fat content, were all affected primarily by the time of year.

Seasonal effects are seen in the composition of milkfat from pasture-fed cows. These are manifest in the changes in solid fat content shown in Fig. 3.4. The lush spring-growth grass is rich in C18:3 fatty acid, which is only partially desaturated in the rumen, giving rise to higher levels of C18:1 as well as C18:0 fatty acids in the milkfat triglycerides. Summer grass gives rise to lower levels

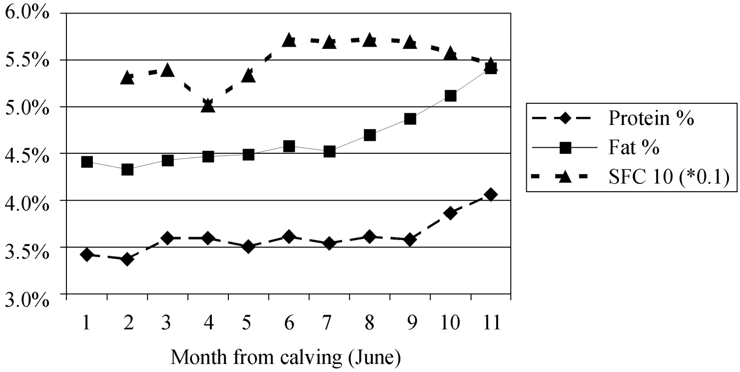

Fig. 3.4 Seasonal variation in milk composition for New Zealand milk (all breeds). Data from Livestock Improvement Corporation (2001) and MacGibbon and McLennan (1987).

of C18:0 and C18:1, but more C16:0 fatty acids in the milkfat (Taylor and MacGibbon, 2002).

3.4.3 Effects of plane of nutrition

Restriction of nutrition is well known to have the effect of reducing milk production; however, there are also impacts on the composition of the milk that is produced. Much of the work that has been done in this area relates to pasture feeding, in order to understand the impact of pasture shortages on milk (for example, in times of drought). Most authors are agreed that restricted feeding results in a lower concentration of milk protein and, importantly, casein (Macheboeuf *et al.*, 1993; O'Brien *et al.*, 1997, 1999; Petch *et al.*, 1997; Mackle *et al.*, 1999; Auldist *et al.*, 2000b). This is particularly important for making cheese (O'Brien *et al.*, 1997, 1999) and, when coupled with genetic variant effects on milk composition, can be particularly important for cheesemaking quality (Macheboeuf *et al.*, 1993; Mackle *et al.*, 1999; Auldist *et al.*, 2000b).

Many experiments concerning the plane of nutrition are complicated by genetic effects, use of supplements to top up the diet of fully fed cows, and seasonal effects. For this reason, the study by Petch *et al.* (1997) is possibly the most definitive. This study used 18 identical twin pairs, fully fed on pasture or fed at 65% of the fully fed rate on pasture (with a third leg based on supplements, not considered here). The study showed that, on the restricted diet, both casein and whey protein were significantly reduced by similar amounts (4–8%), giving no significant effect on casein number. Fat and lactose concentrations were not significantly affected. The experiments of Macheboeuf *et al.* (1993) and Auldist *et al.* (2000b) similarly showed no effect on fat or lactose; however, other studies, including those of O'Brien *et al.* (1997, 1999) and Mackle *et al.* (1999), observed differences in lactose and fat concentrations. Mackle *et al.*

(1999) also recorded differences in fat composition. The significant difference between the two types of result appears to be the use of supplementary feeding of concentrates in the fully fed animals, which can introduce differences due to nutritional quality as distinct from plane of nutrition.

3.4.4 Effect of udder health

Udder health is particularly important in maintaining milk composition. The effects of mastitis on milk composition have been reviewed recently by Auldist and Hubble (1998). A strong correlation between decreasing somatic cell count and increasing casein content in milk received at the factory has been observed (Bob Franks, personal communication, referred to in Lacy-Hulbert and Auldist, 2002). Mastitis has three important adverse effects on milk production, even at sub-clinical levels (Lacy-Hulbert and Auldist, 2002). First, bacterial toxins and the inflammatory response cause damage to mammary epithelial cells, leading to a reduction in mammary-synthesised components. Second, the inflammation of the mammary gland leads to leakiness of the tight junctions, leading to higher leakage of serum proteins, particularly serum albumin, immunoglobulins and, importantly, plasminogen, which can be activated to the proteolytic enzyme plasmin. Third, the bacteria causing the infection produce extracellular proteases and lipases that break down milk proteins and fats, particularly casein, which is more susceptible to enzyme action than globular proteins, because of its extended structure. Plasminogen can also be activated to plasmin by bacterial enzymes, causing further protein hydrolysis. The net result of all this is to produce milk with a lower casein number and poorer cheesemaking properties (Barbano, 1994). Lipolysis can also lead to flavour defects from release of short-chain fatty acids.

Milkfat is affected by increased lipolysis in some mastitic milks, leading to increased levels of free fatty acids which can have adverse flavour effects. Whether this is due to bacterial lipases or animal origin lipases may vary depending on the species of bacterial infection. It is also likely that many mastitic infections lead to fragility of the milkfat globule membrane, making the fat more susceptible to release and hydrolysis by endogenous lipases (Deeth and FitzGerald, 1995).

The degree of mastitis is generally indicated by the somatic cell count (SCC) in milk, and the SCC has been correlated in a number of cases with product deterioration on storage. It seems likely that the storage problems are caused by proteolytic and lipolytic activities resulting from the mastitic condition, rather than the SCC as such. Recent work showed that milk with low SCC (<100 000/ml) when pasteurised had superior keeping qualities, with no reduction in organoleptic properties after 21 days of refrigerated storage. A corresponding milk with higher SCC (>800 000/ml) had significantly deteriorated in this time (Ma *et al.*, 2000). Other work has identified adverse effects of a high SCC on the storage stability of UHT milks and on whole milk powders (Auldist *et al.*, 1996a, 1996b).

3.4.4 Effects of milk handling

This area has been reviewed by Deeth (1993) and Deeth and FitzGerald (1995). Briefly, milk contains powerful endogenous lipases. Milkfat triglycerides are protected from hydrolysis by encapsulation in the milkfat globule, surrounded by the milkfat globule membrane. Severe mechanical shear can break a proportion of the milkfat globule membrane, releasing triglyceride and allowing lipolysis to occur. The sensitivity of the milkfat globule membrane to shear can vary according to cow genetics and environmental factors such as cow nutrition and health, and stage of lactation. There is also evidence for endogenous activators and inhibitors of lipolysis in milk (Deeth and FitzGerald, 1995). Milk from late lactation, and from cows on a low plane of nutrition, is thought to be more susceptible to lipolysis, though understanding of the factors affecting lipolysis is far from clear. Typical sources of shear include some types of milking machine, and some pumps, especially if air is entrained in the milk during pumping. This can be a particular problem with poorly maintained equipment, especially milking machines with overhead milk lines. Homogenisation will induce lipolysis, though it is usually carried out on milks for drinking following an extended pasteurisation step that inactivates most of the lipase activity.

Lipolysis causes off-flavours due to the released short-chain free fatty acids (hydrolytic rancidity), and changes in functionality, which affect manufacturing and product performance. Changes in functionality can be due to free fatty acids, but are more often due to the formation of mono- and diglycerides, which have surface-active properties. One well-known example is a decrease in foam formation, for example in cappuccino coffees.

3.5 Future trends

3.5.1 Impact of genetic engineering

Leaving aside genetic modification for the production of pharmaceuticals in milk, it seems unlikely that genetic modification of cows to change the milk composition for functional or nutritional purposes will be commercially viable for the foreseeable future. There are several reasons for this.

- Consumer acceptance of genetically modified (GM) foods is still variable throughout the world, with some countries having strict labelling requirements and negative public attitudes to GM foods. Because milk is a liquid product handled in large bulk quantities during processing, maintenance of batch identity and keeping GM milk separate are more difficult than with discrete products.
- Milk is an animal product, and is strongly targeted at the health of babies and young people. This has been identified in consumer surveys as a very sensitive area (e.g. compared with the acceptability of GM fruit and vegetables), and for this reason milk will probably be one of the last foods in which genetic modification is accepted.

- The production of commercial-sized herds of GM cows will be very costly and very slow, even if expensive cloning and embryo transfer methods are used. This cannot be justified by a small premium for improved nutrition or functionality arising from genetic modification.
- Finally, and probably most importantly, a switch to genetic modification will severely limit genetic gain, because the ongoing gene pool will be restricted to the genetics of the donor animals for the original GM parents. This segregation from the wider global bovine gene pool will prevent participation in the ongoing genetic improvement of the species, which is currently occurring at about 2% per annum and worth billions of dollars a year in global herd improvement.

3.5.2 Novel forages and feeding regimes

Although it is unlikely that cows will be genetically engineered for altered milk composition in the near future, it is probable that some cows are already consuming GM crop plants such as maize, canola and cotton seeds and oils. There is considerable scope to extend the range and viability of pastoral dairy farming into now marginal areas, by developing GM plants better capable of withstanding drought or extremes of temperature. Plants capable of producing oils and proteins that are protected against rumen breakdown may also be developed, making these components available for gut absorption. Any or all of these changes have the potential to modify milk characteristics, although the significance remains to be seen.

3.5.3 Relative amounts of protein and fat in milk

If the consumer desire for low-fat diets continues, the decreasing demand for fat is likely to drive breeding in the direction of lower fat, higher protein milk. Some of the ways in which this might occur have already been indicated earlier in this chapter. Examples of cows that already produce milk with only 2% fat and normal protein levels, and with elevated levels of unsaturated fatty acids, are known; however, these are rare, and the present valuation of milkfat makes their widespread propagation unlikely. Even against a decreased breeding value for milkfat, optimum breeding means that milkfat production is almost certain to exceed demand, assuming that the current decrease in consumer demand continues (Gibson, 2000). It is perfectly feasible that we may eventually have herds producing milk with 2% fat, relatively rich in unsaturated fatty acids and with high levels of CLA, but that time is well in the future.

3.5.4 Sustainability issues

There is an increasing focus on long-term sustainability in farming and particularly dairying and its effect on greenhouse gases. The principal issue is methane production. Domestic livestock account for about 26% of all methane production (Environmental Protection Agency estimate, see http://www.epa.gov/ghginfo/topics/topic2.htm for more detail), and cattle make up the major proportion of this. Solutions are likely to involve modification of rumen function to minimise methanogenesis, which will also change the overall energy balance of the rumen and possibly alter the fatty acid profile received by the cow. This can be expected to impact on milkfat composition, although the extent is not clear.

3.6 Sources of further information and advice

For general information on pastoral dairy farming and cow lactation, the reader is referred to the excellent *Milk Production from Pasture* by Holmes *et al.* (2002).

There are two recent periodical issues that relate specifically to milk composition and its variability and suitability for various purposes: the British Society of Animal Science Occasional Publication No. 25 (2000) entitled *Milk Composition*, edited by R.E. Agnew, K.W. Agnew and A.M. Fearon, and the *Australian Journal of Dairy Technology*, Volume 56, No. 2 (2001), a special issue on ‘Farm to Fork 2001’. For further information about milk protein polymorphism, the reader is referred to ‘Milk Protein Polymorphism’, IDF Special Issue 9702 (International Dairy Federation, Brussels). For more information about factors relating to cheese manufacture, ‘Cheese Yield and Factors Affecting its Control’, IDF Special Issue 9402 (International Dairy Federation, Brussels) is recommended, particularly Topics 3 and 4.

For recent reviews on the relationship between milk composition and the properties of dairy products, the reader is referred to papers by Williams (2002) and Hillbrick and Augustin (2002) in the *Australian Journal of Dairy Technology*. These report on a major Australian initiative, the ‘Milk for Manufacturing’ project commissioned by the Victorian Department for Natural Resources and Environment.

The following Internet URLs describe some claimed benefits of breed-specific milk. Note that these are unsupported producers’ claims and should be treated with caution:

- http://www.jerseyfarm.com/
- http://www.promisedlanddairy.com/index.html
- http://www.meistercheese.com/gmidwest.html
- http://www.gold-top.co.uk/ (under construction)
- https://www3.quik.com/texasjersey/
- http://www.springhillcheese.com/

The following URL advertises CLA-rich cheese from pasture-fed cows, and describes some background to CLA cheese, including some literature references:

- http://fullcirclefarm.net/Default.htm

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