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# MILK

## and
## Milk Products

### TECHNOLOGY, CHEMISTRY AND MICROBIOLOGY

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CHAPMAN & HALL

# MILK and MILK PRODUCTS

*Technology, chemistry and microbiology*

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# MILK and MILK PRODUCTS

# Preface

Milk has been an important food for man since the domestication of cattle and the adoption of a pastoralist agriculture. It is also the most versatile of the animal-derived food commodities and is a component of the diet in many physical forms. In addition to milk itself, a rural technology evolved which permitted the manufacture of cheese, fermented milks, cream and butter. At a later date, successive advances in technology were exploited in the manufacture of ice cream, concentrated and dried milks and, at a later date, of ultra-heat-treated dairy products, new dairy desserts and new functional products. At the same time, however, dairy products have been increasingly perceived as unhealthy foods and a number of high quality dairy substitutes, or analogues, have been developed which have made significant inroads into the total dairy food market. Paradoxically, perhaps, the technology which, on the one hand, presents a threat to the dairy industry through making possible high quality substitutes offers, on the other hand, an opportunity to exploit new uses for milk and its components and to develop entirely new dairy products. Further, the development of products such as low fat dairy spreads has tended to blur the distinction between the dairy industry and its imitators and further broadened the range of knowledge required of dairy scientists and technologists.

One of the most striking features of the traditional dairy industry is the manner in which technology, chemistry and, subsequently, microbiology were integrated to allow the manufacture of high quality and safe products. It is considered that a similar integration of disciplines is required both to enable the dairy industry to meet the many future challenges, and also to permit the student of Food Science, Food Technology and related subject areas to gain a true knowledge of the nature of dairy products.

In writing this book, we have been very conscious of the requirements, not only of undergraduate and equivalent students, but of the new graduate entering industry and facing new and potentially frightening situations. To this end, the book is structured to meet the requirements both of the student, with a basic knowledge of chemistry, biochemistry and microbiology and of persons working in the dairy industry. The basic approach is to discuss the manufacturing process in the context of technology and its related chemistry and microbiology, followed by a more fundamental appraisal of the underlying science. The dairy industry is defined in a broad context and information is included on imitation products and analogues.

A number of innovations have been adopted in the presentation of the book. Information boxes and * points are used to place the text in a wider scientific and commercial context, and exercises are included in most chapters to encourage the reader to apply the knowledge gained from the book to unfamiliar situations. It is also our firm belief that the control of food manufacturing processes should be considered as an integral part of the technology and for this reason control points, based on the HACCP system, are included where appropriate.

# A note on using the book

## EXERCISES

Exercises are not intended to be treated like an examination question. Indeed in many cases there is no single correct, or incorrect, answer. The main intention is to encourage the reader in making the transition from an acquirer of knowledge to a user. In many cases the exercises are based on 'real' situations and many alternative solutions are possible. In some cases provision of a full solution will require reference to more specialist texts and 'starting points' are recommended.

## CONTROL POINTS

In most chapters control points, derived from HACCP analysis, are included for the **main** processing stages. These are linked to process flow-diagrams. Points designated as CCP 1 are those which ensure elimination of a hazard; those designated CCP 2 are either points at which a hazard can be controlled but not eliminated *or* points which must be controlled to ensure satisfactory product quality. The inclusion of control points is intended to encourage a way of thinking in which control is an integral part of technology. If required, readers may use the control points included to further develop the HACCP approach for themselves.

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# Contents

# 1

# INTRODUCTION

## OBJECTIVES

After reading this chapter you should understand

- The nature of milk
- The importance of milk as an agricultural commodity
- The biosynthesis of milk
- The chemical constituents of milk and their relation to processing
- The nutritional importance of milk constituents
- Milk flavour
- Undesirable substances in milk
- The microbiology of milk at farm level

## 1.1 THE NATURE OF MILK

For young mammals, including human infants, milk is the first food ingested and, in most cases, it continues to be the sole constituent of the diet for a considerable period of time. Milk is a complex biological fluid, the composition and physical characteristics of which vary from species to species, reflecting the dietary needs of the young mammal. The major constituent of milk is water, but according to species milk contains varying quantities of lipids, proteins and carbohydrates which are synthesized within the mammary gland. Smaller quantities of minerals and other fat-soluble and water-soluble components derived directly from blood plasma, specific blood proteins and intermediates of mammary synthesis are also present (Table 1.1).

## 1.2 MILK PRODUCTION AS AN ACTIVITY OF MAN

Domestication of animals such as the cow and the availability of milk surplus to that required to feed the young, meant that animal milk became part of the adult human diet. Many animals are exploited to produce milk for human consumption; cows, goats, sheep, buffaloes,

**Table 1.1** Average composition of cow's milk

| Component | Percentage | Percentage of solids |
|---|---|---|
| Lactose | 4.8 | 37.5 |
| Fat | 3.7 | 28.9 |
| Protein | 3.4 | 26.6 |
| Non-protein nitrogen | 0.19 | 1.5 |
| Ash | 0.7 | 5.5 |

camels and mares all forming the basis of commercial milk production in various parts of the world. In general, the dominant milk-producing animal in a region reflects the geographic and climatic conditions. Goats, for example, can be successfully farmed in mountainous regions with poor grazing, which would be quite unsuitable for cattle. In many parts of the world the cow is of overwhelming importance in milk production and in some countries, including the UK, milk of species other than the cow is not legally defined as 'milk'.

The discussion in this book refers to cows' milk unless other types are mentioned by name.

BOX 1.1 **The friendly cow**

The so-called 'cow culture' has come under severe attack by some environmentalists in recent years. The cow is considered to be an inefficient means of food production and to require land which could otherwise be used for direct production of human food. The cow has also been accused of being a major agent of global warming through production of rumen gases. With respect to food production, the anti-cow argument fails to take account of the ability of the rumen to synthesize nutrients from fibrous and cellulosic plant materials and from simple nitrogen sources such as urea, none of which play any direct role in human nutrition. Further it is simplistic to suggest that substitution of milk analogues made from soya would vitalize farming in developing countries. Quite apart from the disruptive effect on traditional agricultural patterns and the energy cost of transporting and processing soya, it must be recognized that farmers in the third world do not grow rich by supplying cash crops to western markets.

### 1.2.1 The economic importance of milk production

The relative economic importance of milk production to a national or regional economy is largely dictated by the suitability of the area for grass production. Other factors can also be of importance including the extent of government intervention through subsidies or other economic mechanisms and the availability of export markets. In the UK, for example, milk is probably the most important single agricultural commodity and in the years up to 1991 milk sales accounted for more than 20% of total farm sales. The importance of milk in the UK agricultural economy has been attributed to the temperate climate, heavy rainfall and suitability for grass production as well as favourable governmental attitudes including heavy subsidies and guaranteed payments.

In recent years, however, the dairy industry in the UK and other member countries of the European Economic Community (EEC) have been affected by attempts to balance milk production with milk consumption. This has involved, since 1984, a complex system of quotas for each producer. The overall effect has been to reduce milk production within the EEC, but the economic consequences for milk-producing regions have been severe and have led to many farmers abandoning totally dairy farming, or adopting collaborative working practices with neighbours. In the UK the number of dairy cows, which had risen over the years 1965 to 1983, fell over the 5 years from 1984 to 1989 from 3 328 000 to 2 868 000. This was reflected in a loss of confidence amongst dairy farmers and a significant fall in land prices. Dairy farming tends to be concentrated in high-rainfall regions of the west and economic consequences extended beyond the producers. The closure of creameries following reduced milk production, for example, can cause considerable hardship in areas where little alternative employment is available.

> BOX 1.2 **Three acres and a cow**
>
> The milk quota system is often seen as an example of bureaucratic interference. For many years, however, the dairy industry and its structure have been the subject of political and economic controversy. During agitation for land reform during 1885, for example, it was envisaged that farm labourers could attain self-sufficiency if resources were distributed as three acres and a cow per family. The slogan 'Three acres and a cow' thus became an important part of land reform propaganda.

The availability of export markets is of particular importance to countries such as Eire and New Zealand which have a large surplus of milk and which have developed large processing industries. A similar situation exists within the internal economy of the US where states such as Michigan are exporters of milk and dairy products to other parts of the country. Exports of dairy produce from New Zealand and Australia have been affected by the creation of the EEC and it has been necessary to develop alternative markets in the Far East and Middle East.

### 1.2.2 The structure of the dairy industry

The structure of the dairy industry varies widely from country to country. At one extreme the producer is selling surplus milk from one, or a small number of animals, while at the other extreme a single herd may comprise several hundred animals. In the developed world there has been a number of long-term trends. The number of producers have tended to fall, while at the same time the average herd size has increased. At the same time the average milk yield per cow has steadily increased. The increase in milk yield has resulted from improvements in cattle breeding, including herd improvement through artificial insemination schemes, improvements in nutrition and general herd management, including reduction in the incidence of mastitis. More recently the use of bovine somatotrophin (BST) as a means of increasing milk yield has been a cause of considerable controversy in a number of countries.

Increase in herd size and yield has been paralleled by increasing automation of milk production. Hand-milking has almost disappeared from commercial agriculture and machine-milking increasingly involves highly automated parlour systems. In some cases electronic 'tags' allow individual cows to be automatically identified as the parlour is approached, allowing automated feeding and recording of yield.

* Mastitis is inflammation of the udder. The usual cause is bacterial infection, although other factors including milking practices and type of housing may predispose animals to infection. Mastitis may be present in a clinical form, where visible changes may be seen in the milk or, more commonly, in sub-clinical form. Milk yield is reduced by mastitis while severe cases ('August bag') often result in permanent loss of milk production in the affected part of the udder and even in death. A large number of micro-organisms can cause mastitis, some of which are also human pathogens (see page 35–6). Mastitis due to specific mastitis pathogens, which are spread from udder to udder, may be controlled by disinfecting teats, maintaining the hygienic status of milking machines and by prophylactic and therapeutic intra-mammary administration of antibiotics to non-lactating cattle (dry cow therapy). In such circumstances mastitis due to organisms derived from the environment becomes of much greater significance.

Marketing systems for milk also vary widely. In less developed countries, all of the milk may be sold directly to the public, but in the major milk producing countries most milk is sold from the farm on a wholesale basis. The commercial relationships between producer and processor differ from country to country. In countries such as Eire and Australia many of the large-scale processors are owned by the farmers on a co-operative basis, while in the US farmers agree individual contracts with processors. Until recently, wholesale sales in the UK were made through the Milk Marketing Boards, but legislative changes will enable farmers to deal directly with processors.

A common feature to milk marketing arrangements in many countries is the principle of payment according to milk compositional quality. In the past, fat has been considered to be, commercially, the most important component of milk and most quality payment schemes have been based on fat content. More recently other components, especially protein, have increased in relative value and this is reflected in the introduction of protein and/or lactose into payment schemes. The use of compositional quality in determining price paid to the farmer may be illustrated by reference to the situation pertaining in England and Wales during July 1990 in which the producers' price was determined by multiplying the levels of fat, protein and lactose by assigned values for each constituent (Table 1.2).

The producers' price is, however, subject to adjustment. A seasonal price differential is applied to encourage a more even milk supply. This varies from −14.5% of the basic price for milk produced in May, to +30.3% for that produced in August. Milk produced in July has a seasonal differential of +21.6% and thus a basic producers' price of 17.187 pence per litre (ppl; Table 1.2) is increased to 20.899 ppl.

For many years, since the recognition of milk as a vehicle of human

**Table 1.2** Calculation of milk prices on the basis of compositional quality, England and Wales, July 1990

| Composition | (%)[1] | | Assigned value (ppl per 1%) | Producer price (ppl) |
|---|---|---|---|---|
| Fat | 3.95 | x | 2.141 | 8.456 |
| Protein | 3.21 | x | 2.254 | 7.235 |
| Lactose | 4.55 | x | 0.329 | 1.496 |
| | | | | 17.187 |

[1]Assumed values for example only.

disease, there have been continuing efforts both to eradicate milkborne zoonotic diseases, such as tuberculosis and brucellosis, and to raise the overall standard of milk hygiene. Specific programmes were employed to eradicate zoonotic diseases by elimination of the causative organisms from the national herd (see page 38–9), but improvement of the overall standard of milk hygiene largely involved the education of milk producers, supported by laboratory testing to determine the microbiological status of the milk at farm level. In recent years, a number of countries have introduced a weighting into milk payment schemes according to the microbiological status of the milk. The underlying rationale is that all producers should be capable of meeting high standards as determined by total viable count (total bacterial count; TBC). The payment schemes tend, therefore, to be punitive, with only a small, or no, additional payment for achieving the highest hygienic category, but with increasingly severe financial penalties being applied with increasingly high bacterial counts. The schemes vary in detail (Table 1.3), more rigorous standards being applied where the general standards of hygiene are already high.

## 1.3 BIOSYNTHESIS OF MILK

Milk is the product of the mammary gland, that of the cow being illustrated in Figure 1.1. Milk originates in the secretory tissue and collects in a series of ducts, which increase in size as the milk moves

**Table 1.3** Adjustments to milk payments according to microbiological status

*England and Wales Milk Marketing Board*

| Grade | Criteria[1] | Adjustment |
|---|---|---|
| A | $\not> 2 \times 10^4$ | +0.23 |
| B | $> 2 \times 10^4$ but $< 1 \times 10^5$ | 0 |
| $C_1$ | $> 1 \times 10^5$, but no deduction in previous 6 months | $-1.50$[2] |
| $C_2$ | $> 1 \times 10^5$, and $c_1$ deduction in previous 6 months | $-6.00$[2] |
| $C_3$ | $> 1 \times 10^5$ and $C_2$ or $C_3$ deduction has been applied | $-10.0$ |

*Aberdeen and District Milk Marketing Board*

| Average total bacterial count/ml | Adjustment |
|---|---|
| $\leqslant 4.5 \times 10^4$ | 0 |
| $4.6 \times 10^4$ to $9 \times 10^4$ | $-0.243$ |
| $9.1 \times 10^4$ to $1.3 \times 10^5$ | $-1.215$ |
| $> 1.3 \times 10^5$ | $-2.43$ |

[1] Based on the average of at least two valid determinations of total bacterial count per millilitre in the previous month.

[2] Provided at least two results exceeded $1 \times 10^5$, otherwise milk qualifies for Grade B.

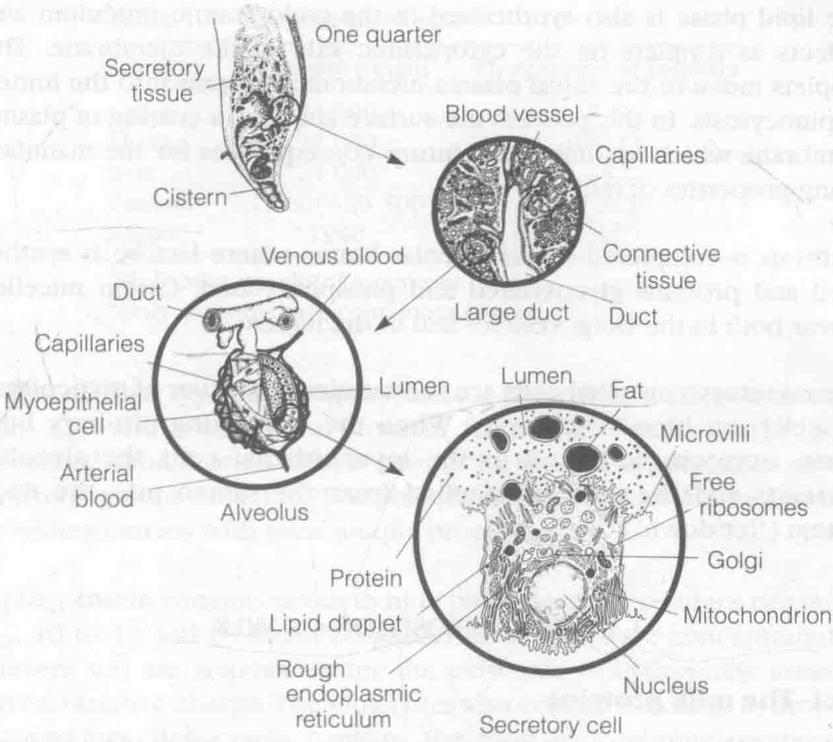


**Figure 1.1** The bovine mammary gland. Redrawn with permission from Swaisgood, H.E. 1985. In *Food Chemistry*, 2nd edn (ed. Fennema, O.R.). Marcel Dekker, New York.

towards the teat. The alveolus may be considered as the smallest complete unit of milk production and is approximately spherical in shape with a central storage lumen surrounded by a single layer of secretory epithelial cells. Secretory cells are orientated so that the apical end, which has a unique membrane, is positioned adjacent to the lumen, while the basal end is separated by a basement membrane from blood and lymph. Metabolites enter the secretory cell from the bloodstream *via* the basement membrane and are utilized in milk synthesis by the endoplasmic reticulum, energy being supplied by mitochondria. The endoplasmic reticulum appears as a series of tubes, the cisternae, which empty into the Golgi apparatus. The Golgi apparatus is transformed into Golgi vesicles which transport the aqueous phase milk components to the apical plasma membrane. The Golgi vesicles then merge with the apical plasma membrane, fuse to become part of the membrane and discharge the aqueous phase into the lumen. In this process the inside of the vesicle membrane becomes the outside of the cell plasma membrane.