1 Production and utilization of milk

1.1 Introduction

Milk is a fluid secreted by the female of all mamalian species, of which there are more than 4000, for the primary function of meeting the complete nutritional requirements of the neonate of the species. In addition, milk serves several physiological functions for the neonate. Most of the non-nutritional functions of milk are served by proteins and peptides which include immunoglobulins, enzymes and enzyme inhibitors, binding or carrier proteins, growth factors and antibacterial agents. Because the nutritional and physiological requirements of each species are more or less unique, the composition of milk shows very marked inter-species differences. Of the more than 4000 species of mammal, the milks of only about 180 have been analysed and, of these, the data for only about 50 species are considered to be reliable (sufficient number of samples, representative sampling, adequate coverage of the lactation period). Not surprisingly, the milks of the principal dairying species, i.e. cow, goat, sheep and buffalo, and the human are among those that are well characterized. The gross composition of milks from selected species is summarized in Table 1.1; very extensive data on the composition of bovine and human milk are contained in Jensen (1995).

1.2 Composition and variability of milk

In addition to the principal constituents listed in Table 1.1, milk contains several hundred minor constituents, many of which, e.g. vitamins, metal ions and flavour compounds, have a major impact on the nutritional, technological and sensoric properties of milk and dairy products. Many of these effects will be discussed in subsequent chapters.

Milk is a very variable biological fluid. In addition to interspecies differences (Table 1.1), the milk of any particular species varies with the individuality of the animal, the breed (in the case of commercial dairying species), health (mastitis and other diseases), nutritional status, stage of lactation, age, interval between milkings, etc. In a bulked factory milk supply, variability due to many of these factors is evened out, but some variability will persist and will be quite large in situations where milk

Table 1.1 Composition (%) of milks of some species

Species	Total solids	Fat	Protein	Lactose	Ash
Human	12.2	3.8	1.0	7.0	0.2
Cow	12.7	3.7	3.4	4.8	0.7
Goat	12.3	4.5	2.9	4.1	0.8
Sheep	19.3	7.4	4.5	4.8	1.0
Pig	18.8	6.8	4.8	5.5	–
Horse	11.2	1.9	2.5	6.2	0.5
Donkey	11.7	1.4	2.0	7.4	0.5
Reindeer	33.1	16.9	11.5	2.8	–
Domestic rabbit	32.8	18.3	11.9	2.1	1.8
Bison	14.6	3.5	4.5	5.1	0.8
Indian elephant	31.9	11.6	4.9	4.7	0.7
Polar bear	47.6	33.1	10.9	0.3	1.4
Grey seal	67.7	53.1	11.2	0.7	–

production is seasonal. Not only do the concentrations of the principal and minor constituents vary with the above factors, the actual chemistry of some of the constituents also varies, e.g. the fatty acid profile is strongly influenced by diet. Some of the variability in the composition and constituents of milk can be adjusted or counteracted by processing technology but some differences may still persist. The variability of milk and the consequent problems will become apparent in subsequent chapters.

From a physicochemical viewpoint, milk is a very complex fluid. The constituents of milk occur in three phases. Quantitatively, most of the mass of milk is a true solution of lactose, organic and inorganic salts, vitamins and other small molecules in water. In this aqueous solution are dispersed proteins, some at the molecular level (whey proteins), others as large colloidal aggregates, ranging in diameter from 50 to 600 nm (the caseins), and lipids which exist in an emulsified state, as globules ranging in diameter from 0.1 to 20 μm. Thus, colloidal chemistry is very important in the study of milk, e.g. surface chemistry, light scattering and rheological properties.

Milk is a dynamic system owing to: the instability of many of its structures, e.g., the milk fat globule membrane; changes in the solubility of many constituents with temperature and pH, especially of the inorganic salts but also of proteins; the presence of various enzymes which can modify constituents through lipolysis, proteolysis or oxidation/reduction; the growth of micro-organisms, which can cause major changes either directly through their growth, e.g. changes in pH or redox potential (E_h) or through enzymes they excrete; and the interchange of gases with the atmosphere, e.g. carbon dioxide. Milk was intended to be consumed directly from the mammary gland and to be expressed from the gland at frequent intervals. However, in dairying operations, milk is stored for various periods, ranging from a few hours to several days, during which it is cooled (and perhaps heated) and agitated to various degrees. These treatments will cause at least some physical changes and permit some enzymatic and microbiological changes which may alter the processing properties of milk. Again, it may be possible to counteract some of these changes.

1.3 Classification of mammals

The essential characteristic distinguishing mammals from other animal species is the ability of the female of the species to produce milk in specialized organs (mammary glands) for the nutrition of its newborn.

The class Mammalia is divided into three subclasses:

1. Prototheria. This subclass contains only one order, Monotremes, the species of which are egg-laying mammals, e.g. duck-billed platypus and echidna, and are indigenous only to Australasia. They possess many (perhaps 200) mammary glands grouped in two areas of the abdomen; the glands do not terminate in a teat and the secretion (milk) is licked by the young from the surface of the gland.
2. Marsupials. The young of marsupials are born live (viviparous) after a short gestation and are 'premature' at birth to a greater or lesser degree, depending on the species. After birth, the young are transferred to a pouch where they reach maturity, e.g. kangaroo and wallaby. In marsupials, the mammary glands, which vary in number, are located within the pouch and terminate in a teat. The mother may nurse two offspring, differing widely in age, simultaneously from different mammary glands that secrete milk of very different composition, designed to meet the different specific requirements of each offspring.
3. Eutherians. About 95% of all mammals belong to this subclass. The developing embryo *in utero* receives nourishment via the placental blood supply (they are referred to as placental mammals) and is born at a high, but variable, species-related state of maturity. All eutherians secrete milk, which, depending on the species, is more or less essential for the development of the young; the young of some species are born sufficiently mature to survive and develop without milk.

The number and location of mammary glands varies with species from two, e.g. human, goat and sheep, to 14–16 for the pig. Each gland is anatomically and physiologically separate and is emptied via a teat.

The wide interspecies variation in the composition (Table 1.1) and the chemistry of the constituents of milk, as discussed elsewhere, renders milk species-specific, i.e., designed to meet the requirements of the young of that species. There is also a surprisingly good relationship between milk yield and maternal body weight (Figure 1.1); species bred for commercial milk production, e.g. dairy cow and goat, fall above the line.

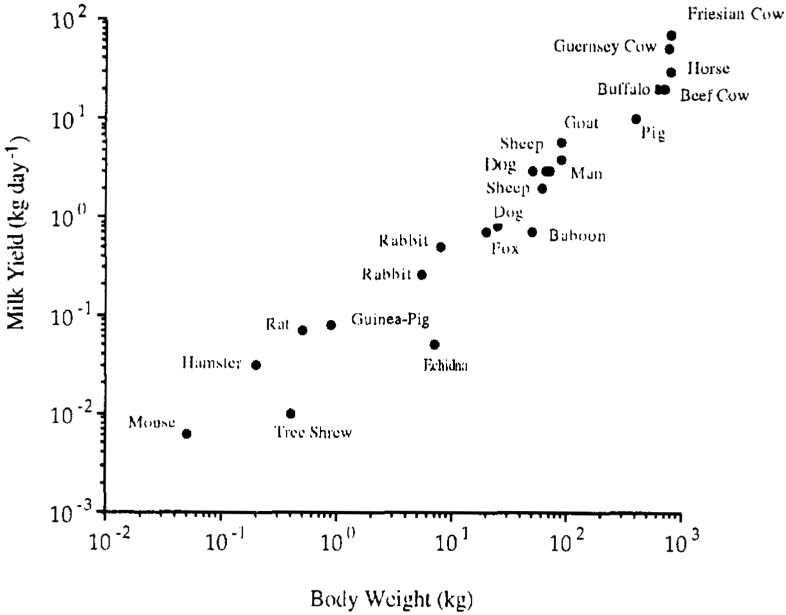

Figure 1.1 Relation between daily milk yield and maternal body weight for some species (modified from Linzell, 1972).

1.4 Structure and development of mammary tissue

The mammary glands of all species have the same basic structure and all are located external to the body cavity (which greatly facilitates research on milk biosynthesis). Milk constituents are synthesized in specialized epithelial cells (secretory cells or mammocytes, Figure 1.2d) from molecules absorbed from the blood. The secretory cells are grouped as a single layer around a central space, the lumen, to form more or less spherical or pear-shaped bodies, known as alveoli (Figure 1.2c). The milk is secreted from these calls into the lumen of the alveoli. When the lumen is full, the myoepithelial cells surrounding each alveolus contract under the influence of oxytocin and the milk is drained via a system of arborizing ducts towards sinuses or cisterns (Figure 1.2a) which are the main collecting points between suckling or milking. The cisterns lead to the outside via the teat canal. Groups of alveoli, which are drained by a common duct, constitute a lobule; neighbouring lobules are separated by connective tissue (Figure 1.2b). The secretory elements are termed the 'lobule–alveolar system' to distinguish them from the duct system. The whole gland is shown in Figure 1.2a.

Milk constituents are synthesized from components obtained from the blood; consequently, the mammary gland has a plentiful blood supply and also an elaborate nervous system to regulate excretion.

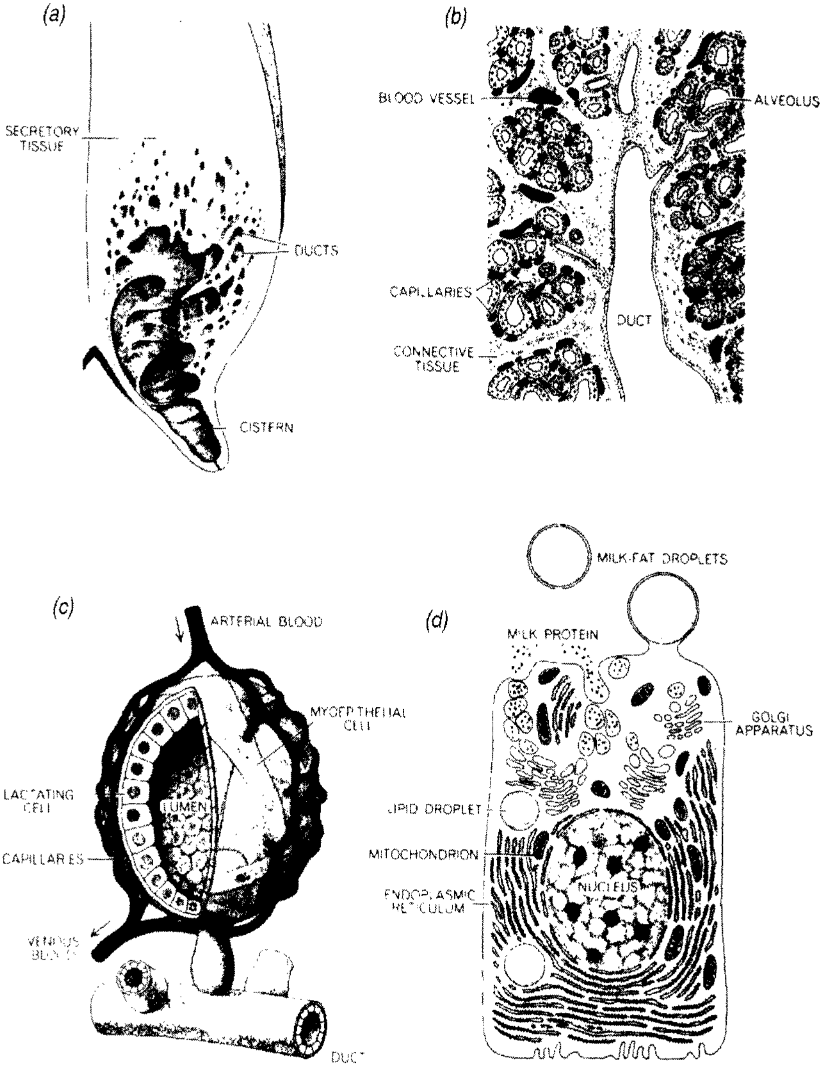

Figure 1.2 Milk-producing tissue of a cow, shown at progressively larger scale. (a) A longitudinal section of one of the four quarters of a mammary gland; (b) arrangement of the alveoli and the duct system that drains them; (c) single alveolus consisting of an elliptical arrangement of lactating cells surrounding the lumen, which is linked to the duct system of the mammary gland; (d) a lactating cell; part of the cell membrane becomes the membrane covering fat droplets; dark circular bodies in the vacuoles of Golgi apparatus are protein particles, which are discharged into the lumen. (From Patton, 1969.)

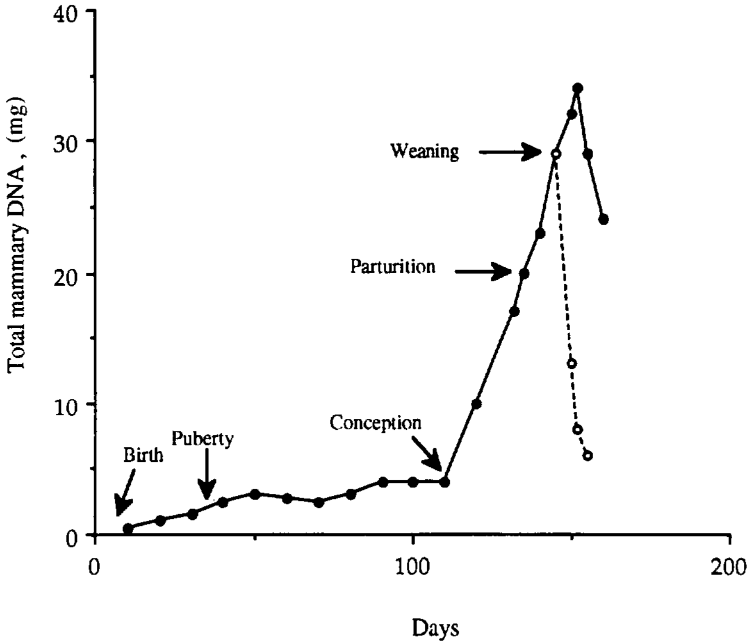

Figure 1.3 Time-course of mammary development in rats (from Tucker, 1969).

The substrates for milk synthesis enter the secretory cell across the basal membrane (outside), are utilized, converted and interchanged as they pass inwards through the cell and the finished milk constituents are excreted into the lumen across the lumenal or apical membrane. Myoepithelial cells (spindle shaped) form a 'basket' around each alveolus and are capable of contracting on receiving an electrical, hormonally mediated, stimulus, thereby causing ejection of milk from the lumen into the ducts.

Development of mammary tissue commences before birth, but at birth the gland is still rudimentary. It remains rudimentary until puberty when very significant growth occurs in some species; much less growth occurs in other species, but in all species the mammary gland is fully developed at puberty. In most species, the most rapid phase of mammary gland development occurs at pregnancy and continues through pregnancy and parturition, to reach peak milk production at weaning. The data in Figure 1.3 show the development pattern of the mammary gland in the rat, the species that has been thoroughly studied in this regard.

Mammary development is under the regulation of a complex set of hormones. Studies involving endocrinectomy (removal of different endocrine organs) show that the principal hormones are oestrogen, progesterone, growth hormone, prolactin and corticosteroids (Figure 1.4).

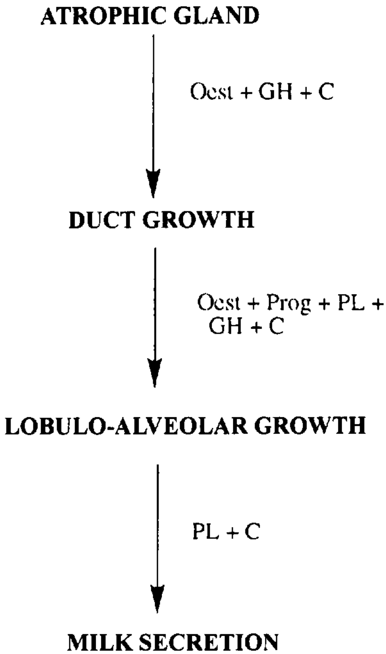

Figure 1.4 The hormonal control of mammary development in rats. Oest, Oestrogen; Prog, progesterone; GH, growth hormone; PL, prolactin; C, corticosteroids.

1.5 Ultrastructure of the secretory cell

The structure of the secretory cell is essentially similar to that of other eukaryotic cells. In their normal state, the cells are roughly cubical, *c.* 10 μm in cross-section. It is estimated that there are *c.* 5×10^{12} cells in the udder of the lactating cow. A diagrammatic representation of the cell is shown in Figure 1.2d. It contains a large nucleus towards the base of the cell and is surrounded by a cell membrane, the plasmalemma. The cytoplasm contains the usual range of organelles:

- mitochondria: principally involved in energy metabolism (tricarboxylic acid (Krebs) cycle);
- endoplasmic reticulum: located towards the base of the cell and to which are attached ribosomes, giving it a rough appearance (hence the term, rough endoplasmic reticulum, RER). Many of the biosynthetic reactions of the cell occur in the RER;
- Golgi apparatus: a smooth membrane system located toward the apical region of the cell, where much of the assembly and 'packaging' of synthesized material for excretion occur;

- lysosomes: capsules of enzymes (usually hydrolytic) distributed fairly uniformly throughout the cytoplasm.

Fat droplets and vesicles of material for excretion are usually apparent toward the apical region of the cell. The apical membrane possesses microvilli which serve to greatly increase its surface area.

1.6 Techniques used to study milk synthesis

1.6.1 Arteriovenous concentration differences

The arterial and veinous systems supplying the mammary gland (Figure 1.5) are readily accessible and may be easily cannulated to obtain blood samples for analysis. Differences in composition between arterial and venous blood give a measure of the constituents used in milk synthesis. The total amount of constituent used may be determined if the blood flow rate is known, which may be easily done by infusing a known volume of cold saline

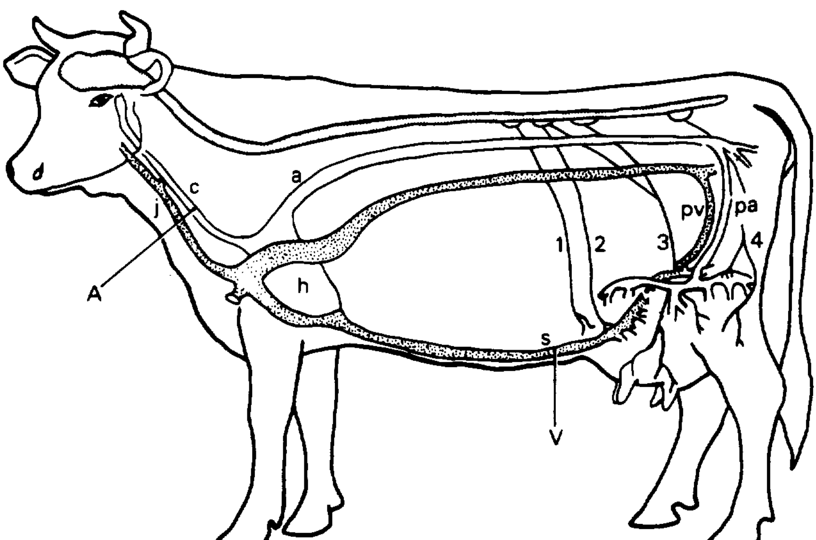

Figure 1.5 The blood vessel and nerve supply in the mammary glands of a cow. Circulatory system (arteries, white; veins, stippled): h, heart; a, abdominal aorta; pa, external pudic artery; pv, external pudic vein; s, subcutaneous abdominal vein; c, carotid artery; j, jugular vein. Nerves: 1, first lumbar nerve; 2, second lumbar nerve; 3, external spermatic nerve; 4, perineal nerve. A and V show blood sampling points for arteriovenous (AV) difference determinations (Mepham, 1987).

solution into a vein and measuring the temperature of blood a little further downstream. The extent to which the blood temperature is reduced is inversely proportional to blood flow rate.

1.6.2 Isotope studies

Injection of radioactively labelled substrates, e.g. glucose, into the bloodstream permits assessment of the milk constituents into which that substrate is incorporated. It may also be possible to study the intermediates through which biosynthesis proceeds.

1.6.3 Perfusion of isolated gland

In many species, the entire gland is located such that it may be readily excised intact and undamaged. An artificial blood supply may be connected to cannulated veins and arteries (Figure 1.6); if desired, the blood supply may be passed through an artificial kidney. The entire mammary gland may

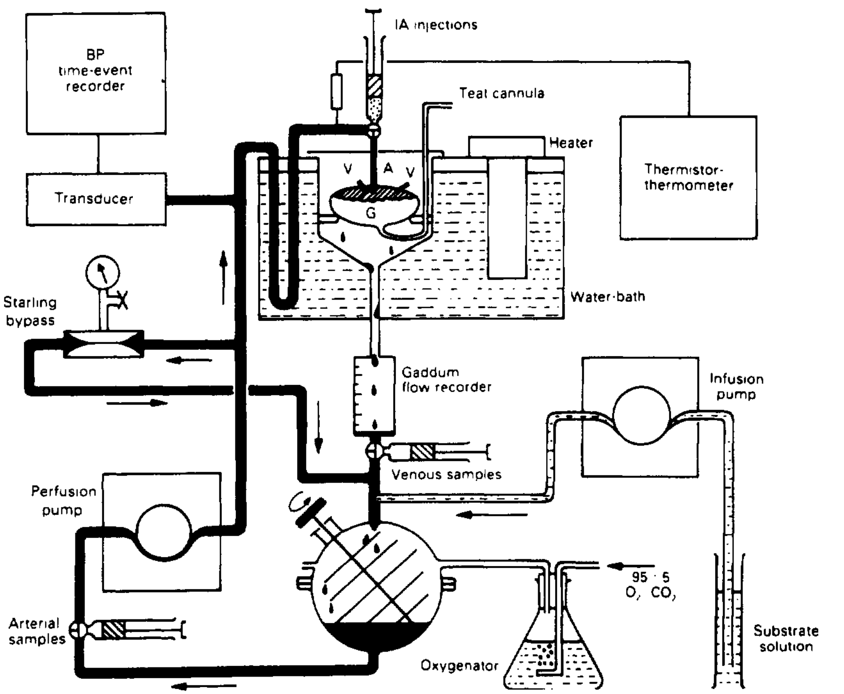

Figure 1.6 Diagram of circuit for perfusion of an isolated mammary gland of a guinea-pig., G, mammary gland; A, artery; V, veins (from Mepham, 1987).

be maintained active and secreting milk for several hours; substrates may readily be added to the blood supply for study.

1.6.4 Tissue slices

The use of tissue slices is a standard technique in all aspects of metabolic biochemistry. The tissue is cut into slices, sufficiently thin to allow adequate rates of diffusion in and out of the tissue. The slices are submerged in physiological saline to which substrates or other compounds may be added.

Changes in the composition of the slices and/or incubation medium give some indication of metabolic activity, but extensive damage may be caused to the cells on slicing; the system is so artificial that data obtained by the tissue slice technique may not pertain to the physiological situation. However, the technique is widely used at least for introductory, exploratory experiments.

1.6.5 Cell homogenates

Cell homogenates are an extension of the tissue slice technique, in which the tissue is homogenized. As the tissue is completely disorganized, only individual biosynthetic reactions may be studied in such systems; useful preliminary work may be done with homogenates.

1.6.6 Tissue culture

Tissue cultures are useful for preliminary or specific work but are incomplete.

In general, the specific constituents of milk are synthesized from small molecules absorbed from the blood. These precursors are absorbed across the basal membrane but very little is known about the mechanism by which they are transported across the membrane. Since the membrane is rich in lipids, and precursors are mostly polar with poor solubility in lipid, it is unlikely that the precursors enter the cell by simple diffusion. It is likely, in common with other tissues, that there are specialized carrier systems to transport small molecules across the membrane; such carriers are probably proteins.

The mammary gland of the mature lactating female of many species is by far the most metabolically active organ of the body. For many small mammals, the energy input required for the milk secreted in a single day may exceed that required to develop a whole litter *in utero*. A cow at peak lactation yielding 45 kg milk day^{-1} secretes approximately 2 kg lactose and 1.5 kg each of fat and protein per day. This compares with the daily weight gain for a beef animal of 1–1.5 kg day^{-1}, 60–70% of which is water. In large measure, a high-yielding mammal is subservient to the needs of its mammary gland to which it must supply not only the precursors for the synthesis of milk constituents but also an adequate level of high-energy-yielding substrates (ATP, UTP, etc.) required to drive the necessary synthetic reactions. In addition, minor constituents (vitamins and minerals) must be supplied.

1.7 Biosynthesis of milk constituents

The constituents of milk can be grouped into four general classes according to their source:

- organ-(mammary gland) and species-specific (e.g. most proteins and lipids);
- organ- but not species-specific (lactose);
- species- but not organ-specific (some proteins);
- neither organ- nor species-specific (water, salts, vitamins).

The principal constituents (lactose, lipids and most proteins) of milk are synthesized in the mammary gland from constituents absorbed from blood. However, considerable modification of constituents occurs in the mammary gland; the constituents are absorbed from blood through the basal membrane, modified (if necessary) and synthesized into the finished molecule (lactose, triglycerides, proteins) within the mammocyte (mainly in the endoplasmic reticulum) and excreted from the mammocyte through the apical membrane into the lumen of the alveolus.

We believe that it is best and most convenient to describe the synthesis of the principal constituents in the appropriate chapter.

1.8 Production and utilization of milk

Sheep and goats were domesticated early during the Agricultural Revolution, 8000–10 000 years ago. Cattle were domesticated later but have become the principal dairying species in the most intense dairying areas, although sheep and goats are very important in arid regions, especially around the Mediterranean. Buffalo are important in some regions, especially in India and Egypt. Mare's milk is used extensively in central Asia and is receiving attention in Europe for special dietary purposes since its composition is closer to that of human milk than is bovine milk.

Some milk and dairy products are consumed in probably all regions of the world but they are major dietary items in Europe, North and South America, Australia, New Zealand and some Middle Eastern countries. Total milk production in 1996 was estimated to be 527×10^6 tonnes, of which 130,

Table 1.2 Consumption (kg caput^{-1} annum^{-1}) of liquid milk, 1993 (IDF, 1995)

Country	Total	Country	Total
Russia[a]	252	Luxembourg[a]	86
Ireland[a]	182	Netherlands	84
Iceland	180	Hungary	81
Finland	170	Estonia[a]	81
Norway	147	Canada	77
Sweden	126	France	77
Denmark	115	Italy	75
United Kingdom	115	Germany	70
Spain	115	Greece[a]	67
Switzerland	101	Belgium	65
New Zealand	101	India	51
Australia	99	Lithuania[a]	46
Czech and Slovak Reps[a]	97	Japan	42
USA	93	South Africa	38
Austria	92	Chile[a]	18

[a]Data for 1991, from IDF (1993).

Table 1.3 Consumption (kg caput^{-1} annum^{-1}) of cheese, 1993 (IDF, 1995)

Country	Fresh	Ripened	Total
France	7.5	15.5	22.8
Greece[a]	0.2	21.8	22.0
Italy	6.7	13.4	20.1
Belgium	4.7	15.1	19.8
Germany	8.0	10.5	18.5
Lithuania[a]	11.6	6.8	18.4
Iceland	5.2	11.9	17.1
Switzerland	2.8	13.6	16.4
Sweden	0.9	15.5	16.4
Luxembourg[a]	5.0	11.3	16.3
Netherlands	1.7	14.1	15.8
Denmark	0.9	14.5	15.4
Finland	2.3	12.0	14.3
Norway	0.2	14.0	14.2
Canada	0.9	12.4	13.3
USA	1.3	11.9	13.2
Austria	3.9	7.5	11.4
Czech and Slovak Reps[a]	4.0	6.6	10.6
Estonia	5.6	4.4	10.0
Australia	–	–	8.8
United Kingdom	–	–	8.3
New Zealand	–	–	8.1
Hungary	3.3	4.6	7.9
Russia[a]	2.8	4.9	7.7
Spain	–	–	7.0
Ireland[a]	–	–	5.6
Chile[a]	2.0	2.0	4.0
South Africa	0.1	1.5	1.6
Japan	0.2	1.2	1.4
India	0.2	–	0.2

[a]Data for 1991, from IDF (1993).

Table 1.4 Consumption (kg $caput^{-1}$ $annum^{-1}$) of butter, 1993 (IDF, 1995)

Country	Butter
Lithuania[a]	18.8
New Zealand	9.3
Belgium	7.0
France	6.8
Germany	6.8
Russia[a]	6.5
Estonia	5.9
Luxembourg[a]	5.8
Finland	5.3
Switzerland	5.3
Czech and Slovak Reps[a]	5.0
Austria	4.3
Denmark	4.1
United Kingdom	3.5
Ireland[a]	3.4
Netherlands	3.3
Australia	3.3
Canada	3.0
Norway	2.3
Sweden	2.3
Iceland	2.2
USA	2.1
Italy	1.8
Greece[a]	1.1
India	0.1
Hungary	0.9
Japan	0.7
Chile[a]	0.6
South Africa	0.5
Spain	0.2

[a]Data for 1991, from IDF (1993).

103, 78, 26 × 10^6 tonnes were produced in western Europe, eastern Europe, North America and the Pacific region, respectively (IDF, 1996). The European Union and some other countries operate milk production quotas which are restricting growth in those areas. Data on the consumption of milk and dairy products in countries that are members of the International Dairy Federation (IDF) are summarized in Tables 1.2–1.6. Milk and dairy products are quite important in several countries that are not included in Tables 1.2–1.6 since they are not members of the IDF.

Because milk is perishable and its production was, traditionally, seasonal, milk surplus to immediate requirements was converted to more stable products, traditional examples being butter or ghee, fermented milk and cheese; smaller amounts of dried milk products were produced traditionally by sun-drying. These traditional products are still very important and many new variants thereof have been introduced. In addition, several new products have been developed during the past 130 years, e.g.

Table 1.5 Consumption (kg caput^{-1} annum^{-1}) of cream (butterfat equivalent), 1993 (IDF, 1995)

Country	Total
Sweden	3.0
Denmark	2.9
Lithuania[a]	2.9
Luxembourg[a]	2.6
Iceland	2.4
Norway	2.4
Switzerland	2.3
Russia[a]	2.1
Finland	2.0
Germany	1.8
Estonia	1.7
Hungary	1.6
Belgium	1.5
Austria	1.3
New Zealand	1.3
United Kingdom[a]	1.1
Greece[a]	1.0
France	1.0
Czech and Slovak Reps[a]	0.9
Ireland[a]	0.9
Netherlands	0.7
Canada	0.6
USA	0.6
Spain	0.4
Italy	0.3
South Africa	0.3
Japan	0.2
Chile[a]	0.2

[a]Data for 1991, from IDF (1993).

sweetened condensed milk, sterilized concentrated milk, a range of milk powders, UHT sterilized milk, ice-creams, infant foods and milk protein products.

One of the important developments in dairy technology in recent years has been the fractionation of milk into its principal constituents, e.g. lactose, milk fat fractions and milk protein products (caseins, caseinates, whey protein concentrates, whey protein isolates, mainly for use as functional proteins but more recently as 'nutraceuticals', i.e. proteins for specific physiological and/or nutritional functions, e.g. lactotransferrin, immunoglobulins).

As a raw material, milk has many attractive features:

1. Milk was designed for animal nutrition and hence contains the necessary nutrients in easily digestible forms (although the balance is designed for

Table 1.6 Consumption (kg $caput^{-1}$ $annum^{-1}$) of fermented milks, 1993 (IDF, 1995)

Country	Total
Finland	37.0
Sweden	28.6
Iceland	25.9
Netherlands	20.7
France	17.3
Switzerland	17.0
India	16.1
Denmark	15.1
Lithuania[a]	14.6
Germany	12.2
Austria	11.1
Spain	9.8
Belgium	9.6
Estonia	8.8
Czech and Slovak Reps[a]	8.8
Japan	8.5
Luxembourg[a]	7.0
Greece[a]	6.8
Norway	6.3
Italy	5.0
Australia	4.8
United Kingdom[a]	4.8
Chile[a]	4.1
Hungary	3.6
South Africa	3.6
Ireland[a]	3.3
Canada	3.0
USA	2.1

[a]Data for 1991, from IDF (1993).

the young of a particular species) and free of toxins. No other single food, except the whole carcass of an animal, including the bones, contains the complete range of nutrients at adequate concentrations.

2. The principal constituents of milk, i.e. lipids, proteins and carbohydrates, can be readily fractionated and purified by relatively simple methods, for use as food ingredients.
3. Milk itself is readily converted into products with highly desirable organoleptic and physical characteristics and its constituents have many very desirable and some unique physicochemical (functional) properties.
4. The modern dairy cow is a very efficient convertor of plant material; average national yields, e.g. in the USA and Israel, are about 8000 kg $annum^{-1}$, with individual cows producing up to 20 000 kg $annum^{-1}$. In terms of kilograms of protein that can be produced per hectare, milk

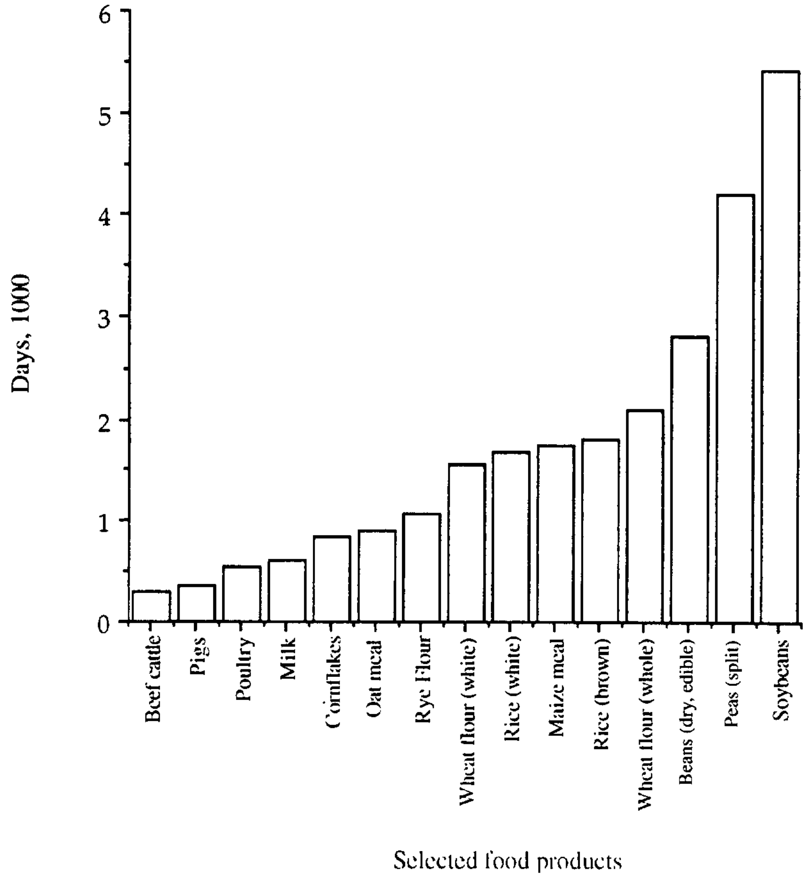

Figure 1.7 Number of days of protein supply for a moderately active man produced per hectare yielding selected food products.

production, especially by modern cows, is much more efficient than meat production (Figure 1.7) but less efficient than some plants (e.g. cereals and soybeans). However, the functional and nutritional properties of milk proteins are superior to those of soy protein, and since cattle, and especially sheep and goats, can thrive under farming conditions not suitable for growing cereals or soybeans, dairy animals need not be competitors with humans for use of land, although high-yielding dairy cows are fed products that could be used for human foods. In any case, dairy products improve the 'quality of life', which is a desirable objective *per se*.

Table 1.7 Diversity of dairy products

Process	Primary product	Further products
Centrifugal separation	Cream	Butter, butter oil, ghee Creams: various fat content (HTST pasteurized or UHT sterilized), coffee creams, wipping creams, dessert creams Cream cheeses
	Skim milk	Powders, casein, cheese, protein concentrates
Concentration thermal evaporation *or* ultrafiltration		In-container or UHT-sterilized concentrated milks; sweetened condensed milk
Concentration *and* drying		Whole milk powders; infant formulae; dietary products
Enzymatic coagulation	Cheese	1000 varieties; further products, e.g. processed cheese, cheese sauces, cheese dips
	Rennet casein	Cheese analogues
	Whey	Whey powders, demineralized whey powders, whey protein concentrates, whey protein isolates, individual whey proteins, whey protein hydrolysates, neutraceuticals Lactose and lactose derivatives
Acid coagulation	Cheese	Fresh cheeses and cheese-based products
	Acid casein	Functional applications, e.g. coffee creamers, meat extenders; nutritional applications
	Whey	Whey powders, demineralized whey powders, whey protein concentrates, whey protein isolates, individual whey proteins, whey protein hydrolysates, neutraceuticals
Fermentation		Various fermented milk products, e.g. yoghurt, buttermilk, acidophilus milk, bioyoghurt
Freezing		Ice-cream (numerous types and formulations)
Miscellaneous		Chocolate products

5. One of the limitations of milk as a raw material is its perishability – it is an excellent source of nutrients for micro-organisms as well as for humans. However, this perishability is readily overcome by a well-organized, efficient dairy industry.

Milk is probably the most adaptable and flexible of all food materials, as will be apparent from Table 1.7, which shows the principal families of milk-based foods – some of these families contain several hundred different products.

Many of the processes to which milk is subjected cause major changes in the composition (Table 1.8), physical state, stability, nutritional and sensoric

Table 1.8 Approximate composition (%) of some dairy products

Product	Moisture	Protein	Fat	Sugars[a]	Ash
Light whipping cream	63.5	2.2	30.9	3.0	0.5
Butter	15.9	0.85	81.1	0.06	2.1
Anhydrous butter oil	0.2	0.3	99.5	0.0	0.0
Ice-cream[b]	60.8	3.6	10.8	23.8	1.0
Evaporated whole milk	74.0	6.8	7.6	10.0	1.5
Sweetened condensed milk	27.1	7.9	8.7	54.4	1.8
Whole milk powder	2.5	26.3	26.7	38.4	6.1
Skim milk powder	3.2	36.2	0.8	52.0	7.9
Whey powder[c]	3.2	12.9	1.1	74.5	8.3
Casein powder	7.0	88.5	0.2	0.0	3.8
Cottage cheese, creamed	79.0	12.5	4.5	2.7	1.4
Quarg	72.0	18.0	8.0	3.0	–
Camembert cheese	51.8	19.8	24.3	0.5	3.7
Blue cheese	42.4	21.4	28.7	2.3	5.1
Cheddar cheese	36.7	24.9	33.1	1.3	3.9
Emmental cheese	36.0	28.9	30.0	–	–
Parmesan cheese	29.2	35.7	24.8	3.2	6.0
Mozzarella cheese	54.1	19.4	31.2	2.2	2.6
Processed cheese[d]	39.2	22.1	31.2	1.6	5.8
Acid whey	93.9	0.6	0.2	4.2	–

[a]Total carbohydrate.
[b]Hardened vanilla, 19% fat.
[c]Cheddar (sweet) whey.
[d]American pasteurized processed cheese.

attributes of the product; some of these changes will be discussed in later chapters.

1.9 Trade in milk products

Milk and dairy products have been traded for thousands of years and are now major items of trade. According to Verheijen, Brockman and Zwanenberg (1994), world dairy exports were US\$23 $\times 10^9$ in 1992; the major flow of milk equivalent is shown in Figure 1.8. Import and export data, as well as much other interesting statistical data on the world dairy industry, are provided by Verheijen, Brockman and Zwanenberg (1994), including a list of the principal dairy companies in the world in 1992, the largest of which was Nestlé, which had a turnover from dairy products of US\$10.6 $\times 10^9$ (*c.* 39% of total company turnover).

Traditionally, dairy products (cheese, fermented milks, butter) were produced on an artisanal level, as is still the case in underdeveloped regions and to some extent in highly developed dairying countries. Industrialization commenced during the nineteenth century and dairy manufacturing is now a well-organized industry. One of the features of the past few decades has

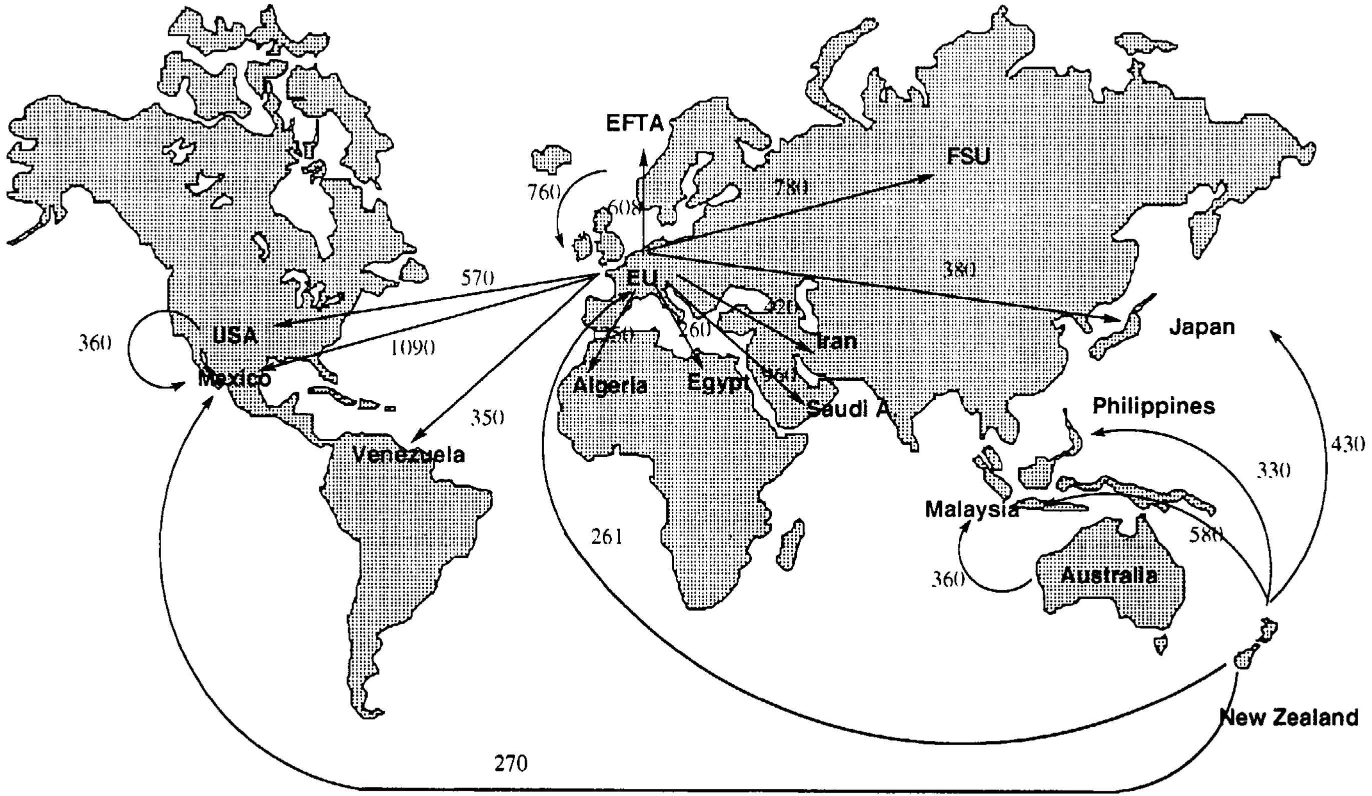

Figure 1.8 Trade flows greater than 250 000 tonnes in milk equivalents, 1992 (in 1000 tonnes) (from Verheigen, Brockman and Zwaneberg, 1994).

been the amalgamation of smaller dairy companies both within countries, and, recently, internationally. Such developments have obvious advantages in terms of efficiency and standardization of product quality but pose the risk of over-standardization with the loss of variety. Greatest diversity occurs with cheeses and, fortunately in this case, diversity is being preserved and even extended.

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