Patrick F. Fox
Timothy P. Guinee
Timothy M. Cogan
Paul L.H. McSweeney

Fundamentals of Cheese Science

Second Edition

Springer

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Patrick F. Fox
School of Food and Nutritional Sciences
University College
Cork, Ireland

Timothy P. Guinee
Teagasc Food Research Centre
Fermoy, Cork, Ireland

Timothy M. Cogan
Teagasc Food Research Centre
Fermoy, Cork, Ireland

Paul L.H. McSweeney
School of Food and Nutritional Sciences
University College
Cork, Ireland

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Preface to Second Edition

Since the publication of the first edition of this book in 2000, the importance and popularity of cheese have increased further. Approximately 19×10^6 tonnes were produced in 2014, representing 35–40 % of milk production. The second edition covers mainly the same topics as the first edition. Two chapters, "Acceleration of Cheese Ripening" and "Analytical Methods for Cheese," have been omitted; the former has been incorporated in "Biochemistry of Cheese Ripening." One new chapter, "Legislation on Cheese" has been introduced, and a specialist has been recruited to write the chapter "Cheese Flavour."

Cheese remains an active subject of research, and considerable progress has been made on the cheese that is summarized here. Advances have been made in aspects of cheese sciences during the past 15 years, but some areas are quite "mature," and consequently new knowledge is limited. Significant advances have been made on the physico-chemical aspects of cheese, e.g. mechanism of the gelation of rennet-altered casein micelles, the rheology of rennet-induced milk gels, syneresis of rennet- or acid-induced milk gels and the functional properties of cheese. Advances are probably most noticeable, however, in the microbiology of cheese, made possible by advances in molecular biology techniques. Most cheese is consumed as "Table Cheese," but the importance of cheese as an ingredient in composite foods, e.g., pizza, sauces, etc., is increasing, and the functionality of cheese in such applications has attracted much attention.

Fundamentals of Cheese Science provides comprehensive coverage of the scientific aspects of cheese, appropriate for anybody working with cheese, from lecturers, researchers and technologists to undergraduate and postgraduate students in food science and technology. The book assumes familiarity with biochemistry, microbiology and dairy chemistry, and it emphasizes fundamental principles rather than technological aspects.

The book is extensively referenced. References are divided into ”Suggested Reading,” comprised mainly of textbooks and reviews, and “References”, i.e., primary references to support claims made.

Cork, Ireland

Patrick F. Fox
Timothy P. Guinee
Timothy M. Cogan
Paul L.H. McSweeney

About the Authors

Patrick F. Fox, PhD DSc, Professor Emeritus of Food Chemistry at University College, Cork, Ireland. His research over the last 55 years has focussed on dairy chemistry and biochemistry with emphasis on milk proteins and enzymes. He is the editor or author of a large number of publications which have become highly cited.

Timothy P. Guinee, PhD, Principal Research Officer in Food Chemistry and Technology at Teagasc Food Research Centre, Moorepark, Fermoy, Cork, Ireland, and adjunct professor at University College Cork. His interests include study of the rheology and functional properties of composite high-protein food matrices and the exploitation of these properties in food manufacture and assembly/formulation, with particular emphasis on gels and cheese-based systems.

Timothy M. Cogan, PhD, Emeritus Senior Principal Research Officer at Teagasc Food Research Centre, Moorepark, Fermoy, Cork, Ireland, and Emeritus Professor in the Department of Food Microbiology, University College Cork. His main research interests during his research career were starters and the microbiology of cheese and butter, particularly lactic butter.

Paul L.H. McSweeney, PhD DSc, Professor of Food Chemistry at University College, Cork, Ireland. The overall theme of his research is dairy biochemistry with particular reference to factors affecting cheese flavour and texture. He is the co-author or coeditor of a number of books on dairy chemistry and cheese science in addition and research papers and reviews.

Chapter 1
Cheese: Historical Aspects

Summary Agriculture dates from about 6000 BC, when certain plants and animals were domesticated in Mesopotamia. Among the domesticated animals were goats, sheep and cattle, the milk of which was consumed by Man as a high-quality nutrient. Milk is also a very good growth substrate for bacteria, some of which produce lactic acid, which causes the milk to gel. The acidified milk was consumed as cultured milk or converted to acid-curd cheese. It was also discovered that milk could be coagulated by certain proteolytic enzymes, e.g., chymosin from the stomach of neonatal mammals; the coagulum was converted to rennet-curd cheese. Cheese has been produced since the earliest civilizations, e.g., Sumer and Egypt and was well established in Classical Rome. Cheese production spread throughout Europe and the Middle East and later to North and South America and Oceania and evolved as at least 1000 varieties. Cheese production was a farm-based operation until the mid-nineteenth century, and much cheese is still produced at an artisanal level. However, the principal varieties are now produced in very large highly mechanized factories by highly developed technology.

Current production of cheese is about 19×10^6 tonnes per annum, predominantly in Europe, North and South America and Oceania. Approximately 35 % of all milk is used for cheese production.

The objectives of this chapter are to provide a brief history of cheese production and identify the principal areas of production and consumption.

Keywords Discovery and spread of cheese • Production and consumption of cheese

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1.1 Introduction

Cheese is the generic name for a group of fermented milk-based food products, produced throughout the world in a great diversity of flavours, textures and forms. Sandine and Elliker (1970) suggest that there are more than 1000 varieties of cheese. Walter and Hargrove (1972) described about 400 varieties and listed the names of a further 400, Burkhalter (1981) classified 510 varieties and Harbutt (2009) includes photographs and descriptions of about 750 varieties.

It is believed that cheese evolved in the 'Fertile Crescent' between the Tigris and Euphratres rivers, in Iraq, some 8000 years ago during the "Agricultural Revolution", when certain plants and animals were domesticated. Among the earliest animals domesticated were goats and sheep; being small, gregarious and easily herded, these were used to supply meat, milk, hides and wool. Cattle were more difficult to domesticate; wild cattle were much larger and more ferocious than modern cattle and were also less well suited to the arid Middle East than goats and sheep. Apparently, cattle were used initially mainly as work animals and were not used as a major source of milk until relatively recently. The nutritive value of milk produced by domesticated animals was soon recognised and milk and dairy products became important components of the human diet.

Milk is also a rich source of nutrients for bacteria which contaminate the milk and grow well under ambient conditions. Some contaminating bacteria utilize milk sugar, lactose, as a source of energy, producing lactic acid as a by-product; these bacteria, now known as lactic acid bacteria (LAB), include the genera *Lactococcus*, *Lactobacillus*, *Streptococcus*, *Enterococcus*, *Leuconostoc*, *Pediococcus* and *Wiessla*. LAB are used in the production of a wide range of fermented milk, meat and vegetable products. They are generally considered to be beneficial to human health and have been studied extensively (see Chap. 6). Bacterial growth and acid production would have occurred in milk during storage or during attempts to dry milk in the prevailing warm, dry climate to produce a more stable product; air-drying of meat, and probably fruits and vegetables, appears to have been practiced as a primitive form of food preservation at this period in Man's evolution. When sufficient acid is produced, the principal proteins in milk, the caseins, coagulate at ambient temperature (21 °C) in the region of their isoelectric points (~pH 4.6) to form a gel in which the fat and aqueous phases of milk are entrapped. Thus, the first fermented dairy foods were probably produced accidentally. Numerous basically similar products are still produced in various regions of the world by artisanal methods, which are probably little different from those used several thousand years ago. Some "descendants" of these ancient fermented milks are now produced by scientifically based technology.

Fermented dairy foods were produced by a fortuitous combination of events, i.e., the ability of LAB to grow in milk and to produce just enough acid to reduce its pH to the isoelectric point of the caseins. Neither the lactic acid bacteria nor the caseins were designed for this function. The caseins were "designed" to be coagulated enzymatically in the stomach of neonatal mammals, the gastric pH of which is around 6, i.e., much higher than the isoelectric point of the caseins. The ability of LAB to ferment lactose, a sugar specific to milk, is frequently encoded on plasmids, suggesting that this characteristic was acquired relatively recently in the evolution of these bacteria. Their natural habitats are vegetation, from which they presumably colonized the teats of mammals which had been contaminated with lactose-containing milk.

An acid-induced milk gel is quite stable if left undisturbed but, if broken, either accidentally (e.g., by movement of the storage vessels) or intentionally, it separates into curds and whey. Acid whey is a pleasant, refreshing drink for immediate consumption while the curds could be consumed fresh or stored for future use. The shelf-life of the curds can be greatly extended by dehydration and/or by adding salt; heavily salted cheese varieties (e.g., Feta and Domiati) are still widespread throughout the Middle East and the Balkans where the ambient temperature is high. Air/sun-dried varieties of fermented milk and cheese are not common today but numerous varieties survive throughout the hot dry areas of North Africa and the Middle East. Today, acid-coagulated cheeses, which include Cottage cheese, Cream cheese, Quarg, *Fromage frais* and some varieties of Quesco Blanco, represent ~22 % of total cheese production and in some countries are the principal varieties. They are consumed fresh (not ripened) and are widely used in other products, e.g., cheesecake, cheese-based dips and sauces.

Some proteolytic enzymes can modify the milk protein system, causing it to coagulate under certain circumstances, offering an alternative mechanism for coagulating milk; this mechanism was also recognized at an early date. Enzymes capable of causing this transformation are widespread and are found in bacteria, moulds, plant and animal tissues, but the most obvious source would have been animal stomachs. It would have been observed that the stomachs of slaughtered young animals frequently contained curds, especially if the animals had suckled shortly before slaughter; curds would also have been observed in the vomit of human infants. Before the development of pottery (~5000 BC), storage of milk in bags made from animal skins was probably common (it is still practiced in many regions of the world). Stomachs from slaughtered animals provided ready-made, easily-sealed containers; if stored in such containers, milk would extract coagulating enzymes (referred to as rennets) from the stomach tissue, leading to its coagulation during storage. The properties of rennet-coagulated milk curds are very different from those of acid-produced curds, e.g., they have better syneretic properties (ability to exude whey) which make it possible to produce low-moisture cheese curd without hardening. Rennet-coagulated curds can, therefore, be converted to more stable, low-moisture products and rennet coagulation has become the principal mechanism for milk coagulation in cheese manufacture; most modern cheese varieties and ~75 % of total world production of cheese are produced by this mechanism.

During the storage of rennet-coagulated curds, various bacteria may grow in the curd and the enzymes in rennet continue to act. Thus, the flavour and texture of the cheese curds change during storage. When controlled, this process is referred to as ripening (maturation), during which a great diversity of characteristics flavours and textures develop. Although animal rennets were probably the first enzyme coagulants used, rennets produced from a range of plant species, e.g., figs and thistle, appear to have been common in Roman times. However, plant rennets are not suitable for the manufacture of long-ripened cheese varieties and gastric proteinases from young animals became the standard rennets until a shortage of supply made it necessary to introduce “rennet substitutes”, which are discussed in Chap. 7.

While the coagulation of milk by in situ production of lactic acid was, presumably, accidental, the use of rennets to coagulate milk was intentional. It was, in fact, quite an ingenious development—if the conversion of milk to cheese by the use of rennets was discovered today, it would be hailed as a major biotechnological discovery! The use of rennets in cheese manufacture is probably the oldest, and is still one of the principal, industrial applications of enzymes.

The advantages accruing from the ability to convert the principal constituents of milk to cheese would have been apparent from the viewpoints of storage stability, ease of transport and, eventually, as a means of diversifying the human diet. Cheese manufacture accompanied the spread of civilization throughout the Middle East, Egypt, Greece and Rome. There are several references in the Old Testament to cheese, e.g. Job (1520 BC) and Samuel (1170–1017 BC), on the walls of tombs of Ancient Egypt and in classical Greek literature, e.g. Homer (1184 BC), Herodotus (484–408 BC) and Aristotle (384–322 BC). Cheese manufacture was well established in Classical Rome and cheese was included in the rations of Roman soldiers. The demand for cheese in Rome must have exceeded supply since the Emperor Diocletian (284–305 AD) fixed a maximum price for cheese. Many Roman writers, e.g., Cato the Elder (234–149 BC), Varro (116–27 BC), Columella (4–70 AD), Pliny the Elder (23–79 AD) and Palladius (c 400–470 AD) described the manufacture, quality attributes and culinary uses of cheese; Columella, in particular, gave a detailed account of cheese manufacture in his treatise on agriculture, *De Re Rustica*.

Movements of Roman armies and administrators contributed to the spread of cheese throughout the then known world. Cheesemaking practice appears to have changed little from the time of Columella and Palladius until the nineteenth century. The great migrations of peoples throughout Europe after the fall of the Roman Empire promoted the spread of cheese manufacture, as did the Crusaders and pilgrims of the Middle Ages. However, the most important contributors to the development of cheese ‘technology’ and to the evolution of cheese varieties during the Middle Ages were the monasteries and feudal estates. In addition to their roles in the spread of Christianity and in the preservation and expansion of knowledge during the Dark Ages, the monasteries were major contributors to the advancement of agriculture in Europe and to the development and improvement of food commodities, notably wine, beer and cheese. Many current cheese varieties were developed in monasteries, e.g., Wenslydale (Rievaulx Abbey, Yorkshire), Port du Salut or Saint Paulin (Monastery de Notre Dame du Port du Salut, Laval, France), Fromage de Tamie (Abbey of Tamie, Lac d’Annecy, France), Maroilles (Abbey Moroilles, Avesnes, France); Trappist (Maria Stern Monastery, Banja Luka, Bosnia). The inter-monastery movement of monks probably contributed to the spread of cheese varieties and to the development of new cheeses.

The great feudal estates of the Middle Ages were self-contained communities which, in the absence of an effective transport system, relied on a supply of locally produced foods. Surplus food was produced in summer and preserved to meet the requirements of the community throughout the year. Especially in cool, wet Europe, fermentation and salting were the most effective principles for food preservation; well-known examples of such products include fermented and salted meat, salted fish, beer, wine, fermented vegetables and cheese, the manufacture of which exploits both fermentation and salting. Cheese probably represented an item of trade when amounts surplus to local requirements were available. Within large estates, individuals acquired special skills which were passed on to succeeding generations. The feudal estates evolved into villages and some into larger communities. Because monasteries and feudal estates were essentially self-contained communities with limited inter-community travel, it is readily apparent how several hundred distinct varieties of cheese could have evolved from essentially the same raw material. Traditionally, many cheese varieties were produced in quite limited geographical regions, especially in mountainous areas. The localized production of certain varieties is still apparent and indeed is preserved for those varieties with a Protected Designation of Origin (PDO). Regionalization of certain cheese varieties is still particularly marked in Spain, Italy, France and Greece, where the production of many varieties is restricted to very limited, sometimes legally-defined, regions. Almost certainly, most cheese varieties evolved by accident because of particular local circumstances, e.g., species or breed of dairy animal, a peculiarity of the local milk supply with respect to chemical composition or microflora, or an 'accident' during the manufacture or storage of the cheese, e.g., growth of moulds or other microorganisms. Presumably, those accidents that led to desirable changes in the quality of the cheese were incorporated into the manufacturing protocol; thus each variety has undergone a series of evolutionary changes and refinements.

The final chapter in the spread of cheese throughout the world resulted from the colonization of North and South America, Oceania and Africa by European settlers who carried their cheesemaking skills with them. Cheese has become an item of major economic importance in some of these "new" countries, notably the USA, Canada, Australia, New Zealand and Argentina, but the varieties produced are mainly of European origin, modified in some cases to meet local conditions and requirements. There is no evidence that cheese was produced in the Americas or Oceania prior to colonization; in fact, animals had not been domesticated for milk production in these countries.

Cheesemaking remained a craft until relatively recently. With the gradual acquisition of knowledge on the chemistry and microbiology of milk and cheese, it became possible to direct the changes involved in cheesemaking in a more controlled fashion. Although few new varieties have evolved as a result of this improved knowledge, existing varieties have become better defined and their quality more consistent. Although the names of many current varieties were introduced several hundred years ago (Table 1.1), it is very likely that those cheeses were not very comparable to their modern counterparts. Cheesemaking was not standardized until relatively recently; for example, the first attempt to standardize the well-known English varieties, Cheddar and Cheshire, was made by Joseph Harding in the mid-nineteenth

Table 1.1 First recorded date for some major cheese varieties[a]

Gorgonzola	897	Cheddar	1500
Schabzieger	1000	Parmesan	1579
Roquefort	1070	Gouda	1697
Maroilles	1174	Gloucester	1783
Schwangenkase	1178	Stilton	1785
Grana	1200	Camembert	1791
Taleggio	1282	St. Paulin	1816

[a]From Scott (1986)

century. Prior to that, ‘Cheddar cheese’ was that produced around the village of Cheddar, in Somerset, England, and probably varied considerably depending on the cheesemaker and other factors. Cheese manufacture was a farmstead enterprise until the mid-nineteenth century—the first cheese factory in the US was established near Rome, New York, in 1851 and the first in Britain at Longford, Derbyshire, in 1870. Thus, there were thousands of small-scale cheese manufacturers and there must have been great variation within any one type. When one considers the very considerable inter-factory, and indeed intra-factory, variation in quality and characteristics which still occur today in well-defined varieties, e.g., Cheddar, in spite of the very considerable scientific and technological advances, one can readily appreciate the variations that must have existed in earlier times.

Some major new varieties, e.g., Jarlsberg, Maasdamer, Regato and Dubliner have been developed recently as a consequence of scientific research. Many other varieties have evolved very considerably, even to the extent of becoming new varieties, as a consequence of scientific research and the development of new technology—notable examples are Quesco Blanco as produced in the USA, Feta-type cheese produced from ultrafiltered milk and various forms of Quarg. There has been a marked resurgence of farmhouse cheesemaking in recent years; many of the cheeses being produced on farms are not standard varieties and it will be interesting to see if some of these evolve to become new varieties.

A major cause of variation in the characteristics of cheese is the species from which the milk is produced. Although milk from several species is used commercially, the cow is by far the principal producer; worldwide, 85 % of commercial milk is bovine, with 11 %, 2 % and 1.5 % being produced by water buffalo, sheep and goats. However these species are major producers of milk in certain regions, e.g., the Mediterranean basin and India; goats and sheep are especially important in cheese production since the milk of these species is used mainly for the production of fermented milks and cheese. Many world-famous cheeses are produced from sheep’s milk, e.g., Roquefort, Feta, Romano and Manchego; traditional Mozzarella is made from the milk of the water buffalo. As will be discussed in Chap. 4, there are very significant interspecies differences in the composition of milk which are reflected in the characteristics of the cheeses produced from them. There are also significant differences in milk composition between breeds of cattle and these influence cheese quality, as do variations due to seasonal, lactational and nutritional factors and of course the methods of milk production, storage and collection.

Brief histories of the history of cheese are provided by several authors, especially by Scott (1986). Kindstedt (2013) gives a very interesting account of the history of cheese and its place in Western culture.

1.2 Cheese Production and Consumption

World production of cheese is ~19×10^6 tonnes per annum (~35 % of total milk production) and has increased at an average annual rate of ~4 % over the past 30 years. Europe, with a production of ~11×10^6 tonnes per annum, is the largest producing block (Table 1.2). Thus, while cheese manufacture is practiced worldwide, it is apparent from Table 1.2 that cheese is primarily a product of European countries and those populated by European immigrants.

Cheese consumption varies widely between countries, even within Europe (Table 1.2). Cheese consumption in most countries for which data are available has

Table 1.2 Production and consumption of cheese, 2011 (IDF 2012)

Country	Cheese production (1000 tonnes)	Cheese consumption (kg per caput)
World	**18,833**	
Africa	*678*	
Egypt	620	10.1
South Africa	47	1.0
Nigeria	9	
Zimbabwe	2	
Oceania	*606*	
Australia	349	11.7
New Zealand	257	3.5
Asia	*981*	
Turkey	519	6.7
Iran	260	4.6
Israel	125	16.1
Japan	45	1.9
China	20	0.2
India	8	
South Korea	4	2.0
North & Central America	*5412*	
United States	4807	15.1
Canada	330	12.3
Mexico	275	3.1
South America	*1388*	
Brazil	675	3.6
Argentina	521	11.5

(continued)

Table 1.2 (continued)

Country	Cheese production (1000 tonnes)	Cheese consumption (kg per caput)
Chile	90	7.2
Uruguay	61	6.3
Colombia	41	0.9
European Union	*8634*	*17.1*
Germany	2196	22.9
France	1930	26.3
Italy	1094	21.8
Netherlands	750	19.4
Poland	650	11.4
United Kingdom	359	10.9
Denmark	276	16.4
Greece	190	23.4
Ireland	180	6.7
Austria	160	19.9
Spain	130	9.6
Czech Republic	110	16.3
Lithuania	104	14.2
Sweden	103	19.9
Finland	101	22.5
Belgium	76	15.3
Hungary	69	11.0
Romania	62	4.3
Estonia	41	19.6
Slovakia	32	10.3
Latvia	28	13.5
Cyprus	14	17.9
Luxembourg	–	24.1
Others	138	12.0
Other European	1132	
Russia	425	5.8
Ukraine	255	4.1
Switzerland	182	21.8
Belarus	149	–
Norway	84	17.4
Croatia	30	7.7
Iceland	7	24.1

increased consistently over many years; along with fermented milks, cheese is the principal growth product within the dairy sector. There are many reasons for the increased consumption of cheese, including a positive dietary image, convenience and flexibility in use and the great diversity of flavours and textures. Cheese can be regarded as the quintessential convenience food: it can be used as a major component of a meal, as a dessert, as a component of other foods or as a food ingredient; it can be consumed without preparation or subjected to various cooking processes. The most rapid growth in cheese consumption has occurred in its use as a food component or ingredient; these applications will be discussed in Chap. 19.

1.3 Cheese Science and Technology

Cheese is the most diverse group of dairy products and is, arguably, the most academically interesting and challenging. While many dairy products, if properly manufactured and stored, are biologically, biochemically and chemically very stable, cheeses are, in contrast, biologically and biochemically active, and, consequently, undergo changes in flavour, texture and functionality, to a degree which is variety-dependent, during storage. Throughout manufacture and ripening, cheese production represents a finely orchestrated series of consecutive and concomitant biochemical events which, if synchronized and balanced, lead to products with highly desirable aromas and flavours but when unbalanced, result in off-flavours and odours. Considering that, in general terms, a basically similar raw material (milk from a very limited number of species) is subjected to a manufacturing protocol, the general principles of which are common to most cheese varieties, it is fascinating that such a diverse range of products can be produced. No two batches of the same variety are identical.

A further important facet of cheese is the range of scientific disciplines involved: study of cheese manufacture and ripening involves the chemistry and biochemistry of milk constituents, chemical characterization of cheese constituents, microbiology, enzymology, molecular genetics, flavour chemistry, rheology and chemical engineering. It is not surprising, therefore, that many scientists have become involved in the study of cheese manufacture and ripening. A voluminous scientific and technological literature has accumulated, including several textbooks (see suggested reading list) and chapters in many others. Many of these textbooks deal mainly with cheese technology or assume an overall knowledge of cheese. The present book is intended to provide a fairly comprehensive treatment of the scientific aspects of cheese.

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Chapter 2
Overview of Cheese Manufacture

Summary The objective of this chapter is to present a very brief description of the principal operations of cheese production so that the operations described in the following chapters can be seen in an overall context

Introduction

The production of all varieties of cheese involves a generally similar protocol (Fig. 2.1), various steps of which are modified to give a product with the desired characteristics. The principal general steps are

1. Selection, standardization and, in most cases, pasteurization of the milk.
2. Acidification, usually via the in situ production of lactic acid by selected bacteria.
3. Coagulation of the milk by acidification or limited proteolysis.
4. Dehydration of the coagulum to yield cheese curd, by a range of techniques, some of which are variety-specific.
5. Forming the curds into characteristic shapes.
6. For most varieties, ripening (maturation) of the curd during which the characteristic flavour and texture of the cheese develop.

The objective of this chapter is to present a very brief description of the principal operations so that the operations described in the following chapters can be seen in an overall context.

Keywords Selection and treatment of cheesemilk • Annato • Coagulation • Salting • Ripening • Processed cheese

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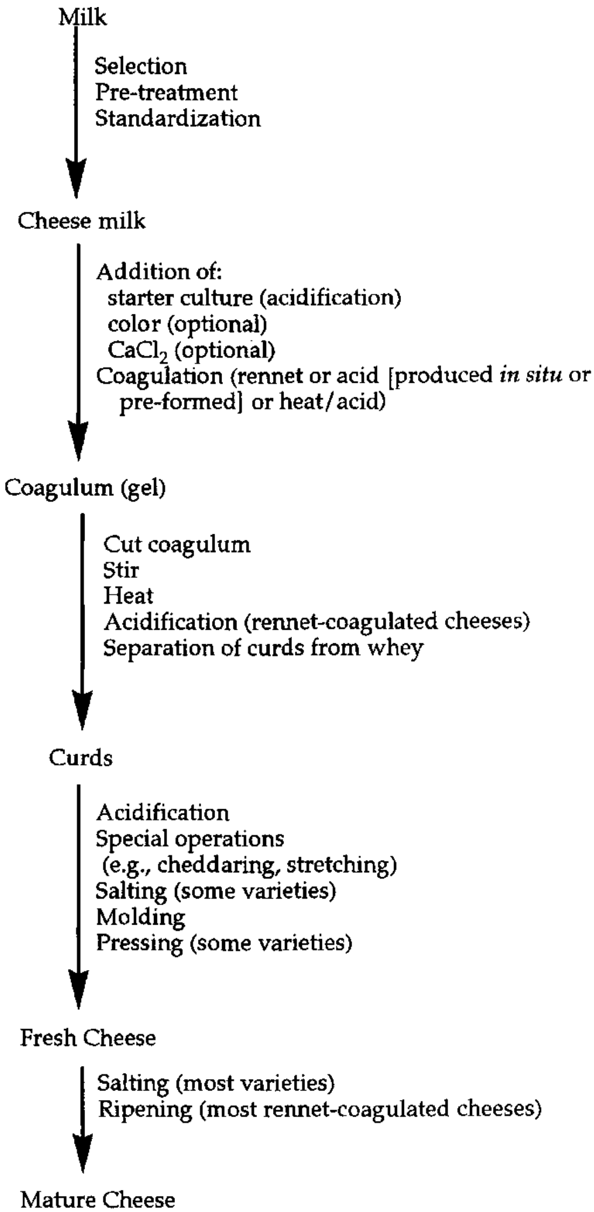


Fig. 2.1 General protocol for cheese manufacture

2.1 Selection of Milk

The composition of cheese is strongly influenced by the composition of the cheese milk, especially the content of fat, protein, calcium and pH. The constituents of milk, which are described in Chap. 4, are influenced by several factors, including species, breed, individuality, nutritional status, health and stage of lactation of the producing animal. Owing to major compositional abnormalities, milk from cows in the very early or late stages of lactation and those suffering from mastitis should be excluded. Somatic cell (leucocyte) count is a useful index of quality. Some genetic polymorphs of the milk proteins have a significant effect on cheese yield and quality and there is increasing interest in breeding for certain polymorphs. The milk should be free of chemical taints and free fatty acids, which cause off-flavours in the cheese, and antibiotics which inhibit bacterial cultures.

The milk should be of good microbiological quality, as contaminating bacteria will be concentrated in the cheese curd and may cause defects or public health problems. This subject will be discussed in Chap. 5.

2.2 Standardization of Milk Composition

Milk for cheese is subjected to a number of pre-treatments, with various objectives.

Different cheese varieties have a characteristic fat-in-dry matter content, in effect, a certain fat-to-protein ratio and this situation has legal status in the "Standards of Identity" for many cheese varieties. While the moisture content of cheese, and hence the level of fat plus protein, is determined mainly by the manufacturing protocol, the fat:protein ratio is determined mainly by the fat:casein ratio in the cheese milk. Depending on the ratio required, it can be modified by:

- removing some fat by natural creaming, as in the manufacture of Parmigiano Reggiano, or centrifugation
- adding skim milk
- adding cream
- adding micellar casein (prepared by ultrafiltration)
- adding milk powder, evaporated milk or ultrafiltration retentate. Such additions also increase the total solids content of the milk and hence cheese yield and will be discussed in Chap. 10.

Calcium plays a major role in the coagulation of milk by rennet and subsequent processing of the coagulum and hence it is common practice to add $CaCl_2$ (e.g., 0.01 %) to cheese milk.

The pH of milk is a critical factor in cheesemaking. The pH is inadvertently adjusted by the addition of 1.5–2 % starter culture which reduces the pH of the milk immediately by about 0.1 unit. Starter concentrates (sometimes called direct-to-vat starters), which are now used widely, have no immediate acidifying effect.

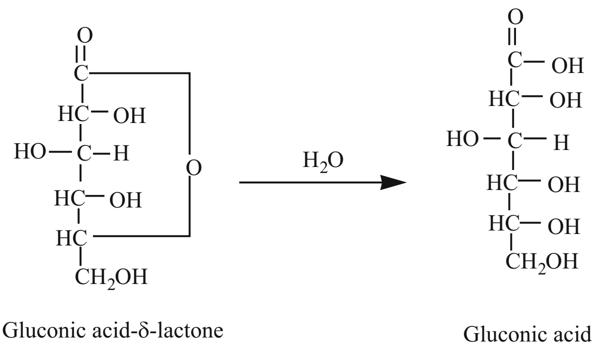
Previously, it was standard practice to add the starter to the cheese milk 30–60 min before rennet addition. During this period, the starter microorganisms began to grow and produce acid, a process referred to as "ripening". Ripening served a number of functions:

- it allowed the starter bacteria to enter their exponential growth phase and hence to be highly active during cheesemaking; this is not necessary with modern high-quality starters.
- the lower pH was more favourable for rennet action and gel formation.

However, the practice increases the risk of bacteriophage infection of the starter as phage become distributed throughout the liquid milk but is reduced after the milk has coagulated (see Chap. 6). Although ripening is still practiced for some varieties, it has been discontinued for most varieties.

The pH of milk on reception at the dairy is higher today than it was previously owing to improved hygiene during milking and the more widespread use of refrigeration at the farm and factory. In the absence of acid production by contaminating bacteria, the pH of milk increases slightly during storage due to the loss of CO_2 to the atmosphere. The natural pH of milk is ~6.6–6.7 but varies somewhat (e.g., it increases in late lactation and during mastitic infection).

To offset these variations and to reduce the pH as an alternative to ripening, the pre-acidification of milk by 0.1–0.2 pH units is recommended, either through the use of the acidogen, gluconic acid-δ-lactone, or by limited growth of a lactic acid starter, followed by pasteurization (referred to as pre-maturation).



2.3 Heat Treatment of Milk

Traditionally, all cheese was made from raw milk, a practice which remained widespread until the 1940s. Even today, significant amounts of cheese are made in Europe from raw milk. The use of raw milk may be undesirable due to:

- Public health safety
- The presence of undesirable microorganisms which may cause defects or variability in flavour and/or texture.