SYMPOSIUM CONTRIBUTION

Cheese technology

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Cheese is a highly nutritious food with many diverse flavours and textures. It can be used as a snack or as part of a dish or prepackaged convenience food. The diversity of cheese is due to an increasing knowledge of the technology of cheesemaking, and the biochemistry and microbiology of cheese ripening. Professor Pat Fox's research career over the past 40 years has contributed to our understanding of cheese technology, biochemistry and microbiology. This paper highlights Pat Fox's contributions in the area of cheese technology.

Keywords Cheese, Cheese maturation, Cheesemaking, Milk treatments, Production statistics.

INTRODUCTION

Approximately a third of the world's milk production is used in cheese manufacture (Table 1). Cheese is a highly nutritious food. It is convenient and versatile and offers a diversity of flavours and textures. The global sale value of cheese represents about 30% of total dairy products sales with a forecast of a 9.8% growth in cheese sales between 2003 and 2007 (Table 2). The growth in the cheese sector is due mostly to convenience packaging, increased use of cheese in the food service sector, and growth in speciality and exotic cheeses. The USA, the UK, France and Germany experienced more than 9% growth in the cheese market during the five-year period from 1998 to 2002 (Table 3).

The manufacture of cheese is a form of milk preservation as milk is highly perishable. All cheeses, whether rennet or acid set, can be classified as soft, semisoft (semihard), hard, or very hard (Figure 1), depending on their moisture content. Although this classification is arbitrary and utilitarian, it helps to systematically group together cheeses that are alike in certain basic features or characteristics (e.g. moisture content), as moisture determines the body, consistency or compactness of cheese. Therefore, the term soft cheese is used to describe cheese that is soft to touch or to pressure applied between fingers. Conversely, the terms hard cheese (e.g. Cheddar) or very hard cheese (e.g. Parmesan) refer to cheeses that are firm or very firm, respectively, and require some form of pressure to break apart. Classification of cheese based on moisture content is given in Table 4. Semisoft, hard and very hard cheeses have upper limits for moisture content and lower limits for fat content—usually expressed as fat in dry matter (FDM). The US Code of Federal Regulations specify that soft cheeses must contain a minimum of 50% FDM, but does not specify a maximum moisture content. However, there is a practical limit for moisture of about 80%, above which the product is no longer a semisolid mass but is liquid.

The method used to clot milk for cheesemaking influences the overall structure, characteristics and firmness of the cheese. The two basic methods for clotting milk for cheese manufacture are by rennet or acid, leading to the respective terms, rennet- or acid-coagulated cheeses. In general, acid-coagulated cheeses are soft whereas rennet-set cheeses are firm.

WHAT DRIVES CHEESE TECHNOLOGY?

The main forces that drive cheese technology are economics, equipment/engineering, consumer demands and regulatory standards. The contributions of these factors are best considered by examining typical cheese manufacturing steps (Table 5), using Cheddar as an example and because it relates to the contributions of Professor P. F. Fox to the science and technology of cheesemaking.

MILK QUALITY AND PRETREATMENT BEFORE CHEESEMAKING

Hydrogen peroxide/catalase treatment of milk

The starting material for good quality cheese is good quality, clean-tasting milk that is low in somatic cell count, free of antibiotics and has a relatively low microbial count. The composition of milk, which is influenced by the breed of cow, season, stage of lactation, disease and genetics, affects the yield, quality and functional characteristics of cheese. Depending on the microbial quality of the raw milk and its source, and to ensure consistent cheese quality, raw milk may be treated with hydrogen peroxide (H_2O_2). This treatment is not

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Table 1 Milk and cheese production in selected countries (1000 metric tons)

	USA		*EU*		*Russia*		*New Zealand*	
	Milk	*Cheese*	*Milk*	*Cheese*	*Milk*	*Cheese*	*Milk*	*Cheese*
2000	76 004	3746	114 900	5437	31 900	220	12 236	297
2001	75 067	3747	114 856	5420	33 000	260	13 162	281
2002	77 002	3900	115 130	5470	33 500	340	13 925	312
2003	77 293	3975	115 150	5500	33 150	320	14 346	272

Table 2 Global value sales of selected dairy products by sector (US$ million, rsp)

	1998	*2003*	*2007*	*% Growth 2003–2007*
Dairy products totals	218 881.5	222 971.3	247 944.2	11.2
Milk	76 080.0	73 067.7	78 242.8	1.4
Cheese	66 584.5	67 810.0	74 439.1	9.8
Yoghurt	24 363.0	23 334.4	34 002.1	20.0
Cream	8 863.7	8 934.4	9 769.9	13.7
Flavoured milk	7 424.2	8 367.1	9 963.1	19.1
Milk powder	6 539.3	6 003.1	7 309.1	21.8

Source: Euromonitor International (2003); Dairy Field (2003)
rsp, retail selling price

currently used in technologically advanced countries with hygienic milking conditions. One of Pat Fox's earliest research works dealt with the effects of H_2O_2 treatment on caseins and its implications in cheesemaking (Fox and Kosikowski 1967). In this research, Pat Fox showed that H_2O_2–catalase treatment of milk resulted in increased use of chymosin and increased proteolysis in cheese and a resultant soft cheese. Hydrogen peroxide is both a bactericidal and a bacteriostatic agent. It is normally used at 0.07–0.1% for a maximum of 40 min at 50–54°C (Scott *et al*. 1998). Kosikowski and Fox (1968) reported that H_2O_2–catalase treatment destroyed almost all the coliforms in milk. The role of catalase is to decompose the toxic effect of residual H_2O_2 and the amount of catalase added.

Bactofugation

The introduction of the bactofuge has helped to control the quality of milk in regions of the world where the bacteriological quality of the milk is poor. Kosikowski and Fox (1968) were the first to demonstrate the effect of bactofugation on the control of microbiological quality of cheese milk. They showed that bactofugation of milk decreased bacterial numbers by 95.3%. The bactofuge is a high-speed centrifuge specially designed for removing bacteria and bacterial spores from milk

Table 3 Growth in the cheese market in selected countries

	US$ billion (2002)	*% Growth in sales (1998–2002)*	*Reason for expansion*
US	13.3	29.7	Convenient packaging, increased varieties
UK	2.6	9.4	Ingredient use of cheese, convenient packaging
France	6.9	12	Prepackaged cheese, foreign cheese
Germany	5.64	13.8	Exotic and foreign cheeses (e.g. feta, mozzarella)

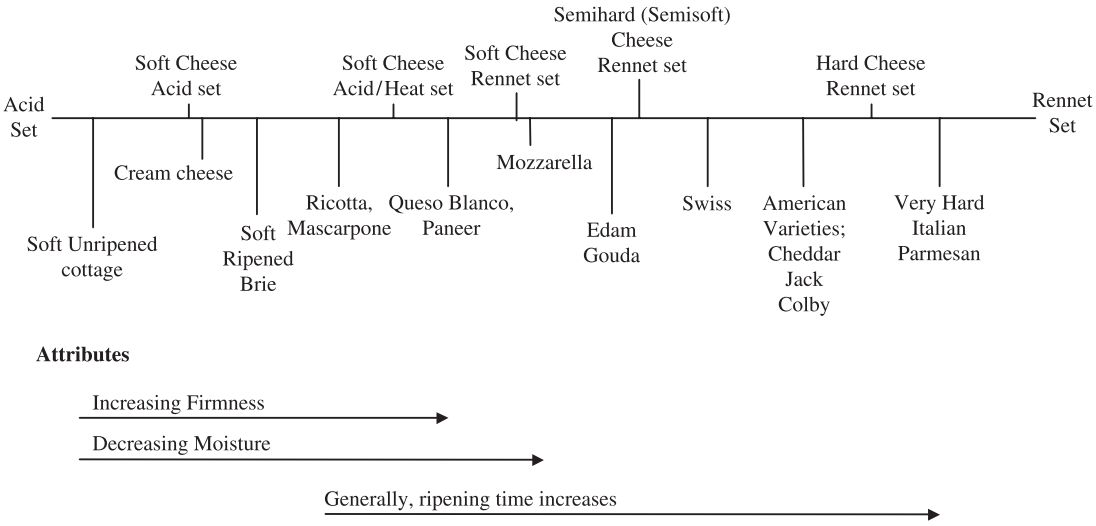

Figure 1 The cheese spectrum.

Table 4 Classification of cheese based on moisture content

Consistency	*Maximum moisture (%)*	*Minimum fat-in-dry matter (%)*
Hard grating	34	32
Hard	39	50
Semisoft	50 (> 39)	50
Semisoft, part skim	50	45 (< 50)
Soft	Not specified	50

at high temperatures. A double bactofuge treatment at 73°C results in at least three log reductions of bacteria and bacterial spores (Walstra *et al*. 1999). Bactofugation reduces the initial volume of milk by 2–3% and the milk protein content by ~7% (Scott *et al*. 1998) results in cheese yield losses of ~6% because of the loss of milk solids in the sludge (Walstra *et al*. 1999). The sludge is ultrahigh temperature (UHT)-treated at 130–140°C for a few seconds and then added back to the cheese milk (Walstra *et al*. 1999).

Chemical treatment

Even when milk is subjected to bactofugation treatment, a certain amount of nitrate (~2.5 g/100 kg milk) is desirable to inhibit spore germination (Walstra *et al*. 1999) in countries that allow the use of nitrates in cheesemaking. Nitrates are not allowed in cheesemaking in the USA. Alternately, lysozyme (100–250 mg/100 mL) may be added to the milk. Lysozyme associates with casein micelles and hydrolyses peptidoglycan bonds of mostly Gram-positive bacteria (e.g. *Clostridium tyrobutyricum*) that tend to grow, when present, in varieties such as Swiss cheese and causes late-gas blowing. Although lysozyme occurs in bovine milk at concentrations of 0–2 mg/L, such concentrations are too low to be effective (Walstra *et al*. 1999).

Use of membrane technologies

Ultrafiltration (UF), reverse osmosis (RO) and microfiltration (MF) are being used increasingly in the dairy industry to concentrate/fractionate milk for the manufacture of high moisture cheeses in high yields. Ultrafiltered retentates are commercially used to produce precheese for the manufacture of some soft and semisoft cheeses, and to prepare a cheese base for processing (Ernstrom *et al*. 1980). However, the use of highly concentrated milks (> 5 times the concentration factor) for the manufacture of semihard and hard cheeses remains a challenge as sensory attributes of the finished cheese differ from that made from regular milk by traditional methods. Low concentration ratio ultrafiltration has been used successfully for the manufacture of Cheddar and related types. Microfiltration of milk using membranes of pore size ranging from 0.01 to 10 μm is used for the removal of bacteria and bacterial spores from milk (Scott *et al*. 1998). Membrane technologies are also used to produce new liquid and dry ingredients for use in standardizing cheese milk. Examples of using liquid or dry milk protein concentrate in cheese manufacture have been reported by St-Gelais *et al*. (1998) and Shakeel-Ur-Rehman *et al*. (2003a,b,c).

Standardization of milk

Milk is standardized by adjusting the casein to fat (C/F) ratio in the milk to control the percentage of fat in the dry matter, produce consistent cheese and meet the regulatory standards of a given variety. Methods for increasing the casein content of cheese milk include the addition of skim-milk powder, condensed skim, milk protein concentrate (liquid or powder) or caseinates or the removal of fat as cream. Conversely, addition of cream increases the fat content of cheese milk. The most desirable C/F ratio in milk used for the manufacture of Cheddar and Gouda-type cheese is 0.7 although ratios as low as 0.64 may be desirable in

Table 5 Typical Cheddar cheesemaking protocol

1	Milk receipt (testing for chemical and microbial quality—fat, pH, antibiotics, somatic cell count, etc.)
2	Pretreatment of milk—bactofugation, vacuum aeration, H_2O_2/lysozyme treatment, membrane concentration/fractionation
3	Standardization
4	Heat treatment/pasteurization (raw milk may be used)
5	Add calcium chloride (optional)
6	Add colour (optional)
7	Acidification—addition of starter or direct acidification to desired pH
8	Add rennet/milk coagulant
9	Cut curd
10	Cooking, draining, curd manipulation
11	Salting
12	Hooping
13	Pressing

Table 6 Effect of standardization of whole milk with skim milk or milk protein concentrate (MPC) on the fat recovery, dry matter recovery and yield of reduced-fat Cheddar cheese

Treatment	*Actual yield (%)*	*45% moisture-adjusted yield (%)*	*Fat recovery (%)*	*Dry matter recovery (%)*
Whole milk + skim milk	7.40 ± 0.56	8.05 ± 0.52	91.85 ± 2.68	42.25 ± 2.82
Whole milk + MPC (1% starter)	18.62 ± 2.89	19.96 ± 1.89	93.77 ± 1.83	61.21 ± 4.66
Whole milk + MPC (2% starter)	18.72 ± 2.47	20.15 ± 2.11	93.42 ± 3.18	61.70 ± 4.15
P-value	0.00	0.00	0.64	0.00

some cases. Under ideal cheesemaking conditions, typical fat recovery would be around 93%, although under practical conditions, fat recovery is less than 93% and independent of the C/F ratio in milk. Table 6 shows that standardization of whole milk with milk protein concentrates increases cheese yields and dry matter recovery in reduced-fat Cheddar cheese.

CHEESE YIELD

During the conversion of milk into cheese curd, milk constituents are separated into two groups, those that are retained in the curd and those that are lost in the whey. Cheese curd retains most of the fat and casein in the original milk while the whey contains mostly water, lactose, proteins (peptides and other nitrogenous compounds) and minerals that are soluble at the pH of cheesemaking. The typical yield of cheese ranges from 9 to 15% depending on the chemical composition of the milk, efficient recovery of fat and casein in the cheese, losses of milk constituent in the whey resulting from milk handling and treatment and cheesemaking procedures, and the final moisture content of the cheese. The chemical composition of the milk is obviously influenced by factors such as climate and season, animal feed, age and breed of cow, stage of lactation and disease state of the animal. The composition of cheese milk resulting from membrane concentration and fractionation of milk (e.g. ultrafiltration, microfiltration and reverse osmosis) also influences cheese yields. Hence, the economics of cheesemaking is to maximize yields through the efficient recovery of milk constituents while minimizing constituent losses in the whey. Large-scale manufacturing plants can also increase vat throughput and maximize yields by fortifying milk with milk solids to 14–17% dry matter content. In addition to yield increases, fortification reduces plant labour costs by increasing the amount of cheese per vat per man-hour. Although the use of high solids milk offers attractive returns to manufacturers, equipment to handle the volume of milk and weight of cheese presents challenges to the industry.

PASTEURIZATION OF MILK

Cheese milk must be adequately pasteurized (72°C × 15 s). In several countries, the use of raw milk for cheesemaking is still prevalent. In the USA, cheese manufactured from raw milk must be stored at a minimum of 1.7°C for at least 60 days before consumption. This regulation limits the manufacture and sale of unripened soft cheeses from raw milk. Fox's group recently carried out several studies to understand differences between raw and pasteurized milk cheeses. Cheeses made from raw milk contained higher numbers of nonstarter bacteria compared to cheeses made from pasteurized or microfiltered milk.

OPTIONAL INGREDIENTS

Following standardization and pasteurization, optional ingredients such as calcium chloride and cheese colour (annatto) may be added to cheese milk. Calcium chloride plays a role in the second stage of milk coagulation, i.e. gelation. The legal limit in the USA for $CaCl_2$ is 0.02% (w/w) milk. Annatto colour extracted from the plant *Bixa Orellana* is added to give uniformity in colour of certain varieties, such as Cheddar.

STARTER

Various starter types are used for cheesemaking. Starters play a role in the acidification of cheese milk to the desired pH during manufacture. In addition, starter bacteria play an important role in the maturation and flavour development of cheese. Current starter technologies include genetically modified starters, adjunct starters and fast-acid starters, which are available commercially as liquid, frozen or dried. In large commercial factories, liquid starters are propagated daily from bulk starter vessels using internal or external pH-controlled starter media before inoculating into milk. The starter medium may also be whey-based. Smaller, less sophisticated plants propagate starters in sterile milk or reconstituted skim milk powder. Frozen cultures are available in concentrated or unconcentrated forms and inoculated directly into milk (also called direct

vat cultures). Frozen cultures may also be available as frozen pellets that are easier to dispense. Dried starters may be spray-dried or freeze-dried. Immobilized cell technology is also possible but it has not been applied commercially (Tamime 2002). Fox's research in the area of starter culture technology focused on the role of starters in cheese flavour development (see O'Keeffe *et al*. 1976; Farkye *et al*. 1990; Law *et al*. 1992) and the contribution of indigenous microflora and nonstarter bacteria to flavour development (McSweeney *et al*. 1993, 1994; Lynch *et al*. 1996).

COAGULANT

Chymosin is the principal milk-clotting enzyme used in cheesemaking. There are several coagulants of animal and microbial origin. These include calf chymosin, bovine and porcine pepsins, *Mucor meihei* protease, *Mucor pusillus* protease, *Cryophonectria prasitica* protease and fermentation-derived chymosins. These enzymes, often called rennets, hydrolyse the micelle-stabilizing κ-casein at or near the Phe_{105}–Met_{106} bond. The rennet-altered milk coagulates in the presence of Ca^{2+} at approximately 30°C. Rennet-hydrolysed κ-casein gives a hydrophobic *para*-κ-casein (f1–105) that remains with the curd, and a hydrophilic (glyco)macropeptide (f106–169) that is lost in the whey. The activity of chymosin and other milk-clotting enzymes is pH dependent, with activity increasing as pH decreases. Fox's group has studied the milk-clotting activities of several enzymes, including bovine, porcine and ovine pepsins, and fermentation-produced chymosin (see Fox 1969; O'Keeffe *et al*. 1976; O'Sullivan and Fox 1991). Fox's research also showed that less than 10% of the enzyme used to clot milk remains active in cheese and plays a role in the initial stages of ripening (O'Keeffe *et al*. 1978a,b). Porcine pepsin is unstable at the pH of cheesemaking and loses its activity during cheesemaking. The residual activities of the microbial enzymes *M. meihei* and *M. pisillus* are independent of the milk pH at setting (see Farkye 1995).

COOKING, WHEY DRAINAGE AND SALTING

Following coagulation and cutting of curd, the curd is cooked, or scalded, to expel whey through syneresis. Cooking also facilitates starter growth and acid development. Fox and his associates studied the effect of the rate of acidification (O'Keeffe *et al*. 1975) and cooking temperature on Cheddar cheese manufacture and quality (Mullan *et al*. 1981; Wilkinson *et al*. 1995).

Salt is added to cheese to slow down or inhibit starter activity and to enhance the taste of cheese. The concentration of salt also affects enzymatic activity in cheese during cheese ripening. The salt content in cheese is best expressed as salt-in-moisture (S/M), which controls the extent to which starter activity continues after salting. Typical S/M levels in Cheddar-type cheeses are 4–6%; beyond 6% S/M the activity of most starter bacteria is inhibited. Fox's pioneer research publication on salt determination in cheese is the standard method used widely in industry (Fox 1963). His group has also studied salt diffusion in dry-salted (e.g. Cheddar; Morris *et al*. 1985) or brine-salted cheese (e.g. Romano; Guinee and Fox 1986a,b).

CHEESE RIPENING

Cheese ripening is an outcome of several biochemical and metabolic processes usually referred to as glycolysis, lipolysis and proteolysis. The relative importance of each of the processes depends on the variety of cheese. Fox has made an outstanding contribution to the understanding and advancement of cheese ripening. He has researched the role of coagulant, indigenous milk enzymes (e.g. plasmin) starter and nonstarter bacteria in proteolysis during cheese ripening.

Proteolysis is the most complex process, the extent of which depends on the variety—from very limited in mozzarella to very extensive in blue mould varieties. The general reaction steps are:

1 initial hydrolysis of caseins by residual coagulant and plasmin to large peptides;
2 breakdown of large peptides by starter proteinases and peptidases into medium and small peptides;
3 further hydrolysis of the medium and small peptides by starter peptidases into dipeptides, tripeptides and free amino acids.

While the level of residual coagulant in cheese is dependent on the pH of milk at setting (Farkye 1995), the plasmin activity is dependent on the cooking temperature used during manufacture, being higher in high-cook cheeses (e.g. Swiss) than in low-cook cheeses (e.g. Cheddar; Farkye and Fox 1990). The peptides produced by the action of residual coagulant and plasmin are often either tasteless or bitter and do not contribute directly to the typical taste of cheese. However, the mixture of small peptides and amino acids directly influences the taste and mouthfeel of cheese (Law 2001). The free amino acids may also be further catabolized into flavour compounds that are unique for each cheese and are dependent on the types of enzymes and microorganisms (particularly nonstarter lactic acid bacteria, NSLAB) present in cheese. The contribution and importance of NSLAB to cheese ripening have been the subject of intense research (see McSweeney *et al*. 1993; Lane

et al. 1997; Gobbetti *et al*. 1999a,b; Ur-Rehman *et al*. 1999; Shakeel-Ur-Rehman *et al*. 2000).

Flavour compounds in cheese are concentrated in the water-soluble fraction. Hence, methods for studying proteolysis and the fractionation and characterizing water-soluble nitrogen (WSN) are important in cheese research and technology. Methods for electrophoretic examination of cheese (Shalabi and Fox 1987), extraction, fractionation and quantification of WSN (Kuchroo and Fox 1982a,b; 1993) and measurement of free amino acid content by the cadmium–ninhydrin reagent (Folkertsma and Fox 1992) are routinely used for the studying cheese proteolysis.

Accelerated ripening of cheese

Cheese ripening is an expensive process. Fedrick (1987) reported interest charges of about $40 per ton per month for ripening cheese in Australia. Hence, technologies for reducing the time and cost for storing and maturing cheese until it is sold have economic significance to the dairy industry and cheese consumers. Several optional technologies have been described for accelerating the ripening of cheese, including:

1 addition of exogenous enzymes;
2 use of starter adjuncts;
3 attenuated starters;
4 genetically modified starters;
5 high pressure processing; and
6 elevated ripening temperature.

An example of Fox's contribution in this area is found in Guinee *et al*. (1991). Accelerated ripening techniques can also be used to manufacture products such as enzyme-modified cheeses for use in processed cheese or as ingredients in products in which high cheese flavour is required.

CHEESE AS AN INGREDIENT

Cheese has been traditionally used for direct consumption (as table cheese). However, in recent years the use of cheese in food service and as an ingredient has increased tremendously. Of the approximately 3904 million kilograms of natural cheese produced in the USA in 2002, approximately 40% (~1528 million kg) was used in the foodservice sector; with mozzarella cheese being the variety used most often (International Dairy Foods Association 2003) due to the increased popularity of pizza. The ability of cheese to be cut, sliced, diced or cubed into various shapes, grated, ground and dried offers more versatility for cheese to be used in various cuisines and food applications. Cutting, dicing, slicing, cubing, etc., are limited to semisoft, hard and very hard cheeses whereas pumping and spreadability are important for soft cheeses. Processed cheese products, cheese powders and enzyme-modified cheeses are increasingly of interest for specific functional applications. There is also considerable interest in the production of cheese varieties for baked, deep-fat fried and retort food product applications. Cheeses such as paneer, queso blanco and other Hispanic-style cheeses offer many advantages (Farkye and Prasad 1995; Farkye *et al*. 1995; Van Hekken and Farkye 2003).

CONCLUSIONS

The cheese industry has experienced tremendous growth in cheese sales and consumption mainly because of increased diversity of cheese and robust flavours. Cheese is also a nutritious and convenient food that allows it to be consumed as a snack or as part of an ingredient in other foods or cuisines. The contribution of Pat Fox has helped to better understand the science and technology of cheesemaking and the biochemistry and microbiology of ripening to ensure good quality and consistent cheese.

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