Handbook of cheese in health

production, nutrition and medical sciences

edited by:
Victor R. Preedy
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Cheese in context of diet and nutrition

1. Cheese in the context of diet and nutrition

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Abstract

Milk and dairy products including cheese are important components of our food supply, contributing a number of nutrients to the diet. Cheese contains a high concentration of essential nutrients, including protein, fat, vitamins and minerals. Cheese can consist of 3 to 40% protein, mostly casein protein, which is highly digestible. Milk proteins are a key source of bioactive peptides (BP). In particular, angiotensin I-converting enzyme inhibitory peptides found in cheese have antihypertensive effects. Depending on the milk and method of manufacture used, cheese can contain 4-48% fat. In addition to affecting a number of physical properties, the fat content also affects nutritional properties. Generally, the fat present is 66% saturated and hence much negative attention has centred on this fact, resulting in the production of low-fat options. Conjugated linoleic acid (CLA) is a beneficial component of milk products including cheese, reported to have antioxidant, anticholesterolaemic and antiatherogenic effects. Most cheeses are good sources of vitamin A, riboflavin, vitamin B12 and folate. Cheese is also a valuable dietary source of minerals, particularly calcium, phosphorus and magnesium. Calcium has been extensively linked with osteoporosis, being important for the development of peak bone mass. Varying levels of sodium are found in cheeses. Salt is used as a preservative during the cheesemaking process, but levels contributed to the diet by cheese are not significant. Therefore, cheese is a highly valuable product in terms of diet and nutrition, being a major source of protein, fat, vitamins and minerals, which are essential in a balanced diet. Other constituents such as CLA and BP have the potential to confer further health benefits to the consumer.

Keywords: dairy products, health, nutritional properties

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Key facts

- Bioactive peptides (BP) are peptides with biological activity, released by food processing or digestion.
- BP have potential use as functional food ingredients and nutraceuticals to promote health and reduce disease risk.
- Biologically active peptides have physiological roles including immunomodulatory and anti-hypertensive.

Summary points

- Cheese is a nutritious food, being a rich source of essential nutrients such as fat, fatty acids, proteins, peptides, amino acids, vitamins and minerals.
- Typically, cheese contains ~66% saturated, 30% monounsaturated and 4% polyunsaturated fatty acids and is hence a significant source of fat in the diet.
- Conjugated linoleic acid is a *trans* fatty acid that has been shown *in vitro* and in animal studies to have many bioactive effects, including anti-carcinogenic, anti-atherogenic and anti-inflammatory.
- Cheese is an important source of protein, with concentrations ranging from ~4 to 40%, with some of the proteins in cheese being more digestible than proteins in milk.
- Bioactive peptides in cheese have become of much interest; e.g. angiotensin converting enzyme inhibitory peptides showing bioactivities such as antimicrobial, anti-inflammatory, anti-hypertensive and cholesterol lowering.
- Lactose, the principle carbohydrate in milk, is lost with the whey during cheese production.
- Cheeses are good sources of vitamin B_{12}, vitamin A, niacin, riboflavin and folate.
- Calcium, phosphorus, sodium and chloride are predominant minerals in Cheddar cheese, but other trace elements including zinc and potassium are also found in smaller quantities.
- Calcium from cheese consumption can contribute to the formation and maintenance of strong bones, the reduction of blood pressure and prevention of dental caries.

Abbreviations

ACE	Angiotensin I-converting enzyme
BP	Bioactive peptides
CLA	Conjugated linoleic acid
CVD	Cardiovascular disease
HDL	High-density lipoprotein
LDL	Low-density lipoprotein

Dictionary of terms

Atherogenic: a substance is atherogenic if it initiates or increases atherogenesis, the deposition of fatty substances in the artery walls.

BP: peptides (polymers of amino acid monomers) that have biological activity.

CLA: a mixture of positional and geometric isomers of linoleic acid (C18:2). CLA contains unsaturated double bonds.

Lipolytic enzymes: enzymes hydrolysing triacylglycerides to free fatty acids by a process known as lipolysis.

Proteolytic enzymes: also called proteinases, enzymes that breakdown long protein molecules into short peptide fragments and amino acids.

Vasoconstriction: narrowing of the blood vessels, decreasing the blood flow rate and hence increasing blood pressure.

Vasodilation: widening of the blood vessels, increasing blood flow rate and hence reducing blood pressure.

1.1 Introduction

Milk and dairy products, including cheese and yoghurts are important components of the diet and can play an essential role in meeting nutritional requirements. The consumption of cheese varies greatly from country to country (Table 1.1). Japan and Mexico have low per capita cheese consumption, 1.7 and 2.7 kg per capita, respectively. In contrast, Greece, France, Germany and Italy have the highest intakes (>20 kg per capita) (IDF, 2010).

Nowadays, there is a multitude of cheeses available on the market, varying in composition, texture, appearance and taste. Cheese is a nutritious food, being a rich source of essential nutrients such as fat, fatty acids, proteins, peptides, amino acids, vitamins and minerals. There has been a shift in cheese production from the optimisation of quality to optimising consumer benefit, hence the production and marketing of cheese as a functional food is becoming increasingly important (Walther *et al.*, 2008).

Table 1.1. Cheese consumption worldwide (reproduced with permission from International Dairy Federation, 2010).

Country	kg per capita		
	2007	2008	2009
EU27	16.4	16.5	16.6
UK	11.2	11.7	10.9
France	25.6	26.0	26.1
Germany	22.3	22.2	22.6
Italy	20.9	20.8	20.9
Ireland	7.1	6.1	6.1
Spain	7.4	7.5	8.2
Greece	29.2	31.2	31.1
USA	14.9	14.8	14.8
Japan	2.1	1.7	1.7
Australia	12.5	12.3	12.0
Mexico	2.5	2.4	2.7
Poland	10.7	10.7	10.8
Netherlands	21.5	20.5	21.0
Belgium	16.1	15.8	15.6
Austria	17.7	17.4	17.4

Interestingly, milk and dairy products such as cheese contain components that can affect health. Some aspects can affect health unfavourably; these include cholesterol, saturated fat and other non-fat components such as milk fat globule antigen membranes. In contrast, other components of dairy products can have benefits for health, such as calcium, CLA and vitamins B6 and B12 (Moss and Freed, 2003).

Therefore, the importance of cheese in diet and health is evident, given the consumption levels of this dairy product.

1.2 Cheese in diet and nutrition

1.2.1 Lipid

The milk composition and method used for cheese production affect the fat content of cheese, which has been shown to vary considerably depending on the type (Table 1.2). Firmness, mouth-feel, texture and flavour are affected by the fat to protein ratio of the milk (Guinee and McSweeney, 2006). Typically, cheese contains ~66% saturated, 30% monounsaturated and 4% polyunsaturated

Table 1.2. Composition of selected cheeses (per 100 g) (adapted from O'Brien and O'Connor, 2004).

Cheese type	Water (g)	Protein (g)	Fat (g)	Carbohydrate (g)	Cholesterol (mg)	Energy (kcal)	Energy (kJ)
Brie	48.6	19.2	26.9	Tr	100	319	1,323
Caerphilly	41.8	23.2	31.3	0.1	90	375	1,554
Camembert	50.7	20.9	23.7	Tr	75	297	1,232
Cheddar (normal)	36.0	25.5	34.4	0.1	100	412	1,708
Cheddar (reduced fat)	47.1	31.5	15.0	Tr	43	261	1,091
Cheshire	40.6	24.0	31.4	0.1	90	379	1,571
Cottage cheese	79.1	13.8	3.9	2.1	13	98	413
Cream cheese	45.5	3.1	47.4	Tr	95	439	1,807
Danish blue	45.3	20.1	29.6	Tr	75	347	1,437
Edam	43.8	26.0	25.4	Tr	80	333	1,382
Emmental	35.7	28.7	29.7	Tr	0	385	1,587
Feta	56.5	15.6	20.2	1.5	70	250	1,037
Fromage frais	77.9	6.8	7.1	5.7	25	113	469
Gouda	40.1	24.0	31.0	Tr	100	375	1,555
Gruyere	35.0	27.2	33.3	Tr	100	409	1,695
Mozzarella	49.8	25.1	21.0	Tr	65	289	1,204
Parmesan	18.4	39.4	32.7	Tr	100	452	1,880
Processed cheese[1]	45.7	20.8	27.0	0.9	85	330	1,367
Ricotta	72.1	9.4	11.0	2.0	50	144	599
Roquefort	41.3	19.7	32.9	Tr	90	375	1,552
Stilton	38.6	22.7	35.5	0.1	105	411	1,701

Tr = trace.

[1] variety not specified.

fatty acids and is hence a significant source of fat in the diet. The British Heart Foundation recommends the intake of foods high in saturated fat and cholesterol, such as cheese, to be limited (British Heart Foundation, 2009). This recommendation is based largely on evidence that increased saturated fatty acids intake can elevate total and LDL cholesterol, thereby increasing risk of coronary heart disease. Such guidelines have led to consumer demand for low-fat, low-cholesterol and low-sodium products and the cheese industry has responded accordingly, with the development of low-fat cheese products (Olson and Johnson, 1990).

Palmitic, myristic and stearic acids are the most common saturated fatty acids in cheese; oleic acid is the most common unsaturated fatty acid. While these fatty acids may increase total and LDL cholesterol, they can also increase anti-atherogenic HDL cholesterol. Given that a low ratio of LDL to HDL is associated with lower risk of CVD, cheese fatty acids can result in a favourable

cholesterol profile (by increasing the total HDL:cholesterol ratio) (Parodi, 2006). In fact, cheese consumption is positively associated with serum HDL cholesterol (Høstmark *et al.*, 2009). In addition, it has been reported that individual fatty acids have different effects on blood cholesterol levels (Hayes *et al.*, 1991; Rioux and Legrand, 2007). Palmitic acid (C16:0) is less cholesterolemic than lauric (C12:0) and myristic (C14:0) acids and slightly cholesterolemic compared to linoleic acid (Hayes *et al.*, 1991).

Trans fatty acids have been linked to an increased risk of coronary heart disease (Willett, 2006). In contrast however, ruminant *trans* fatty acids have shown a neutral or slightly negative correlation with coronary heart disease risk in both men and women (Chardigny *et al.*, 2008; Jakobsen *et al.*, 2008). CLA is a *trans* fatty acid present in milk and dairy products at concentrations ranging from 0.2 to 1.6 g/100 g fat (Fritsche and Steinhart, 1998; Lin *et al.*, 1995) and has become of interest due to its potential beneficial effect. In dairy products, the principal isomer of linoleic acid present in CLA is *cis*-9, *trans*-11-octadecadienoic acid, accounting for greater than 82% of total CLA (Chin *et al.*, 1992). CLA has been shown *in vitro* and in animal studies to have many potential bioactive effects, including anti-carcinogenic (Belury, 2002; Martinasso *et al.*, 2010), anti-atherogenic (Koba *et al.*, 2002) and anti-inflammatory (Martinasso *et al.*, 2010). However, these studies supporting CLA as potentially beneficial to health have not been confirmed by human epidemiological studies (Voorrips *et al.*, 2002) and substantiation with human clinical trials is needed (Wahle *et al.*, 2004).

The cholesterol content of cheese is in the range of 10-100 mg/100 g (Table 1.2). For many years, it has been advised that dietary cholesterol intake be minimized, as a measure to reduce risk of CVD. However, dietary cholesterol affects blood cholesterol level to a much lesser extent than saturated fat (Keys, 1984) and in particular, the body's response to the consumption of 100 mg/day of dietary cholesterol (equivalent to approximately 100 g of Cheddar cheese consumption) elevates plasma cholesterol only slightly (Parodi, 2004).

1.2.2 Protein

Cheese is an important source of protein, with concentration ranging from ~4 to 40% (Table 1.2). Proteins are amino acid polymers that serve a number of functions in the body, including regulation of cells, organs and tissues, with function being dependent on amino acids present in the protein (Nelson and Cox, 2005). Whey proteins represent only 2-3% of total protein in cheese, with the remainder being casein. The biological value of cheese protein is less than that of total milk protein, due to the passing of whey proteins into the whey during cheese production. However, some of the proteins in cheese are more digestible than proteins in milk, having been partially hydrolysed during cheese ripening (McSweeney, 2004).

Proteins in the body exist in a state of equilibrium, constantly being broken down or replaced. Since proteins are not stored in a non-functional form in the body (Lee and Nieman, 2007), protein consumption is essential for human health. Essential amino acids must be provided by the diet as they cannot be synthesised by the body (Bender and Millward, 2005). All the essential

amino acids, except methionine and cysteine, are provided by cheese in quantities in excess of the recommendations for both adults and children (Tome *et al.*, 2002).

BP in cheese have become of much interest. These intermediates of proteolysis have shown bioactivities including antimicrobial, anti-carcinogenic, anti-inflammatory, blood pressure lowering and cholesterol lowering (Bachmann *et al.,* 2003). It has been suggested that these BP could be liberated by digestive enzymes in the gastrointestinal tract (Korhonen and Pihlanto, 2006; Parrot *et al.*, 2003). BP containing proline and hydroxyproline can resist degradation by digestive enzymes, which is important as the bioactivity of these peptides is dependent on amino acid composition and their ability to reach a target site (Phelan *et al.*, 2009).

Some BP have the ability to inhibit ACE activity. ACE inhibitory peptides can modulate the immune and nervous systems (Meisel, 1993). Inhibition of ACE decreases angiotension 2 (a vasoconstrictory peptide) and increases bardykinin (a vasodilatory peptide) levels, hence reducing blood pressure and CVD risk (Fitzgerald and Murray, 2006). A number of cheeses have been reported to contain ACE inhibitory peptides, with strengths varying from 37% inhibition (Crescenza) to 82% inhibition (Italico) (Smacchi and Gobbetti, 1998). While the ACE inhibitory activity of a cheese increases with proteolysis, beyond a certain point of proteolysis there is a decrease in ACE inhibitory activity (Meisel *et al.*, 1997). A number of human studies have also reported an anti-hypertensive effect of milk derived BP (Mizuno *et al.*, 2005; Sano *et al.*, 2005). Milk and dairy products are the greatest sources of BP (Möller *et al.*, 2008) and hence have potential as ingredients in functional foods. Cheese manufacturers should control the maturation of cheese to ensure maximum benefit to consumer health.

1.2.3 Carbohydrate

Lactose, the principal carbohydrate in milk, is lost with the whey during cheese production. Any remaining lactose is further fermented into lactic acid and, therefore, ripened cheese is essentially lactose-free (Table 1.2). Hence lactose-intolerant people can consume most cheeses without ill effects. This is important given the high prevalence of lactose intolerance in adulthood, approximately 70% of the global population (Heyman, 2006).

1.2.4 Vitamins and minerals

Vitamins, excepting vitamin D, cannot be made in the body and hence consumption in the diet is essential. Depending on cheese type, the vitamin contents can vary greatly. Factors affecting fat content of cheese, including milk type and production method, also influence the concentration of fat-soluble vitamins in cheese. Most of the fat-soluble vitamins are retained in the cheese curd with the milk fat (Parodi, 2004), whereas the concentration of water-soluble vitamins is generally lower due to losses in the whey. Cheeses are good sources of vitamin B_{12}, vitamin A, niacin, riboflavin and folate (Table 1.3).

Table 1.3. Typical vitamin and mineral content and the percentage of reference nutrient intake (RNI) provided by one portion (50 g) of Cheddar cheese (adapted with permission from Foods Standards Agency, 2002).

Vitamin/Mineral	Content per portion	Males		Females	
		RNI	RNI (%)	RNI	RNI (%)
Vitamin A (RE) (μg)	194	700	28	600	32
Folate (μg)	15	200	8	200	8
Niacin (NE) (mg)	3.5	17	21	13	27
B_{12} (μg)	1.2	1.5	80	1.5	80
Vitamin D (μg)	0.3	n/a	n/a	n/a	n/a
Riboflavin (mg)	0.2	1.3	15	1.1	18
Calcium (mg)	370	700	53	700	53
Sodium (mg)	362	1,600	23	1,600	23
Phosphorus (mg)	252	550	46	500	46
Potassium (mg)	38	3,500	1	3,500	1
Zinc (mg)	2	9.5	21	7	30

NE = niacin equivalents; RE = retinol equivalents; RNI = reference nutrient intake.
n/a = not available.

The concentration of minerals found in cheese is dependent on a number of factors, including manufacturing procedure, method of coagulation and the amount of salt and calcium chloride added (Lucey and Fox, 1993). For example, rennet-coagulated cheeses contain substantially more calcium than acid-coagulated varieties (Renner, 1987). Calcium, phosphorus, sodium and chloride are predominant minerals in Cheddar cheese, but other trace elements including zinc and potassium are also found in smaller quantities (Table 1.3).

Cheese contains a high concentration of calcium (Table 1.3), which has a bioavailability equivalent to that of milk (Recker *et al.*, 1988), due to the formation of complexes between calcium and casein peptides that prevent precipitation of calcium in the intestine (Ebringer *et al.*, 2008). Calcium chloride is often added in cheese production to reduce rennet coagulation time, reduce the quantities of rennet required, increase gel firmness and increase calcium concentration of cheese (Kruif and Holt, 2006). Adequate intake of calcium is essential; if calcium intake is inadequate, the body will demineralise bone to maintain normal calcium levels in the blood (Theobald, 2005). Osteoporosis is micro-architectural deterioration of bone with a decrease in bone mass, and while many factors influence the aetiology of osteoporosis, it has been shown that low calcium intake during growth has consequences for bone health in later life (Matkovic *et al.*, 2005). Calcium from cheese consumption can contribute to the formation and maintenance of strong bones, the reduction of blood pressure (Griffith *et al.*, 1999) and contribute to prevention of dental caries (Aimutis, 2004).

The addition of salt to cheese has a major influence on cheese quality and is central to cheese production. It functions as a preservative (Adams and Moss, 2008), influences the structure and flavour of cheese by affecting activity of proteolytic and lipolytic enzymes (Fox *et al.*, 2000) and affects the rheology of the cheese (Fox *et al.*, 2004). The sodium levels in cheese vary greatly depending on the amounts added during cheesemaking. For example, Cream cheese and Cottage cheese contain the lowest amounts of sodium (300 and 380 mg/100 g respectively), whereas Roquefort and Feta cheeses contain the largest quantities (1,670 and 1,440 mg/100 g respectively) (Holland *et al.*, 1989). High salt intake and hypertension have been linked, but this is still being challenged, with some studies showing no correlation between sodium intake and blood pressure (Smith *et al.*, 1988). Obesity, alcohol, inactivity and low potassium intakes have been suggested to have a greater effect on blood pressure than high salt intakes (German *et al.*, 2009). Dietary guidelines for the general public usually suggest that salt intake should be restricted, but the negative attention cheese receives as a result of its salt content may be unwarranted when the bigger picture is considered. Cheese contributes only about 5-8% of total sodium intake, even in countries with a high sodium intake (Renner, 1987). Additionally, cheese is a rich source of calcium, which has been suggested to reduce blood pressure (Allender *et al.*, 1996; Bucher *et al.*, 1996). Thus, despite the salt concentration of cheese, it also contains other components that may mitigate against increases in blood pressure (calcium and BP).

1.3 Conclusion

Cheese has been consumed and enjoyed by humans for many thousands of years. The many varieties of cheese are excellent sources of proteins, lipids, minerals and vitamins which have a positive nutritional impact in the context of a balanced diet. In addition, cheese is a rich source of other constituents, such as BP and CLA, which may have beneficial health effects.

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2. The consumption of cheese in relation to dairy foods: a USA perspective

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Abstract

Consumption of cheese in the United States has grown over a long period of time. Cheese demand has been supplied by an industry that has developed technologies that facilitated production efficiency and fostered products of high and consistent quality. In addition to the changes within the production sector, changes in factors that affect cheese demand and how consumers obtain the food they desire have also occurred. Modern marketing and retailing of foods have helped create an away-from-home consuming public that has several alternatives for including cheese in the dining experience; the hamburger, pizza and Hispanic foods are prime examples. Also over time, there have been ongoing efforts to develop cheese products that meet the changing views as to what constitutes a healthy diet as exemplified by pursuit of low-fat and low-sodium products. It appears safe to say that cheese plays a major role in the economic situation of the dairy industry and in the nutritional profiles of the consuming public in the United States.

Keywords: milk products, nutrition, production

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Key facts

- USA cheese production and consumption have steadily grown over a relatively long period of time, each responding to changes in industry and market factors.
- USA cheese production evolved from an on-farm activity to a large-scale, technology intensive process beginning in the late 1850s; Americans' cheese consumption has steadily grown for almost as long.
- Milk and dairy products supply nutrients that play an essential role in a healthy diet and industry research has long focused on providing a wide variety of cheese products to supply that need.
- Most cheeses contain vitamin A and vitamin B2 and important minerals such as calcium, which is one of the main reasons most people consume cheese.
- Cheese and other dairy products are good sources of protein; a serving of cheese could provide anywhere from 2 to 30 grams of protein.

Summary points

- The cheese industry is an important economic component of the USA dairy industry that absorbs a large share of total milk production.
- Cheese consumption in the USA, relatively large by world-wide standards, has been upward trending for many years supported by an industry that has made high quality cheese available in many varieties at reasonable prices.
- Another key factor supporting rising USA cheese consumption has been the development of a significant 'away from home' food sector (such as restaurant chains) that features many 'cheese-heavy' alternatives.
- Milk offers a unique set of nutrients; those mainly supplied by cheese are calcium, phosphorus, zinc, protein and vitamins A and B2 (riboflavin).
- There has been much research focused on development cheeses that can make their contribution to nutritious diets greater and efforts to promote a healthy diet often include cheese.

Abbreviations

OTA	Other than American
S&U	Supply and use
USDA	United States Department of Agriculture

Dictionary of terms

Check-off program: a program paid for by producers who specify that a certain amount of the revenues received for their product is dedicated to the operation and objectives of the program.

Demand: the quantity of a good or service that economic agents are willing and able to purchase at a given price (Black *et al.*, 2009).

Mineral: a naturally occurring, homogeneous inorganic substance with a specific chemical composition and characteristic crystalline structure, color and hardness (Webster's II New Riverside University Dictionary, 1984).

Mom and Pop: a term often used to describe small, neighborhood retail outlets for all kinds of products.

Per capita: a measure of some value on a per person basis, for example the total national cheese consumption divided by the total population of a country.

Protein: any of a group of complex nitrogenous organic compounds of high molecular weight that have amino acids as their basic structural units and that are found in all living matter and are required for growth and repair of animal tissue (Webster's II New Riverside University Dictionary, 1984).

Supply: the amount of a good or service made available for sale (Black *et al.*, 2009).

Vitamin: any of various relatively complex organic substances found in plant and animal tissue and required in small quantities for controlling metabolic processes (Webster's II New Riverside University Dictionary, 1984).

2.1 Introduction

Cheese is manufactured in many countries around the world but few of them also have the levels of consumption seen in the United States. In 2010, the estimated per capita consumption in the United States was approximately 15.1 kg, down slightly from the previous year. Cheese consumption has grown at a relatively steady rate over time, a growth that has roots in the history of overall USA dairy industry developments. Many, but not all, of those developments occurred in the post-World War II period (Weimar and Blayney, 1994).

Cheese is one of a wide array of manufactured dairy products derived from the milk produced by many different animals. In the United States, Holstein cows provide the most milk by far. In 2010, just over 88.45 million metric tons of milk was produced. The milk must be handled carefully

since it can be a medium for disease transmission. Rapid collection and movement from the farm into fluid or manufactured product processing channels is the first step to ensuring safe milk and dairy products for the consuming public. Appropriate storage of processed or manufactured products and timely delivery to retail outlets and other end-product users are the next steps.

The underlying structure of the cheese consumption 'story' to follow is based on the basic economic framework of supply and demand (consumption). The focus is the development of the cheese industry and its increasing importance in the United States over time. An in-depth historical review of the cheese industry is well beyond our charge but some key features are identified that support cheese manufacturing and consumption (Weimar and Blayney, 1994; Zurborg, 2005). We also offer some general impressions of cheese as part of a healthy diet and the nutritional facets of cheese in that regard.

2.2 Cheese supply (production)

There can be no cheese without milk so the story of the USA cheese supply begins with a quick overview of milk production. Milk cows were brought to what would become the United States by early colonists, many from two countries with long traditions of cheese production, England and France. As early coastal towns grew and farms were pushed to more distant areas, transportation systems evolved to supply agricultural products, including milk, to the urbanizing areas. Westward expansion across the North American continent carried dairy farmers with it and ultimately milk was, and is now, produced in all of the states in the USA, but not uniformly so. First New York, then Wisconsin, and now California have been the largest milk producing State in the country.

Cheese was likely produced by the early colonists on farmsteads in the coastal towns but, as with milk production, cheese production was eventually pushed away from the towns to more distant areas. And, Westward expansion across the North American continent carried cheese production with it as well. The movement of cheese production to farmsteads in more rural areas, combined with the growing demand for cheese in the urbanizing coastal locations, led to a major change in production of cheese in the USA. By the late 1850s, cheese 'factories' were operating at several locations in the Northeastern parts of the United States and appeared in other States as well (Zurborg, 2005).

The factory system essentially began as a cooperative activity. Several milk producers would deliver their milk to a single location where it would be made into cheese. This approach had a twofold effect. First, by bringing milk to one cheese maker, it is likely that the quality of the cheese produced improved. Secondly, as larger quantities of milk were manufactured into cheese, economies of scale were achieved to reduce costs of the final product to consumers. As factories grew larger, technologies were developed that increased cheese output, improved its quality and made storage more available. From this early system, the modern larger-scale cheese factories of today that produce much of the cheese in the USA have evolved. Cheese production first was centered in the Northeast and New York, then in Wisconsin and the Upper Midwest, and

currently in several pockets of those two regions and other States as well. Cheese production is more concentrated in some areas than is milk production.

2.2.1 (Modern) Cheese production

Cheese production is a straightforward process with at least 4 major steps. First, the milk destined to become cheese is curdled by adding a coagulating agent. The resulting curds are stirred and, usually, heated. The watery remaining part of the milk (whey) is then drained off and the curds are collected and generally pressed into some form. The pressed curds are finally put through alternative processes to 'finish' the cheese. The process described here can be carried out on farms, by small manufacturers or by large companies/corporations, all of which occurs in the United States.

The annual total cheese production, excluding Cottage cheese, trend shown in Figure 2.1 generally mirrors the trend of milk production over time. We have shown two categories of cheese production, American and OTA, that are discussed in greater detail in the next section. From 1970 to 2010, total production grew from 0.998 billion to just over 4.717 billion kilograms, averaging about 3.8% growth per year. The OTA category has grown faster over the period, averaging almost 5.1% per year, while American production grew at an average of 2.7%. As the chart shows, production of OTA cheese surpassed American cheese production between 1985 and 1990. Analysis of the growth rates before and after 1987 shows an interesting finding about the 'switch in production'. Prior to 1987, both cheese categories were growing a good pace, 5.6 and 6.9%, respectively, per year. In the period following 1987, the annual averages have fallen to 1.8 and 4%, respectively. There is no immediately apparent reason for the changing production pattern that can be tied to a supply-side factor. The answer may be gleaned from our examination of the consumption of cheese that follows.

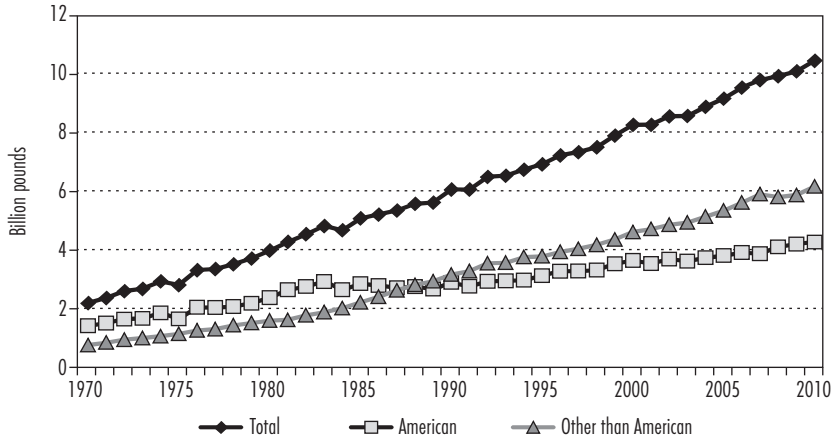

Figure 2.1. Cheese production (excluding Cottage cheese) from 1970 to 2010 (preliminary data of USDA).

2.3 Cheese demand (consumption)

As noted previously, the steady increase in USA cheese demand/consumption has been going on for many years. The cheese industry has evolved to produce the cheese demanded, but the demand (and by extension, consumption) has also been affected by several non-industry related historical factors (Davis *et al.*, 2011). The USDA has provided estimates of domestic cheese consumption in a S&U framework for many years. The S&U is an accounting framework that makes use of known quantity data in a formulaic procedure, ultimately based on the underlying equality of S&U commonly asserted in economic analyses, to derive a residual quantity that is consumption. Two aggregate categories have been defined: American and OTA cheeses that do not include Cottage cheese. The general S&U framework may be used to analyze any one specific cheese that might be of interest, but data constraints might be more prevalent in such cases.

The per capita estimates of total cheese consumption in Figure 2.2 range from 11.4 pounds (about 5 kg) in 1970 to 15.1 kg in 2010 with an average growth rate of 2.8% per year. The more interesting feature of the consumption situation is the growth paths of the two cheese types. As Figure 2.2 shows, between 1985 and 1990 there was a shift in per capita consumption patterns as the OTA varieties overtook American varieties and kept on growing as the American consumption seemed to level off (really slower growth). Can this change be explained by some market factors?

The American cheeses, Cheddar, Colby and Jack (sometimes referred to as Monterey Jack) were for many years the only types of cheese produced in large quantities in the USA. As a result, by default they also were the most consumed. Estimates of per capita American cheese consumption from 1970 to 2010 are shown in Figure 2.2. They range from 3.2 to 6 kg and grew at an average rate of about 1.7% per year. One of the early pioneers of the cheese industry in the United States,

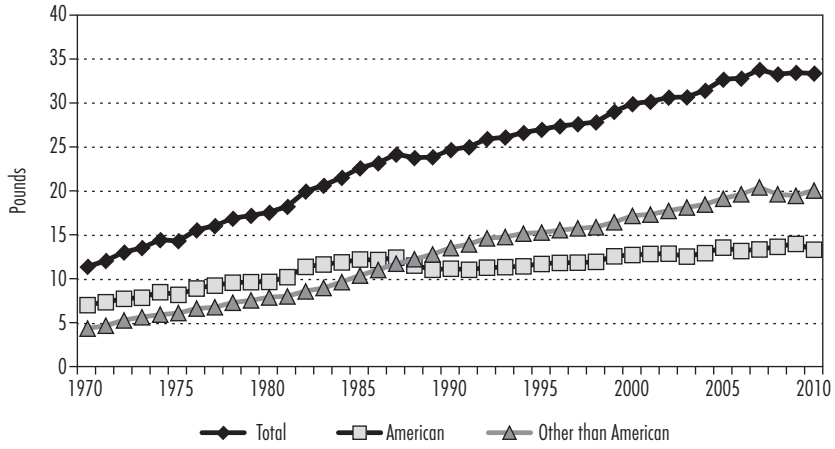

Figure 2.2. Annual per capital consumption of American and Other than American cheeses in the United States from 1970 to 2010 (preliminary data of USDA).

J.L. Kraft, came up with, what has been called by some, America's major contribution to global cheese production and consumption, processed cheese (using the American styles) and patented the manufacturing process in 1916 (Zurborg, 2005).

In the mid-1930s, growing production of Italian cheese varieties in the USA strengthened the cheese business and added new products to the growing array of cheese available to consumers. Production increases of other varieties followed, including Swiss and more recently, Hispanic cheese, which expanded cheese consumption options to consumers even further. Referring again to Figure 2.2, the OTA 2010 estimate of per capita consumption was about 9 kg, up from 2 kg in 1970. OTA cheese consumption growth has averaged about 3.9% per year over the period.

In addition to the technological production advances that made cheese a consistently high quality product available at reasonable prices, significant changes in how food is consumed in the United States have played an important role in food demand. There are at least three major factors to recognize on the demand side of the cheese S&U equation. First, the technological advancements in refrigeration that emerged for maintaining milk quality on the farm and for cheese production in the factories were extended to consumers in the form of affordable home refrigerators. As a result, food product quality could be maintained for longer periods of time at home.

Secondly, retail food outlets underwent a significant evolution as they grew from small Mom and Pop shops and stores to large, well stocked grocery stores, to the super stores of today. Dairy cases provided shoppers with a greater variety of products, again with refrigeration to maintain quality. Having a wide array of food products in a single place made food shopping more efficient.

Lastly, the potential location of an individual's or a family's food consumption was forever altered by the development of 'away from home' eating establishments; traditional sit down restaurants, casual dining venues and fast food chains. Away-from-home food consumption clearly has had impacts on all foods, but it may have been more important for cheese than for many others. Many foods initially unique to some specific locale have become ubiquitous around the world.

The hamburger is one of those foods. The first of the hamburger chains in the United States was White Castle (1916), followed by more readily recognized chains; McDonald's in 1940, Burger King in 1954 and Wendy's in 1969. In the context of cheese consumption the hamburger is not the key, it is the cheeseburger. The fast food experience is based on more than a single item such as the hamburger; a good example is pizza.

As consumption of Italian foods of all kinds grew, pizza was propelled into the fast food set available to American consumers. Again, the consumption experience is not necessarily focused solely on a single item like cheese. But, cheese was a traditional ingredient, mainly a topping, in some styles of pizza. In 1958, the first Pizza Hut opened in Wichita Kansas, to be followed by other chains such as Little Caesar's in 1959, Domino's in 1960, Papa John's in 1984, Godfather's Pizza in 1973 and Chucky Cheese in 1977. Over time, cheese used in pizza other than as a topping

have been developed; one example, first widely seen in 1995, is stuffing the crust with cheese. These actions increase the overall use of cheese.

Another development adding to overall cheese use and consumption is the increase in consumption of Hispanic foods, both at home and away from home that tend to be cheese 'heavy'. Fast food chains such as Taco Time, founded in 1959, Taco Bell, first opening in 1962 and Chipotle's casual dining restaurants that opened in 1993 are part of that trend.

USA dairy farmers themselves contribute to efforts to increase dairy product demand. Legislation passed in 1983 established a check-off program to fund research and promotion efforts focused on dairy products. Producers provided 15 cents per 45.3 kg of milk produced for the programs. The promotion efforts are perhaps better known; the 'milk mustache' and cheese advertising campaigns are two examples. However, the most recent report on the research and promotion programs to Congress (USDA, 2011) highlighted the following research efforts as important as well: the continued work to develop low-fat natural cheeses, low-fat processed cheeses, low-sodium cheeses that satisfy consumer expectations, and more Hispanic varieties. The research program is expected to help deliver new opportunities for dairy product usage and nutrient/health positioning.

2.4 Other dairy product consumption

The patterns of cheese consumption in the USA are interesting but there might be some question as to why we have spent the time and effort to discuss them. Part of the answer is the relationship among cheese and other dairy product consumption (Davis *et al.*, 2010). In Figure 2.3, we have shown the consumption of several manufactured dairy products, including the total cheese from 1975 to 2010.

The visible difference of the total cheese trend from the others illustrate the point to be made exactly. Since 1975, consumption of manufactured dairy products, except for cheese, have been relatively flat or have trended downward. Fluid milk is not included in the chart but the trend for it is even more markedly downward sloping than any of the products shown. What this set of relationships suggests is that consumers are increasing consumption of milk and dairy product components by consuming more cheese.

2.5 Cheese and its nutritional value

'Who moved my cheese?' is a book by Spencer Johnson (1998) that speaks about change and the different directions life takes when change occurs. The cheese in the book's title symbolizes something of value, a tangible good, or a highly desirable item. What is it about cheese that makes it such an item? Arguably, all food items are valuable/desirable to some degree; they are necessary for human life. Cheese is a product made from milk, a food product that has its own

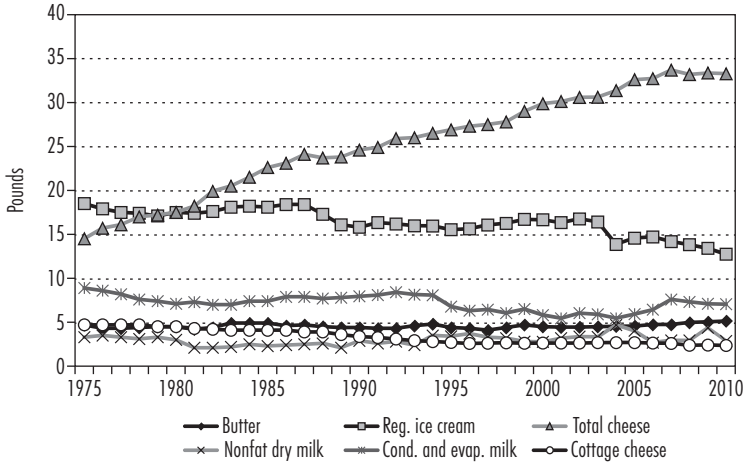

Figure 2.3. Annual per capita consumption of selected dairy products from 1975 to 2010 (preliminary data of USDA).

history and is one of the dairy products recommended as part of a program for a healthy diet and body (National Dairy Council; USDA and USA Department of Health and Human Services).

Cheese is both a separate food item and is a significant ingredient in many other foods. Consumers often say 'with cheese' when ordering hamburgers, submarine sandwiches and pizza. Depending on the type of milk used to make cheese, the nutrient contents found in any specific cheese variety may vary. The nutritional components of cheese; and some benefits of consuming cheese are explored in this section.

2.5.1 The nutritional value of cheese

Cheese is a highly nutritious dairy product that provides three major categories of nutrients: minerals, protein and vitamins (Miller *et al.*, 2007). USDA's MyPlate food guide recommends 3 cups of milk or the equivalent daily, with 14.2-28.4 g of natural cheese or 56.7 g of processed cheese (like American cheese) considered the equivalent of one cup. Almost half of dairy intake in America comes in the form of cheese.

Among the most important nutrients obtained from cheese are: the minerals calcium, phosphorus, zinc, protein, vitamin A and vitamin B2 (or riboflavin). We first consider the minerals, then protein and finally vitamins in the following sections.

2.5.2 The minerals

One of the reasons most people consume cheese or any other dairy product is to obtain the calcium. In 2006, 28% of the calcium in the American food supply came from cheese (Hiza and Bente,

2011). Of all the minerals found in the human body, calcium is the most abundant exceeding the amounts of other minerals. A person who receives the right amount of calcium is likely to have healthy bones and teeth and experience normal vascular contraction and vasodilatation, muscle function, nerve transmission, intracellular signaling and hormonal secretion (Office of Dietary Supplements). Calcium deficient individuals may experience problems such as muscle cramping, dry skin and brittle nails, bones fractures and breakage, and increased PMS symptom in women (Office of Dietary Supplements). Cheeses vary in calcium content; processed American cheese provides 323 mg per 56.7 g serving, while a hard, dry cheese like Romano or Parmesan cheese will have 452 mg per 14.2-28.4 g serving (USDA and US Department of Health and Human Services).

Cheese is also a major contributor of dietary phosphorus, the source of 11% of phosphorus in the American food supply. Combined with calcium, phosphorus helps construct bones and teeth and store energy. The levels of phosphorus found in cheese may vary depending on the product form. Swiss cheese is an example of a cheese type that contains high levels of phosphorus (USDA-ARS).

Zinc is a nutrient that is involved in wound healing, blood formation, maintaining a healthy immune system and growth and development of children. Meat, poultry, fish and grains are the largest sources of zinc in the food supply, but cheese contributes important amounts of zinc: 8% of the zinc in the American food supply (Hiza and Bente, 2011). One cheese variety that has a high percentage of zinc is Swiss (USDA-ARS). Men may appreciate zinc because it plays a serious role in the production of testosterone, which is the hormone that gives a man his muscularity. In women, zinc may be used to reduce PMS symptoms and help produce normal growth in babies. The lack of zinc can be connected to anorexia and bulimia, which are eating disorders.

2.5.3 Protein

Dairy products like cheese are also good sources of protein. In the early 1900s, cheese was being studied as a substitute for the proteins from meat and other products (USDA, 1911). Dietary proteins supply amino acids used by the body to build tissues and are necessary for growth and development of children and for maintenance of well-being of adults. Protein is also needed to create enzymes, hormones, antibodies and other physiological compounds, maintaining normal metabolism and health, and fighting infection (Miller *et al.*, 2007). It is a complete source of protein; that is, all of the essential amino acids are found in cheese. The protein found in cheese (known as casein) supplies the body with the amino acids that are essential for building muscles. Cheese is the main dairy food source of protein, contributing 9% of protein in the USA food supply (Hiza and Bente, 2011). Many individuals use cheese as a meat alternate, providing the main protein source in their meals. It can be used as a meat alternate in the USDA's national school lunch program. Different levels of protein are found in various types of cheese. A serving of cheese could provide anywhere from 2 to 30 grams of protein (National Dairy Council). The highest amounts of protein are found in dry hard cheeses like parmesan (USDA-ARS).

2.5.4 The vitamins

There are two essential vitamins that are found in most cheeses: they are vitamin A and vitamin B2. Vitamin A is best known for promoting good vision. Retinol, which is the active form of Vitamin A, is produced by animals (Sarubin and Thomson, 2007). Retinol produces dark-colored dyes in the retina of the eye. In addition to promoting good vision, Vitamin A helps assist in the development of healthy mucus membrane, strong teeth, soft skin and a well structured body (Sarubin and Thomson, 2007). Cheese supplies 9% of the vitamin A in the USA food supply. A cheese variety that is high in vitamin A is Cheddar cheese (USDA-ARS).

Vitamin B2 is a B complex vitamin that is essential to energy metabolism and is an antioxidant that reduces free radicals in the body that can damage cells, making them more vulnerable to illness (University of Maryland Medical Center). Overall, dairy products provide 27% of vitamin B in the USA food supply. Most of that comes from milk; cheese by itself contributes 4% of vitamin B in the USA food supply. Of the different types of cheese products, roquefort cheese provides a high percentage of vitamin B (USDA-ARS).

2.6 What are the benefits of consuming cheese?

While cheese provides protein, essential minerals and vitamins, it is important to choose cheeses that are not excessive in saturated fats or sodium. The USDA MYPlate food guide recommends low-fat cheeses (MyPlate, 2012). Low-fat dairy products come with fewer calories but are often higher in calcium. The market has responded and low-fat versions of many traditionally popular cheeses are now widely available.

Disclaimer

The views expressed here are those of the authors, and may not be attributed to the Economic Research Service or the US Department of Agriculture.

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3. Sensory characteristics of cheese

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Abstract

Sensory characteristics of cheeses constitute probably the most important attributes driving consumers' choice. Prior to and during ingestion itself, the consumer can perceive several sensory features of cheese, which are generally grouped under appearance, flavour and texture. All such attributes determine the eating quality of cheeses and consequently their eventual acceptability. There is a wide diversity of cheese types worldwide, each one with a unique sensory profile. It reflects the characteristics of the milk feedstock, the cheesemaking conditions and the physical and chemical changes throughout ripening. Consumer-driven demand of healthy foods has meanwhile led to development of food products with improved nutritional characteristics, including cheeses with low fat content and enriched in specific fatty acids. However, manufacture of these cheeses implies modulation of chemical composition of the milk or curd, which may hamper the expected sensory profile. In fact, cheeses with low fat content usually show atypical sensory attributes; conversely, enrichment in conjugated linoleic acid isomers and *n*-3 polyunsaturated fatty acids does not bring about significant sensory changes, thus unfolding the technical and market feasibility of cheeses with beneficial health features. The chief aim of this chapter is to briefly review the human perception of cheese sensory characteristics and discuss the impact of reducing fat content and increasing preferentially the levels of health-beneficial fatty acids upon the sensory profile of the final cheese.

Keywords: appearance, flavour, low-fat cheese, polyunsaturated fatty acids-enriched cheese, texture

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Key facts

- α-linolenic acid (18:3*n*-3) is the precursor of *n*-3 long chain polyunsaturated fatty acids (LC-PUFA), such as eicosapentaenoic (EPA, 20:5*n*-3), docosapentaenoic (DPA, 22:5*n*-3,) and docosahexaenoic acid (DHA, 22:6*n*-3).
- The health benefits of *n*-3 PUFA are mostly associated with dietary intake of *n*-3 LC- PUFA, while the principal role of α-linolenic acid seems to be as precursor of *n*-3 LC-PUFA.
- α-linolenic acid is present chiefly in the plant kingdom, while fish and fish oil are the richest sources of EPA, DPA and DHA.
- Recent nutrient intake guidelines from WHO/FAO recommend that *n*-3 PUFA should represent 0.5-2% of total energy intake.
- The minimum dietary intake requirement of α-linolenic acid for adults is 0.5% of diet energy and adequate intake of EPA plus DHA should range in 250-2,000 mg/day.
- Putative conjugated linoleic acid isomers (CLA) health benefits were revealed by Pariza *et al.* (1979) who discovered that ground beef contains an anticarcinogenic factor consisting of conjugated isomers of linoleic acid.
- CLA are naturally produced during ruminal biohydrogenation of dietary unsaturated FA and by endogenous conversion of octadecenoic isomers in the tissues and mammary gland.
- Ruminant fats are naturally rich in CLA and constitute the main source of these isomers in the human diet.
- The predominant natural CLA isomer in humans and animals is rumenic acid (18:2 *cis*-9, *trans*-11).
- Optimal dietary intake in humans has not yet been established, but, based on animal studies, a daily consumption of 0.8-3.0 g CLA may have a significant health benefit to humans.

Summary points

- This chapter focuses on the sensory characteristics of cheese that determine eating quality and thus consumer acceptability.
- Sensory features of cheese are generally categorised as appearance, texture and flavour, and are perceived by the human senses prior to and during ingestion.
- Throughout cheesemaking and chiefly during ripening, several physicochemical changes occur in cheese that are responsible for their unique sensory properties.
- Cheeses with reduced fat content are hardly preferred by the consumer, owing to atypical sensory characteristics when compared with their full-fat counterparts.
- Cheese enrichment in conjugated linoleic acid and/or *n*-3 polyunsaturated fatty acids does not apparently affect their sensory features and consumer acceptability at large.

Abbreviations

CLA	Conjugated linoleic acid
FA	Fatty acids
PUFA	Polyunsaturated fatty acids

Dictionary of terms

Bioactive peptide: an amino acid sequence (with a variable size) that is able to play beneficial physiological roles upon human health, such as antithrombotic, antihypertensive, antimicrobial and immunomodulatory effects.

Cheese appearance: cheese characteristics assessed visually before consumption and includes such properties as colour, uniformity, visual texture, size and shape, as well as packaging attributes.

Cheese flavour: results from the combination of several volatile and non-volatile compounds released from cheese that stimulate consumers' olfactory, taste and chemesthesis systems.

Cheese texture: physical properties of cheese that are perceived by consumers via a combination of touch, vision and hearing.

CLA: a collective term that refers to a mixture of positional and geometric isomers of linoleic acid, in which the double bonds are conjugated.

Free-, low- and reduced-fat cheese: in accordance with European Regulation (EC No. 1924/2006), fat-free and low-fat cheese refer to a cheese containing no more than 0.5 and 3 g of fat per 100 g, respectively, and reduced-fat cheese refers to a cheese with at least 30% fat reduction relative to its full-fat counterpart.

Glycolysis in cheese: fermentation of residual lactose retained in the curd to lactic acid, effected by lactic acid bacteria (adventitious or deliberately added to milk).

Lipolysis in cheese: hydrolysis of the ester bonds linking fatty acid residues to glycerol in triacylglycerols, effected by lipases, thus releasing free FA, and sequentially di- and monoacylglycerols.

***n*-3 PUFA:** a family of PUFA that have the first double bond at the third carbon from the terminal methyl group. It includes α-linoleic acid (18:3*n*-3) and several long chain PUFA, such as eicosapentaenoic (20:5*n*-3), docosapentaenoic (22:5*n*-3) and docosahexaenoic (22:6*n*-3) acid.

Proteolysis in cheese: regarded as the most complex and in most varieties also the chief biochemical phenomenon throughout cheese ripening. It basically consists in hydrolysis of casein molecules into large- and medium-size peptides, which can be further degraded to small peptides and eventually to free amino acids.

3.1 Introduction

Cheese is a major dairy product, which is strongly appreciated by consumers at large, not only owing to its outstanding nutritional value but also due to the unusual complexity and variety of

its sensory attributes. Cheese sensory features are characteristics perceived by the human senses prior to and during ingestion, encompassing observation, manipulation, smelling and tasting, which, as a whole, are generally classified under appearance, flavour and texture (Delahunty and Drake, 2004). This set of attributes determines the eating quality of cheeses and thus the associated consumer's acceptability. The aforementioned quality is the result of an integrated response by the human senses, which is stimulated by sensory inputs, while being conditioned by several individual's factors, e.g. sensory acuity, past experience, actual expectation and cultural and environmental background (Delahunty and Drake, 2004). Owing to their importance toward intended (and eventual) acceptability of cheeses, their sensory characteristics have attracted a great deal of attention by researchers, who consequently produced extensive literature on this topic. Unfortunately, the utilization of distinct descriptors by different authors regarding sensory analysis has made it difficult to compare the sensory features of the various cheese types, as well as to clearly define the sensory profile of any given cheese variety.

Although cheeses are manufactured from a narrow range of raw materials (i.e. ovine, caprine, bovine and buffalo milks) and using essentially similar technological protocols (Fox *et al.*, 2000), a great many cheeses exist worldwide that are associated with distinct (and original) sensory properties. Such sensory features are a consequence of chemical and microbiological characteristics of feedstock milk, specific steps along cheesemaking and environmental patterns prevailing throughout ripening. The characteristics of milk depend on numerous factors linked to the animal source, such as species, breed, stage of lactation, physiological status and diet (Coulon *et al.*, 2004). The cheesemaking conditions then determine the pattern and extent of various biochemical phenomena, which, in view of their variability, contribute to develop diverse, yet unique sensory features. On the other hand, the flavour of freshly-made curd is rather bland and quite difficult to differentiate among cheese varieties; hence, it is during ripening that most sensory characteristics actually develop (McSweeney and Sousa, 2000). The major underlying biochemical pathways during ripening are glycolysis of residual lactose and catabolism of lactate, catabolism of citrate, lipolysis, catabolism of free FA, proteolysis and catabolism of amino acids, which, as a whole, are responsible for the unique physicochemical changes playing a role upon generation of flavour compounds (McSweeney, 2004). The general pathways of biochemistry phenomena involved in the production of flavour compounds in cheeses during ripening are represented in Figure 3.1.

Furthermore, consumers have become increasingly aware of the relationships between diet and health. This triggered a growing demand for food products with enhanced nutritional value. To meet said trend, several studies have been developed that are aimed at improving the nutritional value of cheeses and their positive impact upon health, particularly encompassing low fat content and enrichment in health-beneficial FA. However, such deliberate alterations in cheese composition also affect its typical sensory properties, so they may compromise eventual acceptability by consumers.

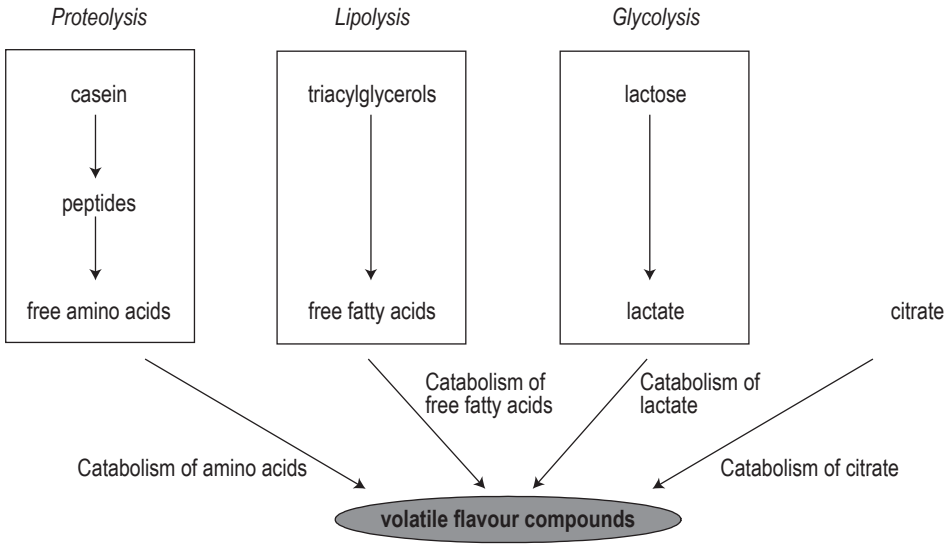

Figure 3.1. Biochemical pathways leading to formation of flavour compounds in cheeses during ripening (adapted from McSweeney, 2004).

Therefore, this chapter aims at reviewing the human perception of cheese sensory characteristics and discussing the impact of improving the nutritional value of cheese upon such sensory characteristics, with a focus on reduction of fat content and modulation of FA profile.

3.2 Human perception of sensory characteristics of cheese

The sensory characteristics of a cheese are the most important quality criterion underlying one's choice as consumer. Prior to and during consumption, those sensory characteristics, generally categorized as appearance, texture and flavour, are duly perceived and induce specific responses in consumers that determine eventual acceptance (or rejection) of a given cheese. Appearance is generally the first sensory characteristic perceived by a consumer, who visually assesses a cheese in a quick and non-invasive way before starting the eating process (Ross, 2009). Cheese appearance includes a number of characteristics, e.g. colour, uniformity, presence of eyes (or holes) and moulds, type of rind and visual texture (Delahunty and Drake, 2004). Moreover, the size, shape and packaging attributes are also a part of the marketing image and thus classified as appearance characteristics (Murray and Delahunty, 2000). Each cheese type has specific appearance properties; for instance Gouda, Edam and Emmental cheeses exhibit eyes, Camembert has white surface moulds and Roquefort contains dark internal moulds. Hence, consumers seek in each cheese variety those appearance properties that are typical thereof; so their absence often determines rejection. Moreover, said appearance properties create sensory expectations, relating to some attributes that will become accessible only later upon eating (Delahunty and Drake, 2004).

Cheese texture is a composite sensory attribute that results from a combination of physical properties as size, shape and number and conformation of structural elements and is experienced via a combination of sight, touch and even hearing (Delahunty and Drake, 2004; Pinho *et al.*, 2004). Perception of cheese texture starts before consumption, by looking at the cheese surface and at its cut, and continues during ingestion as tactile sensations in the mouth (Ross, 2009). Cheese texture characteristics have been classically described using such terms as adhesiveness, cohesiveness, crumbliness, firmness and rubberiness (Delahunty and Drake, 2004).

Cheese flavour results from perception of a combination of several sapid and aroma compounds, prior to consumption when consumer smells the cheese, and during consumption when compounds are released by mastication, and accordingly stimulate the olfactory, taste and chemesthesis systems (Delahunty and Drake, 2004). Recall that the smell/aroma of a food results from nasal and retronasal perception of the volatile compounds released therefrom (Pripp *et al.*, 2006). A very many volatile compounds have been identified in cheeses, including FA, esters, ketones, alcohols, aldehydes, amines, amides, phenols and sulphur compounds (McSweeney and Sousa, 2000). On the other hand, taste is perceived in the oral cavity, where non-volatile compounds lead to five distinctive taste qualities: sweet, salty, sour, bitter and umami (Pripp *et al.*, 2006). Compounds such as sodium chloride and other mineral salts of potassium, calcium and magnesium contribute to salty taste (Engel *et al.*, 2000) and hydrophobic peptides and some free amino acids to bitterness (McSweeney and Sousa, 2000), whereas glutamic acid is responsible for umami taste (Drake *et al.*, 2007). In addition to smell and taste, another aspect of flavour is chemesthesis, which refers to the sensory system responsible for chemical irritant detection (Delahunty and Drake, 2004). Many of the known chemical irritants are indeed perceived via stimulation of the trigeminal nerve ending in the mouth, nose or eyes (Lawless and Heymann, 2010). Examples of this type of perception in cheese are pungency, prickle/bite and sharpness in mature Cheddar cheese (Delahunty and Drake, 2004).

The component balance theory, originally proposed by Mulder (1952), suggests that cheese flavour results from a balance of numerous compounds rather than the independent effect of a reduced number of single components, which, when present at certain levels and in the correct proportions, create the typical flavour of every cheese variety (Collins *et al.*, 2003). This means that disproportionate concentrations of certain flavour compounds may lead to undesirable flavours, also termed off-flavours (Fox *et al.*, 2000).

3.3 Sensory characteristics of cheese with improved nutritional value

Cheese has suffered from a negative health image, mainly due to association of fat, saturated FA, cholesterol and salt content to increased risk of cardiovascular diseases (Ash and Wilbey, 2010). However, cheeses are good dietary sources of several healthy nutrients, such as some lipids (e.g. PUFA and CLA), proteins (e.g. bioactive peptides), vitamins and minerals. Consequently, many studies have been carried out aimed at improving the nutritional performance of cheeses;