J. Korean Dairy Technol. Sci. 24(2) : 25~29, 2006

Camembert Cheese: Technology, Microbiology, Biochemistry

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I. Introduction

Surface mould ripened soft cheeses such as Camembert are characterized by the presence of a felt-like coating of white mycelia due to the growth of *Penicillium camemberti* at the surface. The presence of this mould gives these cheeses a different appearance, as well as a typical aroma and taste. It also lead to a more complex ripening than in other varieties of cheese with simple flora. Theses cheeses are becoming increasingly popular with consumer and there is an increasing demand for them.

II. Different Worldwide Productions

Camembert is a typical example of surface mould-ripened cheeses. It is a cheese with a soft consistency and a flat cylindrical form, approximately 11 cm in diameter and 2.5 cm thick. Camembert originates from the Normandy region of France. It is believed by some to date from about 1790 and has been attributed to a farmer, called Marie Harel, from the small village of Camembert. Though first made on farms, Camembert has been made by industrial companies since the beginning of the 20th Century. The manufacture of surface mould-ripened cheeses became progressively widespread in France, followed by other European countries (Table 1).

Camembert manufactured in Normandy and meeting certain manufacturing norms benefits from a label of origin. Conversely, the name "Camembert" is not protected and is used for cheeses manufactured elsewhere in France or in other countries. The other principal cheeses with a surface mould are Brie and Coulommier. Products also exist which are marketed with trade names. Brie from Meaux and from Melun are characterised by their large diameter (35 and 27 cm, respectively) and also possess a label of origin. In 2002, France produced approximately 270,000 tonnes/year of Camembert, Brie and Coulommier. The total production of surface mould-ripened cheeses is a little greater as products marketed under a trade name should be added. Germany produced (in 1999) about 20,000 tonnes of Camembert-type cheeses. Denmark also produces significant quantities. Many other countries around the world, including USA, Argentina, New Zealand and several European countries produce cheeses with a surface mould, but in limited amounts. Without it being possible to give precise figures, it can reasonably be estimated that in 1999, surface mould-ripened cheeses represented about 8 % of the total production of cheese in the 15 countries of the western europe and about 2- % of worldwide production.

Table 1. Surface mould-ripened cheeses production

France (2002): 270,000 tonnes
Camembert: 122,000 t (13,000 t aoc)
Brie: 158,000 t (8,000 t aoc)
Germany (1999): 20,000 t
Camembert: 18,000 t
Brie: 2,000 t
Denmark, USA, Argentina, New Zealand, etc...

III. Technology

Traditional Camembert is made from raw milk having undergone maturation by the addition of a mesophilic starter

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Table 2. Traditional Camembert technology

Raw milk maturation	
	Addition of mesophilic starters (0.1-0.2%)
	Overnight at 12-15℃ (pH 6.4)
Coagulation	
	Temperature: 30-32℃
	rennet: (15-20 ml/100L)
Draining	
	Moulding after ~ 1h30
	Draining for 20h (pH ~ 4.7)
Ripening	
	3 weeks at 11-13℃, RH 90-95%
	Packaging and storing

(Table 2).

The pH at renneting is approximately 6.2 and the coagulation time is between 30 and 45 minutes. The moulding of the curd is undertaken by means of a ladle (5 ladles per mould) either manually or using a robot. Draining takes place spontaneously at 26～28℃ during the first hours, then at a progressive reduction in temperature approaching approximately 20℃ by the end of draining. A curd with a low mineral content is thus obtained, with a pH of 4.6～4.7 at the end of draining. Dry-salting is performed and maturation takes place over a minimum period of 21 days in cellars at 11～13℃ and 90 % relative humidity.

Camembert without label of origin, is manufactured with raw or pasteurised milk. Coagulation generally takes place continuously in Alpma-type production lines. The coagulum is cut up into cubes of 2～2.5 cm per side and the moulding (manual or automated, in multi-moulds) takes place 30 to 50 minutes after cutting.

Distribution requirements, as well as market demands, have led to a modification in previous technology and have created new types of surface mould-ripened cheeses. The latter, called soluble or stabilised cheeses, are often sold under trade names. Pasteurised milk is renneted after a very short maturation period. The coagulum is cut into cubes, 0.7～1 cm in size, and stirring and washing of the curd are undertaken. A part of the whey is drawn off before moulding. The starter used consists of thermophilic streptococci or a mixture of streptococci and lactococci. The curd obtained is much less acidic than for Camembert. These cheeses rapidly acquire a soft texture giving them a mature appearance, their taste is milder than that of traditional Camembert and their storage properties is improved.

Ⅳ. Microbial Flora

The composition of the flora of Camembert manufactured from raw milk is complex and evolves extensively during ripening (Table 3).

Yeasts become established on the surface of the cheese from the first day after manufacture, quickly forming a dense layer. The main species present are *Klyuveromyces lactis*, *Saccharomyces cerevisiae* and *Debaromyces hanseni*. The yeast-like mould *Geotrichum candidum* grows together with yeasts but its growth is limited due to salting. Six or seven days after curd making, the growth of *P. camemberti* becomes visible to the naked eye and is apparent has a light felt-like white coating over the whole surface of the cheese. This felt-like coating, the density of which depends on the strains present, becomes fully developed after 9～10 days. By metabolizing lactic acid, *P. camemberti* induces a marked increase in surface pH, which enables the growth of acid sensitive bacteria on the surface. The latter consists of micrococci and corynebacteria (*Brevibacterium linens* is present at high number). The presence of these corynebacteria is revealed by the appearance of yellow-orange areas on the surface of the mature cheese. In the interior of the cheese, the flora consist essentially of lactococci. Some yeasts develop but they remain at a much lower number than at the surface. The series of surface microorganisms is necessary for full development of the aroma of traditional

Table 3. Flora of Camembert cheese

Starter:	
	Lactococcus lactis
Yeasts:	
	Kluyveromyces
	Debaryomyces
Moulds:	
	Geotrichum candidum
	Penicillium camemberti
Surface bacteria:	
	Corynebacteria: (*brevibacterium, Arthrobacter*)
	Micrococci

Camembert. In the case of pasteurised milk Camembert, the flora is much less complex and the aroma of the product is much less intense. In order to obtain a more aromatic product, many manufacturers add selected strains of yeasts, *G. candidum* and corynebacteria to the milk, as well as the lactic fermenting starter and *P. camemberti* spores.

V. Principal Biochemical Changes during Ripening

The major processes of maturation (glycolysis, lipolysis and proteolysis) are clearly marked by the important enzymatic potential of *P. camemberti* (Table 4).

Form the end of curd making in Camembert chesse, the surface fungal flora (i.e. yeasts, *Geotrichum* and *Penicillium* in particular) use lactic acid for their growth. There is, as a result, a marked increase in the external pH and an internal migration of lactate toward the surface of the cheese. In traditional Camembert, the surface pH increases steadily to approach 7.0 at the end of the maturation; the increase is lower in the interior where the final pH is about 5.5～6.0 (Table 5).

This drastic pH change has a marked effect on the maturation process and is indicated by:

- The development on the surface of an acid-sensitive flora, consisting of corynebacteria and micrococci contributing to the final flavour of the product.
- An increase in enzymatic activities of microbial origin, the optimum pH of which is very often closer to neutrality than in the acid zone.
- Calcium phosphate is insoluble at neutral pH and precipitates at the surface.
- Finally, and as discussed below, this increase in pH markedly modifies the rheological properties and gives rise to a softer curd.

The degree of lipolysis in Camembert reaches 3～6% and sometimes 6～10% in well matured traditional products (Table 6).

This lipolysis is mainly due to the synthesis of an extracellular alkaline lipase by *P. camemberti* which remains very active at pH 6.0. Extracellular lipases of *G. candidum* also play a role (Table 7).

Proteolysis in Camembert is significant compared to other cheeses, such as pressed varieties. At the periphery of mature Camembert, soluble nitrogen represents close to 35% of the total nitrogen (Table 8).

Ammonia, resulting from the deamination of free amino

Table 4. Glycolysis

Growth of yeasts, *Geotrichum* and *Penicillium* ➔ pH surface: 4.7 ➔ 7.0

Four main consequences:

- Growth of bacterial surface flora
- Increase of enzymes activities
- Calcium phosphate migration
- Texture

Table 5. Evolution of pH during maturation

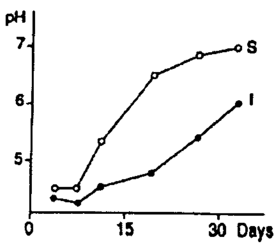

Table 6. Lipolysis

Cheese variety	*Meq acid/100 g of fat*
Gouda	6.14 ± 0.50
Camembert	22.27 ± 13.73
Danish Blue	45.34 ± 14.93

Mean values of six samples

Table 7. Lipases in Camembert cheese

Penicillium camemberti
- optimal pH: 9.0
- 50% of activity at pH 6.0

Geotrichum candidum
- optimal pH: 6.5
- preference for oleic acid

Table 8. Proteolysis

Cheese variety	*pH 4.6 soluble nitrogen*	*NPN*	*amino acids*
Camembert	32	20	8
Blue Cheese	50	30	10
Saint-Paulin	18	10	3-4
Comté	31	23	10

% total nitrogen

acids, reaches significant concentration in the case of traditional well-matured products. This extensive degradation of caseins is in the main, due to the high proteolytic activities of *P. camemberti*. This mould releases in the curd an extracellular acid protease (optimum pH 3.5) and an extracellular metalloprotease (optimum pH 6.0) as well as extracellular exopeptidases responsible for the production of high amounts of free amino acids (Table 9).

Ⅵ. Development of Aroma

The presence of *P.camemberti* in Camembert-type cheeses confers upon them a typical aroma which plays a major role in their uniqueness. The differences in aroma between traditional cheeses manufactured from raw milk and cheeses made with pasteurised milk, having a less complex flora, shows that other constituent of the flora (yeasts, *Geotrichum*, surface bacterial flora) are necessary to obtain a final rich and typical aroma. There are many components in the volatile fraction of Camembert and they belong to very different families of compounds (Table 10).

Not all produce an odour, but the aromatic sensation and

Table 9. Proteolytic system of *Penicillium camemberti*

Aspartyl proteinase (opt. pH: 3.5)
Metalloproteinase (opt.pH:6.0)
Acid carboxypeptidase (opt. pH: 3.5)
Alcaline aminopeptidase (opt. pH:8.0)

Table 10. Flavour: alcohols

Compound	*Flavour note*	*Threshold (ppm)*	*Quantity (ppm) in Camembert*	*Origin*
Oct-1-en-3-ol	Mushroom	0.1	+ to +++	fatty acids *P. camemberti*
Phenylethanol	Rose, floral	9.1	1.1	Phenylalanine Yeasts

the role of certain compounds have been clearly identified (Table 11).

Oct-1-en-3-ol gives rise to a characteristic mushroom like sensation. Its perception threshold is low (0.01mg/kg) and its excessive presence constitute a defect. This key compound is produced rather late, by the secondary metabolism of. *P. camemberti* probably from linoleic and linolenic acids. Sulphur compounds have a marked influence on the aroma of traditional Camembert to which it imparts a flavour of garlic and cabbage to matured cheeses (Table 12).

Methanethiol obtain from enzymatic cleavage between the carbon and the sulphur atom of methionine, is a highly reactive compound which condense spontaneously to form dimethyldisulphide and dimethyltrisulphide and is also

Table 11. Flavour: Sulfur compounds

Compound	*Flavour note*	*Threshold (ppb)*	*Origin*
Methanethiol	cabbage	2	methionine *Brevibacterium* *Geotrichum* *Penicillium*
Dimethyldisulfide	garlic, cabbage	9 to 170	methionine
2,3-Dithiopentane	garlic	6	methionine
Methylthioacetate	cauliflower	5	methionine

Table 12. Flavour: Free fatty acids

Compound	*Flavour note*	*Threshold (ppm)*	*Quantity (ppm) in Camembert*	*Origin*
Propionic acid	pungent	40	35 to 137	Lactose
Butyric acid	Rancid, cheesy	0,3 to 7	35 to 206	triglycerides
Isovaleric acid	Rotten fruit,feet	0,07	100	Leucine

the precursor of other sulphur compounds. *Penicillium camemberti* and *G. candidum* and the coryneform bacteria are capable of converting methionine to methanethiol. *Brevibacterium linens* in particular is considered to be the main organism responsible for the production of sulphur compounds, but it appears that certain strains of *G. candidum* also have a marked potential. Alcohols and esters also add a floral or fruity flavour to Camembert. Phenylethanol and its esters (acetate and propanoate) add a floral sensation. These compounds, produced by yeast at the beginning of the maturation process, are present at concentration just below their nasal detection threshold but are detectable by the most sensitive cheese tasting specialists. Finally, ammonia, obtained from the deamination of amino acids, is also one of the important constituents of the aroma of traditional Camembert (Table 13).

Ⅶ. Development of Texture

The texture of traditional Camembert undergoes rapid changes during maturatiom and is an important factor in characterizing it (Table 14).

The outer region becomes soft while the centre remains firmer. This difference is visible to the naked eye by studying a section of cheese; the periphery of the cheese appears to be homogeneous and smooth while the central region retains the appearance of a lactic curd. This radical change in texture is due mainly to changes in pH during maturation. After manufacture, a firm and brittle curd is obtain and the is closed to 4.7. As mentioned previously; the development of the fungal flora, *P. camemberti* in particular, leads to an increase ein the surface pH and the establishment of a pH gradient from the center to the surface of the cheese. The production of ammonia by surface flora also contributes to the development of this gradient. The caseins, which form the protein network responsible for the structure of the cheese, are initially very close to their isoelectric point. During the increase in the peripherical pH their net charge and their solubility increase. Protein-protein and protein-water interactions are modified and the texture of the cheese becomes softer. This softening becomes particularly pronounced when the pH exceed 5.2. Note that in the manufacture of surface mould-ripened "stabilized" cheeses, acidification is more limited than in the case of Camembert in order to obtain a postproduction pH of 5.2. These cheeses very rapidly acquire a soft and homogeneous texture in the centre, which confer on them a mature appearance. Manufactured from pasteurized milk, they have a milder taste and a longer self-life than raw milk cheeses.

Table 13. Flavour: Methyl ketones

Compound	Flavour note	Threshold (ppm)	quantity (ppm) in Camembert	Origin
Heptan-2-one	Blue cheese	1.3 to 3	+ to +++	fatty acids *P. camemberti*
Nonan-2-one	Fruity, musty	1.7	++ to +++	fatty acids *P. camemberti*
Oct-1-en-3-one	Mushroom	0.005		fatty acids *P. camemberti*

Table 14. Development of texture

Softening of the outer part of Camembert is due to the pH gradient
Three conditions are necessary:
A high water content
A pH higher than ~ 5.2
Cleavage of αs1-casein (Phe23-Phe24)

Ⅷ. References

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