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SWISS CHEESE

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SWISS CHEESE

1 Introduction

Swiss-type cheeses were originally manufactured in the Emmen valley (Emmental) in Switzerland; their precursors were various mountain cheeses.Emmental cheese is probably the best-known Swiss-type cheese and is frequently referred to simply as «Swiss cheese». Swiss-type cheeses have round regular cherry-sized eyes which vary in size from medium to large (1–3 cm).

The propionic acid fermentation leads to characteristic eyes [**118, 123**] and to a nutty flavour [**125**] and can either occur spontaneously or be achieved by a culture of selected propionibacteria. A spontaneous fermentation leads to irregular eye formation, because of great strain diversity of the natural propionibacterial flora in milk.

The number and size of eyes vary markedly and cracks or splits are quite common. Comté and Beaufort are typical examples of cheese varieties with a spontaneous propionic acid fermentation. The use of a culture of selected propionibacteria allows a more regular eye formation as a result of controlled propionic acid fermentation. All these cheese varieties are referred to as Swiss-type cheeses. The body and texture of Swiss cheese are typical of hard or semi-hard cheeses. The characteristics of Swiss-manufactured Emmental cheese are:

- hard cheese made with raw milk from cows that have not been fed on silage;
- high pH of ~5.2 at whey drainage;
- cooking to ~53°C (inactivation of much chymosin activity);
- maturation in a warm room (23°C) to promote propionic acid fermentation followed by a maturation at 13°C;
- cylindrical shape;
- firm dry rind;
- weight: 60–130 kg;
- 1000–2000 round eyes, diameter 1–4 cm
- flavour: mild, nutty, slightly sweet, becoming more aromatic with increasing
- age;
- cheese body – ivory to light-yellow, slightly elastic;
- ripened for 4–8 months (up to 15 months).

Today, Emmental-type cheese (Fig. 1) is produced in many countries and a great variety of other Swiss-type cheeses are also available on the market, including Jarlsberg, Maasdammer, Leerdammer and many other products denoted as «Swiss-type cheese». They are manufactured by methods differing from traditional Swiss production in terms of treatment of milk, extent of mechanisation, the starters used and the weight and shape. Descriptions and analytical values presented in the following entries focus mainly on Swiss Emmental cheese.

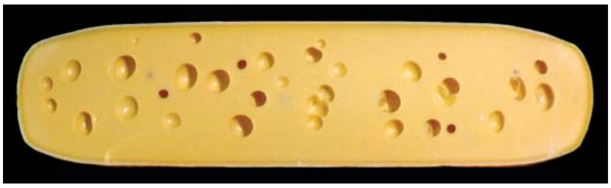

Figure 1: Sectional view of a Swiss Emmental cheese

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2 What factors affect eye development in Swiss cheese?

The main characteristic of Swiss-type cheeses is, besides the nutty and sweet taste, their eyes. For eye formation, the following four main factors are needed:

1. A source of gas.
2. A certain gas pressure and a well-balanced solubility of the gas.
3. Nuclei for eye formation.
4. An adequate body texture and rind.

Propionic acid fermentation produces the CO_2 that leads to the formation of the characteristic eyes. For Emmental cheeses, the inoculation size of *Propionibacterium freudenreichii* is very small (a few hundred cfu ml^{-1} milk). Propionic acid fermentation begins about 30 days after the start of manufacture when the cheese is held at about 20–24°C for roughly 7 weeks and then continues at a slower rate at 10 to 13°C.

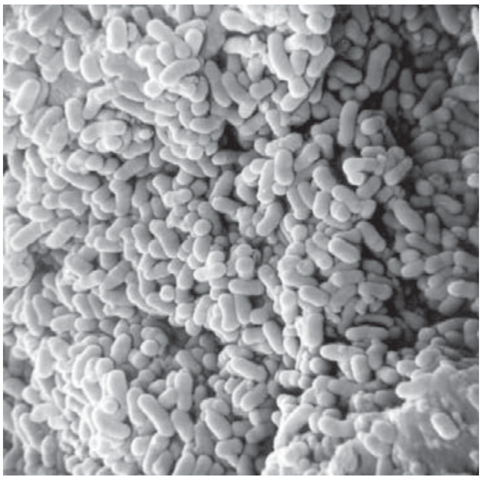

Figure 1: Scanning electron micrograph of a culture of *Propionibacterium freudenreichii*

Propionibacteria appear under the microscope as short rods (Fig. 1) which grow only at low oxygen concentrations (anaerobic to aerotolerant). They occur naturally in the rumen and intestine of ruminants, in soil and in silage. Strain diversity of the natural propionibacterial flora is still great. They are sensitive to salt [**46**] and grow optimally at a pH between 6 and 7 (growth range pH 4.6–8.5). *The optimal growth temperature is 30°C, but growth occurs also at 14°C.*

Small quantities of CO_2 are also produced during the lactic acid fermentation and through the degradation of citrate. The fermentation of citrate leads to a higher number of eyes in the initial stage of the propionic acid fermentation, but to a lower number of eyes in the mature cheese.

In a cheese loaf of approximately 80 kg, total CO_2 production is about 120 l before the cheese is sufficiently aged for consumption. About 60 l remain dissolved in the cheese body, ~ 20 litres are found in the eyes and ~ 40 litres are lost from the loaf.

The saturation concentration of carbon dioxide in Emmental cheese is around 34mmol kg^{-1} and depends on pH and temperature of the body. At 10°C, 50% more carbon dioxide is soluble than at 20°C; at a pH of 4.8 twice as much CO_2 is soluble than at pH 5.2. The high pH of Swiss-type cheeses and the ripening step in the warm room are therefore two important factors that are responsible for a lower solubility of CO_2 and consequently for better eye development.

Nuclei (i.e. points of development for future eyes), can be achieved by the non-homogeneity of the curd, physical openness and the content of gas in the curd. For eye formation in Emmental cheese, the gas content of the curd is of major importance. Microscopic air bubbles attached to curd particles are the main areas of future eyes. However, proper dip filling of the moulds is imperative since too many air inclusions acting as nuclei for future eye development can lead to undesirable openness as, for example, in the defect of the so-called «thousand holes». As the name of the defect suggests, the cheese is littered with thousands of small holes.

A soft and elastic texture is crucial for a regular eye formation. This is why the technology of Emmental cheese production is aimed at the achievement of optimum conditions not only for propionic acid fermentation, but also for the development of a soft and elastic texture. Furthermore, the rind is also essential for eye formation. Brining of the cheeses for 2–3 days and the rather low relative humidity in the ripening room (70–80%) lead to a firm and dry rind [**43**], which reduces the loss of CO_2. The brining and the low relative humidity of the ripening room results in a loss of water from the rind and, consequently, to a compact protein network at the surface of the cheese, which acts as a barrier for gas diffusion. If the rind is too soft and too porous, the brine can be supplemented with calcium, which leads to a stronger protein matrix. On the other hand, if the rind is too rigid, the calcium available in the brine can be eliminated by precipitation. Thus the porosity of the rind can be controlled by adding or removing calcium.

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Since eye formation is an indispensable step in the production of Emmental cheese [**118**], defects related to eye formation are usually unacceptable. Especially in Swiss Emmental cheese production, round, regular cherry-sized eyes which vary in size from medium to large (1–3 cm) are essential. Defects in eye formation include:

- lack of eyes;
- irregular eye formation, slits or cracks.

Propionibacteria are responsible for the formation of eyes and the manufacturing procedure of Swiss cheese must be aimed at the achievement of optimum conditions for propionic acid fermentation.

Propionibacteria are sensitive to low pH and high salt concentration [**46**]. In a cheese with excessive acidification during lactic acid fermentation leading to a low pH at the beginning of ripening, the propionic acid fermentation is reduced markedly. Also at a high salt concentration, the growth of propionibacteria can be slowed down to a great extent. A salt concentration of 5% (w/v) in the aqueous phase can even stop their growth.

Furthermore, propionibacteria are sensitive to copper. In the production of Swiss Emmental cheese, copper vats are used to control propionic acid fermentation. Usually, the copper content in milk is too low to stop propionic acid fermentation completely. Therefore, the lack of eyes is usually not a result of too high copper content.

There might be, of course, additional, technological reasons for the lack of eyes. A cooking temperature that is too high can inactivate large numbers of propionibacteria. Even if the lethal temperature of about 62°C is not reached during cooking, the temperature remains high during pressing, which can reduce the numbers of propionibacteria considerably. In addition, the conditions in the fermentation room have a great impact on the propionic acid fermentation. Optimal growth temperature of propionibacteria is around 30°C. Even though growth may also occur at low temperatures (e.g. 14°C), the temperature of the fermentation room (usually ~23°C) should not be too far from the optimal temperature, because, as a consequence, the propionic acid fermentation would be greatly slowed down. The length of time cheeses remain in the fermentation room should be adjusted accordingly.

As outlined in [**118**], not only is the liberation of gas by propionibacteria a prerequisite for eye formation, but also the availability of nuclei for future eye development. Elimination of these nuclei, e.g. through milk pretreatments such as microfiltration or centrifugation, prevents the formation of eyes.

During ripening, a high loss of gas might be the result of an overly porous rind or foil. In the case of the former problem, controlling the brining conditions is necessary such as NaCl concentration of the brine, the duration of brining or the use of $CaCl_2$ in the brine in order to get a firmer rind. The choice of the right 250 Cheese problems solved foil, if used, with the desired porosity must also be taken into consideration. Furthermore, the size and shape of the cheese also have an impact on gas diffusion. If the volume to surface area ratio is low, the loss of gas might be too high.

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4 What causes irregular eye formation, slits or cracks in Emmental cheese?

Irregular eye formation, slits and cracks are often a result of undesirable fermentations and/or an inadequate body texture. The former include excessive propionic acid fermentation or its restart towards the end of ripening (so-called «late fermentation») and butyric acid fermentation [**91**].

A strong propionic acid fermentation is very often coupled with a strong aspartase activity of the propionibacteria [**121**] used together with a high availability of aspartate. Furthermore, excessive proteolysis leads to a shorter body. This defect becomes particularly evident when a large amount of casein is decomposed into low molecular mass peptides [**88**].

The additional carbon dioxide released by decarboxylation of amino acids clearly reduces the keeping quality of the cheese and leads to oversized and irregular eye formation and taller loaves. The cheese body often cannot withstand the pressure of the gas and cracks or splits appear (Fig. 1). Excessive aspartase activity also increases the risk of irregular eye formation with cracks and splits [**121**]. This defect is called late or secondary fermentation.

Figure 1: Swiss cheese with the defect of late fermentation

Figure 2: Swiss cheese trials with differing intensity of butyric acid fermentation

Butyric acid fermentation is highly undesirable in Swiss cheese, not only because of the production of strong off-flavours, but also because lactate fermentation by *Clostridium tyrobutyricum* into butyric acid, acetic acid, carbon dioxide and hydrogen causes the cheese loaf to blow. The insolubility of H_2 in water is responsible for a very easy and quick cheese blowing. At atmospheric pressure, when 1 g butyric acid (from 2 g lactic acid) is produced, 1000 ml gas (CO_2 and H_2) is liberated. Fig. 2 shows Swiss cheese trials with differing intensity of butyric acid fermentation. The eye formation is irregular, and is accompanied by cracks and splits.

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5 What is aspartase of Propionibacterium?

Aspartase is an enzyme found in propionibacteria and also other microorganisms that catalyse the deamination of aspartate. For a long time it was known by cheesemakers that different cultures of propionibacteria could lead to very different cheeses. But the cause for this variation was unknown until recently when it was ascribed to the differing aspartase activities of various propionibacterial strains.

The metabolism of propionibacteria in Swiss cheese is rather complex and not yet fully understood. Different metabolic pathways have been described for the utilisation of lactate and aspartate, both of which are available in cheese.

The lactic acid produced by the lactic starters is usually broken down to propionate, acetate and CO_2 as follows (the classic metabolic pathway):

$$3 \text{ lactate} \rightarrow 2 \text{ propionate} + \text{acetate} + CO_2 + \text{ATP}$$

In the presence of aspartate, the fermentation of lactate is coupled to the fermentation of aspartate to produce succinate but no propionate. Consequently, more lactate is fermented to acetate and CO_2 than to propionate:

$$\text{lactate} + 2 \text{ aspartate} \rightarrow \text{acetate} + CO_2 + 2 \text{ succinate} + 2NH_3 + \text{ATP}$$

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FRÖHLICH-WYDER, M.T. and BACHMANN, H.P. (2004). Cheeses with propionic acid fermentation, in *Cheese: Chemistry, Physics and Microbiology* Volume 2 *Major Cheese Groups,* 3rd edn, P.F. Fox, P.L.H. McSweeney, T.M. Cogan and T.P. Guinee (eds.), Elsevier Academic Press, London, pp. 139–156.

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6 How does aspartase of Propionibacterium affect Swiss cheese?

Propionibacterial strains can differ strongly in their aspartase activity [**121**]. In the manufacture of Emmental cheese, the use of cultures with differing aspartase activity leads to different products. Strains with high aspartase activity ferment higher amounts of lactate, gain more energy and are thus present in cheese at higher numbers than strains that utilise only a little aspartate. The higher number of propionibacteria is responsible for increased amounts of acetate, propionate, succinate and CO_2 and therefore for more intense flavour and larger eyes. Tables 1 and 2 show the characteristics of Emmental cheeses made with propionibacteria with either strong or weak aspartase activity. Figure 1 shows the outer appearance of Emmental cheeses produced with different propionibacteria. The number and size of eyes and the height of loaves are greater for cheeses made with a culture with strong aspartase activity as a result of increased CO_2 release. The storage time for the cheeses in the warm room may be shortened by up to 10 days. The intensity of aroma is also more pronounced compared with cheeses made with propionibacteria of low aspartase activity. Thus, propionibacteria with strong aspartase activity accelerate ripening by a combined effect of aspartate metabolism and of the increased number of propionibacteria.

The capability of strains to utilise aspartate is a very important factor when selecting new cultures. A very high aspartase activity will increase the amount of CO_2 and therefore the risk of late fermentation. However, moderate aspartase activity may have a positive effect on the quality of Emmental cheese as regards eye formation and flavour intensity.

Table 1: Mean values of metabolites and propionibacterial counts in Emmental cheese (6 and 12 months) made with propionibacteria with weak or strong aspartase activity (adapted from Fröhlich-Wyder and Bachmann, 2004)

Parameter (mmol/kg^{-1})	Emmental cheeses of 6 months			Emmental cheeses of 12 months		
	Weak (*N* = 10)	*Strong* (*N* = 8)	*t*-test	*Weak* (*N* = 10)	*Strong* (*N* = 8)	*t*-test
Lactate	57.4 ± 10.5	45.3 ± 17.4	ns	47.0 ± 8.5	11.3 ± 6.7	***
Acetate	48.4 ± 1.3	53.1 ± 5.1	*	47.6 ± 0.6	58.7 ± 1.7	***
Propionate	60.1 ± 4.4	67.1 ± 10.2	ns	63.2 ± 4.2	83.6 ± 3.6	***
Succinate	4.0 ± 0.6	11.9 ± 1.7	***	5.1 ± 2.8	17.7 ± 2.5	***
CO_2	27.6 ± 1.6	33.6 ± 2.0	***	nd	nd	
Propionibacteria (log CFU/g^{-1})	nd	nd		6.7 ± 0.9	8.4 ± 0.3	***
Aspartate	2.219 ± 0.861	0 ± 0	***	4.834 ± 0.585	0.588 ± 0.097	***
Asparagine	2.863 ± 1.100	0.125 ± 0.237	***	1.886 ± 0.494	0.054 ± 0.154	***

nd, not determined; ns, not significant; * p<0.05; *** p<0.001

Table 2: Sensory and quality parameters of Emmental cheese (6 and 12 months) made with propionibacteria with weak or strong aspartase activity (mean values and *t*-test, adapted from Fröhlich-Wyder and Bachmann, 2004)

Parameter (Index)	Emmental cheeses of 6 months			Emmental cheeses of 12 months		
	Weak (*N*=10)	Strong (*N*=8)	t-test	Weak (*N*=10)	Strong (*N*=8)	t-test
Openness (1 – 6)	5.3 ± 0.6	4.6 ± 0.6	*	4.6 ± 0.6	4.6 ± 0.8	ns
Number of eyes (0 – 5)	4.7 ± 0.6	5.3 ± 0.4	*	4.4 ± 0.6	5.4 ± 0.3	***
Size of eyes (1 – 5)	4.9 ± 0.3	5.8 ± 0.6	**	4.5 ± 0.5	5.8 ± 0.6	***
Maturity (2 – 8)	4.4 ± 0.8	5.3 ± 0.6	*	6.5 ± 0.5	6.8 ± 0.4	ns
Intensity of aroma (0 – 7)	3.1 ± 0.2	3.5 ± 0.2	***	3.7 ± 0.4	3.8 ± 0.3	ns
Sweetness (0 – 7)	2.3 ± 0.2	2.2 ± 0.1	ns	2.5 ± 0.3	2.4 ± 0.2	ns
Height of cheese (cm)	19.1 ± 1.5	21.3 ± 1.7	*	18.1 ± 1.8	20.6 ± 1.0	**

ns, not significant; * p<0.05; ** p<0.01; *** p<0.001: index indicate the range of appreciation (lowest number = lowest possible score; highest number = highest possible score)

Figure 1: Emmental cheese (5 months old) made with propionibacteria with strong (no. 5) or weak (nos 1 and 3) aspartase activity

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7 How may the size and quantity of the eyes in Emmentaltype cheese be controlled?

In order to control the size and quantity of the eyes in Emmental cheese, weneed to know the main factors of eye development [**118**]. The size and quantity of eyes can be controlled by controlling the source of gas production, the quantity of nuclei in the cheese matrix and to some extent also the extent of proteolysis.

The main source of gas production is the metabolic activity of the propionibacteria and to some extent also the facultatively heterofermentative lactobacilli [**56**]. In Emmental cheese, interactions between propionibacteria and lactic acid bacteria have a major impact on propionic acid fermentation and, thus, on gas production. Understanding the characteristics of, and the interactions between, these microbial groups results in an easy tool to control eye formation.

As outlined in [**121**], the use of a culture of propionibacteria with high aspartase activity leads to more and larger eyes in Emmental cheese. A culture of propionibacteria with weak aspartase activity, consequently, will produce fewer and smaller eyes. Furthermore it is possible to control stepwise the size and quantity of eyes by mixing these two types of cultures in defined ratios (Fig. 1). Facultatively heterofermentative non-starter lactobacilli (FHL) are used in the Swiss artisanal cheese industry to slow down the propionic acid fermentation, i.e. to control eye formation. As a consequence of inhibition of propionibacteria by FHL, less propionic acid and, thus, less carbon dioxide are produced.

The mechanism of inhibition is not yet conclusively clarified, but can be used efficiently to control the size and quantity of eyes in Swiss cheese. Since the introduction of cultures of Lactobacillus casei in Switzerland in 1989, the defect of late fermentation has decreased considerably.

Propionibacteria with differing aspartase activity are not inhibited equally; propionibacteria with weak aspartase activity are inhibited much more by FHL than are propionibacteria with strong aspartase activity. This is why propionibacteria with strong aspartase activity are generally more prone to causing late fermentation.

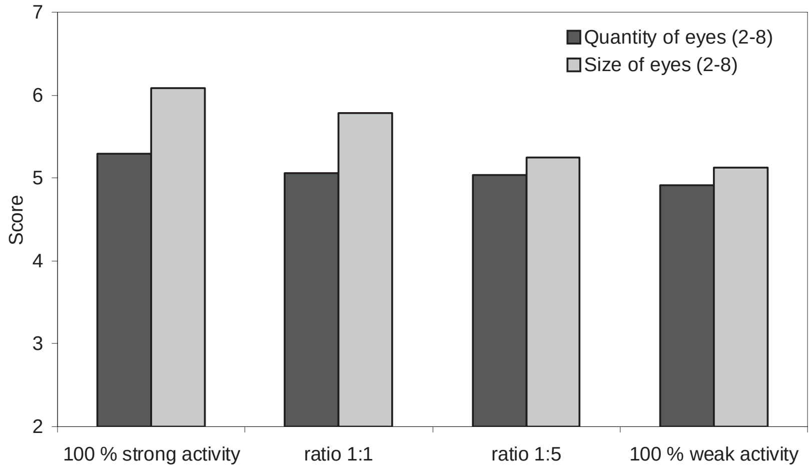
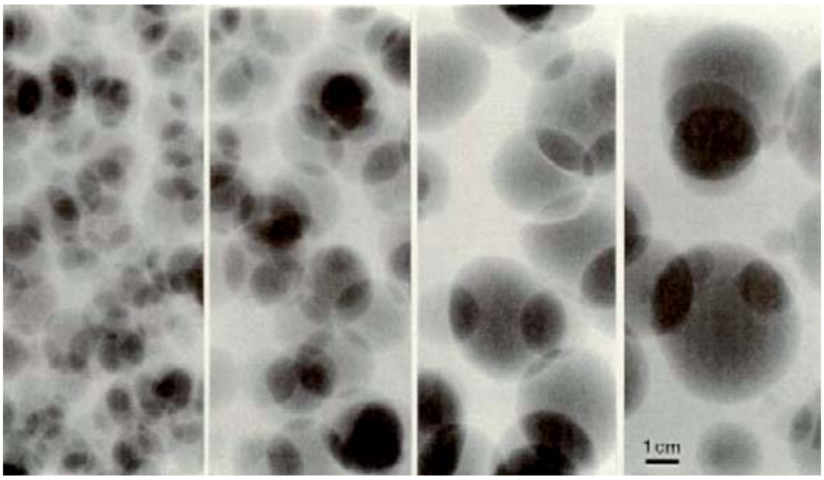


Figure 1: Influence of different ratios of cultures of propionibacteria with opposing aspartase activity.

Hence, smaller eyes are achievable by the use of a propionibacterial culture with low aspartase activity combined with a culture of citrate-positive FHL; small to medium sized eyes by the use of a propionibacterial culture alone with low aspartase activity; larger eyes by the use of a propionibacterial culture with high aspartase activity.

The quantity of future areas of eye formation, the nuclei, influences fundamentally the quantity and size of eyes [**118**]. At a comparable rate of gas production, fewer nuclei lead to larger eyes and vice versa. The quantity of nuclei can easily be controlled by centrifugation of a certain percentage of the cheese milk (Fig. 2).

Propionibacteria with the ability to ferment aspartate need, as expected, the amino acid aspartate for its metabolism. Increasing levels of proteolysis liberates more amino acids and more aspartate which can be metabolised by propionibacteria. The result is higher gas production, more and larger eyes. A propionibacterial culture with high aspartase activity combined with Lb. helveticus, a highly proteolytic Lactobacillus, leads therefore to especially large eyes in a Swiss-type cheese.



0% 90% 96% 100%

Figure 2: Eye formation in an Emmental cheese made with uncentrifuged (0%) or partially (90, 96 or 100% v/v) centrifuged vat milk.

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8 How do I control the elastic texture of Swiss-type cheese?

A soft and elastic texture is crucial for a regular eye formation [**118**]. This is why the manufacturing procedure of Swiss-type cheese must be aimed at the achievement of optimum conditions not only for propionic acid fermentation, but also for a soft and especially elastic texture. There are several ways in order to influence texture. The following will be discussed:

- technology;
- proteolysis;
- composition of milk fat.

A fundamental step during Emmental cheese production is the addition of water (12–18%) to the milk or to the curd in order to dilute the substrate (lactose) for lactic acid bacteria. This leads to a relatively high pH after the lactic fermentation (5.20–5.30), but also at whey drainage, which explains the high calcium content of the cheese and, consequently, the long and elastic texture [**17**]. Calcium plays the key role in the formation of the protein network by building calcium phosphate bridges between the casein micelles.

The role of the water and fat is Swiss cheese should be mentioned: a rather high water and fat content are prerequisites for a soft and elastic texture. Swiss Emmental cheese is a full-fat hard cheese with approximately 50% fat-in-dry-matter and a maximum water content of about 38%. On the other hand, a too high fat content is responsible for a too soft body texture and a lower pH in the cheese. The reason for the latter is the unfavourable protein to fat ratio and a low protein level reduces the buffering capacity [**22**]. This fact leads consequently to a weaker propionic acid fermentation with consequently fewer and smaller holes. Also, the ripening conditions have an impact on the cheese body. Swiss-type cheeses are kept in the fermentation room for the main part of gas production and eye formation. The temperature of this step (20–24°C) is rather too high to promote growth of propionibacteria and, thus, gas production. In addition to that, the high temperature supports a soft and elastic texture.

The high elasticity is also promoted by a low proteolysis rate during ripening compared to other cheese varieties. Most Swiss-type cheeses are cooked to a high temperature; Emmental cheese is heated to 52–54°C after cutting. During pressing, the temperature remains at around 50°C for hours. At this temperature, undesirable microorganisms are eliminated, but also enzymes such as chymosin are largely inactivated. Thus, overly intensive proteolysis is avoided and hence a texture that is too short and too crumbly.

Proteolysis can also be controlled by using an appropriate starter culture: Lactobacillus helveticus has higher proteolytic activity than Lactobacillus delbrueckii subsp. lactis [**18**]. Furthermore, mesophilic lactococci are less proteolytic than are in general thermophilic lactobacilli.

During winter, hay and fodder beet are common components of a basal diet for dairy cows in the lowland regions of Europe. Generally, the concentration of saturated fatty acids is very high in milk fat from cows fed such a diet. An elevated level of saturated fatty acids is responsible for a rather hard cheese texture. In order to achieve a softer texture even in winter, it is possible to supplement the cows' diet with oilseeds such as linseed, sunflower seed and rapeseed. Supplementation with oilseeds results in an increase in the proportion of unsaturated fatty acids, and therefore in a `softer' milk fat, which leads to a softer cheese texture.

The ratio of oleic acid ($C_{18:1}$) to palmate acid ($C_{16:0}$) may be used to describe the hardness of fat. In winter, with a hay and fodder beet diet, the ratio may reach only 0.5. A supplementation with oil seeds can lead to an increase of the ratio to over 1.0 (Fig. 1). A ratio of >0.8 corresponds to a «soft» milk fat.

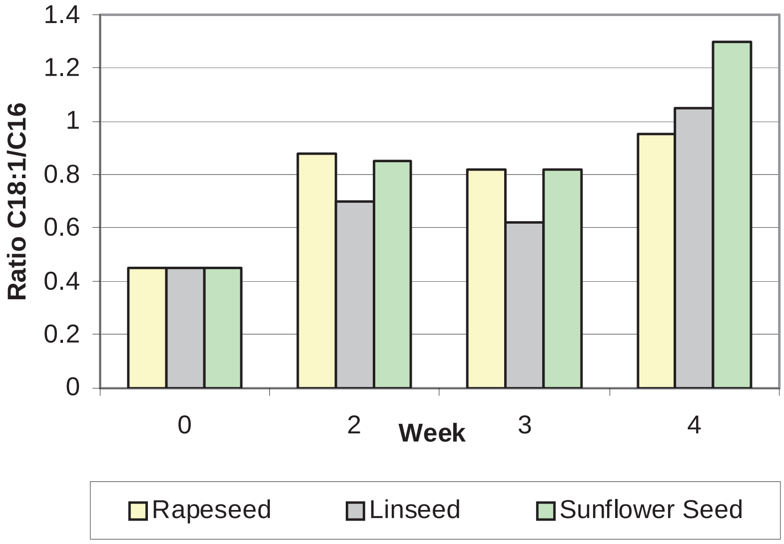

Figure 1: Influence of oilseed supplementation on the ratio of oleic acid ($C_{18:1}$) to palmate acid ($C_{16:0}$) in the milk fat (blend of milk from 11 cows; Week 0, no supplementation; week 2, 2 weeks feeding with each 1 kg oilseed; Week 3, 3 weeks feeding with each 1 kg oilseed; Week 4, 4 weeks feeding with each 1 kg rapeseed, 1.5 kg linseed or 1.5 kg sunflower seed.

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9 Why does Swiss cheese have a sweet flavour?

One of the main characteristics of Swiss-type cheeses is its sweet and nutty flavour. The sweet taste of Emmental cheese is considerably higher than that of other hard cheese varieties. The sweet taste of Swiss-type cheeses originates in the main part from the propionic acid fermentation. The following, which are liberated during lactic and propionic acid fermentation, are very potent taste compounds: acetic, propionic, lactic, succinic and glutamic acids, each in free form and/or as their ammonium, sodium, potassium, magnesium or calcium salts, as well as the corresponding chlorides and phosphates of these cations. Magnesium and calcium propionate are the main compounds that cause the sweet taste of Swiss-type cheese.

Other volatile compounds may contribute to the sweetish note of Swiss-type cheeses. These compounds derive from glycolysis, proteolysis and lipolysis during ripening [**88**]. In addition, furanones, which are responsible for caramellike flavour, may contribute to a sweetish note. Furanones are products of the Maillard reaction which occurs during heat treatment [**188**].

Non-volatile compounds such as free amino acids, which are liberated during proteolysis, may also contribute to the sweet taste of Swiss-type cheeses, but to a lesser extent. Sweet amino acids include proline, serine, glycine, alanine and others.

Further reading

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10 What are the causes of the most common flavour defects of Swiss cheese?

As we already know, Swiss cheese has a particular dominating flavour due to propionic acid fermentation which is described mainly as sweet and nutty [**125**]. However, a flavour defect may occur that becomes evident only with progressing ripening. The most common flavour defects in Swiss cheese are produced by:

- butyric acid fermentation;
- excessive lipolysis;
- excessive proteolysis.

Butyric acid fermentation is totally undesirable, since lactate fermentation by Clostridium tyrobutyricum into butyric acid, acetic acid, carbon dioxide and hydrogen causes the cheese loaf to blow [**91**]. Furthermore, even small amounts of butyric acid cause off-flavours. Therefore, in Switzerland, Emmental cheeses have to be manufactured with milk from cows that have not been fed silage. Feeding cows with silage of low microbiological quality is the primary route of contamination of the milk with spores of Cl. tyrobutyricum. As few as 50 spores per litre of cheese milk are sufficient to cause a butyric acid fermentation.

Spores can also be eliminated either by physical treatment, i.e. bactofugation or microfiltration prior to processing, or by the use of additives such as nitrate, lysozyme or nisin in order to restrict germination. However, these additives are not permitted in Switzerland for the production of Emmental cheeses. A particularly serious defect results from the presence of Clostridium sporogenes. This species leads to a non-specific and very intense proteolysis, leading to putrid spots in the cheese loaf (Fig. 1).

Lipolysis in Emmental cheese is catalysed by bacterial lipases and the indigenous lipoprotein lipase in milk which is, however, thermolabile and therefore its activity is reduced by cooking at temperatures over 50°C. Lactic acid bacteria have only limited lipolytic activity, with Streptococcus thermophilus having the highest. Propionibacteria, in contrast, have lipolytic activity, 10–100 times more than lactic acid bacteria and which is highly straindependent. Lipolysis in Swiss-type cheeses is consequently mainly caused bypropionibacteria and is generally recognised as necessary to produce typical Swiss cheese flavour. The amount of free fatty acids present varies from 2 to 7 g kg^{-1}. Nevertheless, higher contents give flavour defects such as rancidity (caused mainly by butyric and caproic acids) [**90**]. The release of free fatty acids starts in the warm room simultaneously with the growth of propionibacteria.

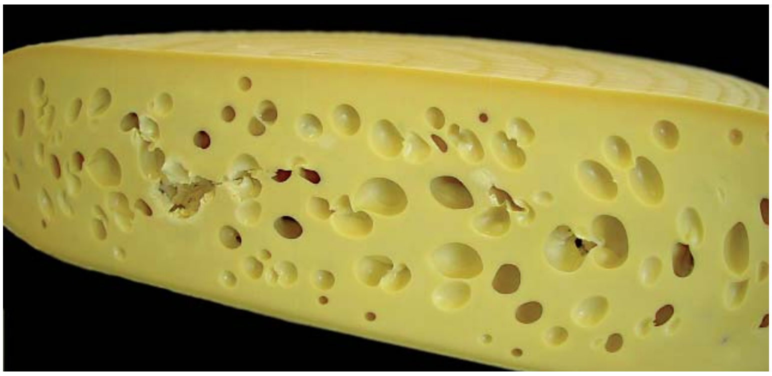

Figure 1: Intense proteolysis by Clostridium sporogenes with putrid spots.

Other bacterial, but undesirable, lipases may originate from the raw milk flora. These lipases become especially evident if the raw milk has been stored under unfavourable conditions before processing (too long and at too high temperatures) and these enzymes are usually heat stable.

Excessive proteolysis gives an overripe and sharp taste and a shorter body. This defect becomes particularly evident when a large amount of casein is decomposed into low-molecular compounds and amino acids. The latter are further metabolised to strong flavour compounds, e.g. sulphurous compounds. This is certainly a desirable process in other cheese types, but in Swiss-type cheeses the specific propionic acid flavour should dominate.

Excessive aspartase activity has also a great impact on flavour development [**121**]. Propionibacteria with strong aspartase activity need the amino acid aspartate for this pathway. The more aspartate is available, the stronger is their metabolism. A strong aspartase activity leads also to a stronger propionic acid fermentation and, as a result, to the defect of late fermentation. Consequently, more propionic and acetic acids are liberated, and, if present at excessive concentrations, may also lead to an overripe and sharp taste.

Frequently, the course of proteolysis [**90**] in a cheese loaf varies from one zone to the other, a phenomenon that is due to temperature changes in the cheese loaf during lactic acid fermentation. Since the outer zone cools faster, there often develops a bacterial flora which is proteolytically more active than the microorganisms in the centre of the loaf. This usually leads to cheese defects such as short and firm body, sharp taste, or the development of whitish colour under the rind.

Further reading

CHAMBA, J.F. and PERREARD, E. (2002). Contribution of propionic acid bacteria to lipolysis of Emmental cheese. Lait 82, 33–44. 264 Cheese problems solved

11 Is my Emmental cheese hygienically safe?

The original Emmental cheese in Switzerland must be manufactured from raw milk. The contamination of raw milk by pathogenic microorganisms can never completely be excluded, despite intensive efforts at hygiene [**59, 60**]. Infectious diseases in dairy cattle, contamination of milk during milking, storage, transport or processing present potential hazards. This fact has raised the question of whether Swiss Emmental cheese made from raw milk is hygienically safe. In order to find an answer to that question, the ability of potentially pathogenic bacteria to survive and grow during the manufacture and ripening of Swiss Emmental cheese had been examined. From this research it can be concluded that the hygienic safety of Emmental cheese made from raw milk is comparable to cheese made from pasteurised milk. As it can be seen in Fig. 1, no pathogens can be detected after 1 week of ripening. Already after cooking, there is a remarkable decrease in the number of pathogens.

The number of pathogens decreases in Emmental cheese because of the socalled hurdle technology: each step of the manufacturing procedure of Emmental cheese is a hurdle for the survival and growth of pathogens [**16**].

The synergistic effect of these steps is responsible for a hygienically safe product. The following technological steps are such hurdles:

- high milk quality;
- short milk storage;
- antagonistic starter culture flora;
- rapid acidification;
- antimicrobial effect of lactic acid;
- high cooking temperatures;
- brining;
- long ripening period (more than 120 days).

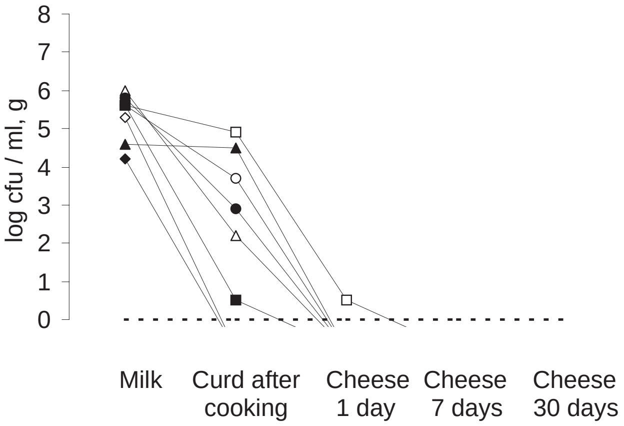

Figure 1: Survival of Aeromonas hydrophila (◇), Campylobacter jejuni (◆), Escherichia coli (△), Listeria monocytogenes (▲), Pseudomonas aeruginosa (○), Salmonellatyphimurium (●), Staphylococcus aureus (□) and Yersinia enterocolitica (■) during manufacture and ripening of Swiss Emmental cheese made from raw milk (only data of batches with longest survival are shown).
- - - detection limit (Bachmann and Spahr, 1995).

Another pathogenic agent which could become problematic in cheese production is Mycobacterium avium subsp. paratuberculosis [**62**]. This bacterium occurs worldwide and is responsible for a chronic enteritis in ruminants, also known as Johne's disease. Crohn's disease, a chronic enteritis in humans, bears considerable similarities to Johne's disease. Studies have shown that a high percentage of people with Crohn's disease are infected with M. avium subsp. paratuberculosis. Whether the association of this bacterium and the disease is causal or coincidental is not known. But the similarities of these two diseases have raised the question of whether milk, among others, could transfer this bacterium. For that reason, the same investigation as described earlier had been carried out with M. avium subsp. paratuberculosis only. As Fig. 2 shows, there is a decrease in the numbers of M. avium subsp. paratuberculosis in Swiss Emmental cheese, but to a much lesser degree than other pathogens. Nevertheless, a Swiss Emmental cheese consumed only after 4 months is hygienically safe, comparable to a cheese made from pasteurised milk.

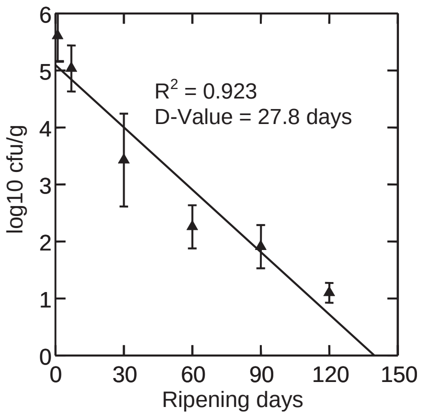

Figure 2: Inactivation curves for Mycobacterium avium subsp. paratuberculosis in Swiss Emmental cheese during 120 days of ripening (Spahr and Schafroth, 2001).

Further reading

BACHMANN, H.P. and SPAHR, U. (1995). The fate of potentially pathogenic bacteria in Swiss hard and semihard cheeses made from raw milk. J. Dairy Sci. 78, 476–483.

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