development of jarlsberg cheese technology

the starting point

In the autumn of 1955, dairy science student Per Sakshaug (later Manager of Jæren Dairy and Headmaster of Jæren Dairy College), under the supervision of Professor Ystgaard, conducted cheesemaking experiments for his Masters Thesis, "Addition of propionibacteria culture to cheese milk", at the Agricultural University of Norway (32). Interesting results were obtained, and a good-quality cheese was produced using the Research Dairy's cheese vats. Interest was awakened to further the development of a Gouda with large eyes. From that point on, the development of a Gouda with large eyes resulting from propionibacteria metabolism was led by Professor Ystgaard, and it was this work that eventually led to today's Jarlsberg cheese. In addition to the effect on eye production, it was also expected that the addition of a pure culture of *Propionibacterium freudenreichii* subsp. *Shermanii* would add an interesting taste to the cheese.

As the work progressed, Professor Ystgaard felt it was important to retain the Gouda technology. This meant, for example, that only mixed cultures of so-called mesophilic lactic acid bacteria were used in addition to the propionibacteria. These lactic acid bacteria are called mesophilic because their optimal growth temperature is around 30°C. It was decided that the cheese cooking temperature, that is, the highest temperature to which the cheese mass and whey is heated in the vat, was to be the same as the relatively low temperature used for Gouda. This low temperature does not inhibit the mesophilic lactic culture and its metabolism of lactose and citric acid in the milk. In other words, the necessary good growth of the starter bacteria should be guaranteed by using these conditions.

In the following description of the development of the cheese technology, we will limit ourselves to some of the research projects and Masters research work conducted at the Dairy Institute from 1956 to 1965, the year when Professor Ystgaard concluded that the cheese was fully developed as a new cheese type. Our description, therefore, builds largely on work published from the Institute during the development period or submitted as MSc theses at the Agricultural University. Later, several Masters Theses and other research reports were also written about Jarlsberg cheese or about the propionibacteria culture, but only a few of these will be mentioned.

the first cheesemaking experiments that led to a new cheese

From about 1910, the most important cheese produced in Norway was the so-called large-eyed Gouda. Before that, a variant with very small eyes had been produced. However, for several years leading up to 1955, achieving sufficient numbers of large eyes in the cheese became an increasing problem.

In his Masters research, Sakshaug began with the hypothesis that in the original Norwegian Gouda cheese, propionibacteria were probably an important aid to achieving satisfactory eye formation. Propionibacteria are principally gut bacteria and would therefore be a part of the normal flora of the milking parlor. Sakshaug speculated that because parlor and milking hygiene had improved, the incidence of propionibacteria had been reduced. These factors, combined with pasteurization of the cheese milk, could have resulted in minimal amounts of propionibacteria in the cheese milk.

The formation of very large eyes in Emmental type cheese is primarily due to propionibacteria which form large amounts of carbon dioxide (CO_2) by metabolizing the lactic acid that has been formed from lactose in the milk by the lactic acid starter bacteria in the cheese. Propionibacteria metabolize the salt of lactic acid (lactate) to propionic acid, acetic acid and CO_2. *Sakshaug's hypothesis was that the eye formation in Gouda would be improved and more like that in cheese produced earlier if a pure culture of propionibacteria was added to the cheese milk following pasteurization*. A review of the literature showed that many research groups had previously studied the effect of adding propionibacteria to Emmental cheese milk. However, no reports could be found referring to the addition of propionibacteria to pasteurized cheese milk for Gouda production using the technology that was common in Norwegian dairies. Researchers at Iowa State College (4) had reported the development of a cheese they called Iowa Swiss. The technology used for this cheese was similar to that used for Gouda, but some of the research used a cooking temperature of 41.1°C, which is too high for Gouda.

Sakshaug's MSc research project comprised 24 cheese vats, each with 400 liters of milk. The same cheesemaking technology was used for all vats. Sixteen round cheeses were made from each vat, each weighing 2.5 kg. To detail the cheesemaking technology used would take too long, but it is important to mention that an ordinary mixed mesophilic culture of lactic acid bacteria was used, the same as is used for butter and cheese production in Norway. The cooking

temperature was 37°C. The experimental setup involved the addition of a strain of *Propionibacterium freudenreichii* subsp. *shermanii* at three different levels to three cheese vats containing 1% of the mesophilic lactic culture. In a fourth vat, only the lactic culture was added. The cheeses were made on the same day and the same milk was used in each of the four vats. This experiment was repeated six times during the period September 4 to October 3, 1955.

The strain of *Propionibacterium freudenreichii* subsp. *shermanii* originally came from Iowa State University. Professor Ystgaard had developed a good collaboration with Dr. F.E. Nelson following a study trip to Iowa State. Nelson gave the culture to Professor Ystgaard, and it was later found to be crucial for Jarlsberg's special properties.

After pressing, the cheeses rested in the moulds overnight. Half of the cheeses (8) were then placed in 20% brine at 8-12°C and salted for two days. The remaining eight were left in the molds for an additional two days and were then transferred to the brine and salted for two days. The cheeses from each of the 24 vats were divided between three warm Ripening Rooms (16°-, 19°- and 22°C, respectively), and were continually assessed such that they could be transferred to cold storage as soon as they were ready. The number of necessary days in the Ripening Room varied from 12 to 26. After three months of cold storage, the cheeses were analyzed and organoleptically assessed. Examples of eye formation and the general appearance of the cheeses made during Sakshaug's first cheesemaking series are shown in Figure 1.

Sakshaug emphasized that his research material was too small to draw general conclusions concerning the effect of adding the propionibacteria culture on eye formation, but he pointed out some tendencies in the results:

- The control cheese showed good eye formation. The produced Gouda was not without eyes, such as was often the problem in Norwegian dairies at that time. The results of the sensory assessment gave reason to maintain that the addition of *Propionibacterium freudenreichii* subsp. *shermanii* to the cheese milk made a slight improvement in the quality of the experimental cheese.
- Cheeses with the lowest and medium levels of propionibacteria generally tasted better than the control cheese. The addition of this culture had an clear effect on the concentrations of volatile organic acids in the mature cheese, but no measurable influence on the protein breakdown in the cheese. Volatile organic acids are considered important for cheese flavor.
- The variation in temperature in the Ripening Rooms within the range used in this research did not have a marked effect on the general quality of the cheese, although it was felt that the texture and taste were better in cheeses that had been stored at 19°C.

Sakshaug's comments on the sensory assessment disclose that coordination of the three authorized cheese graders had been a challenge. The cheese's sensory characteristics were different in several respects from the Gouda they were used to assessing. In the section on sensory assessment of the cheeses, Sakshaug wrote: *"The texture of the cheese was assessed according to the norms for Gouda cheese, but the other characteristics were judged as though the cheese were a new type."* Concerning the sensory results, he said: *"The differences in the scores for taste are, however, surprisingly small since there is a marked difference in the taste between cheeses with and without addition. This cannot be explained in any way other than that the control cheese has been judged as a Gouda cheese and the others have been judged as a different type. This shows that the cheese assessment was so subjective that it is pointless to statistically analyze the data."*

work with the propionibacterium culture

Even though Sakshaug's research could only show tendencies, the staff at the Dairy Institute was determined to continue studying the addition of propionibacteria to Gouda cheese in greater depth. Thus, a more extensive research project was initiated, focused on developing the cheesemaking technology in order to produce a "new" cheese type.

At the same time as the technology was being developed, it was also important to look into the best conditions for maintaining the propionibacteria culture Sakshaug had used. It was assumed that this particular culture was responsible for the good eye formation and the individual taste in the experimental cheeses. Research was begun to optimize the routines for culture production in the volumes that would be necessary for both the research cheese development and also potentially in commercial production. In-depth studies of the microorganism, including growth conditions and morphology, were conducted. However, this work was not published as it was simply regarded as laboratory work aimed at achieving the necessary greatest possible stability in the full-scale cheesemaking. The laboratory data from this work is not available today, but Professor Strand, one of the authors of this book, participated actively in this work. The work was largely organized and led by associate professor in Dairy Technology, Erling Brandsæter.

In order to select robust variants of the strain, Brandsæter cultivated the strain on various agar substrates and systematically selected the largest colonies that developed. This work resulted in the selection of a culture that was more salt-tolerant than the original culture. The modified culture so obtained is the same as is used in today's production, and is not particularly inhibited by the salt concentrations found in cheese. This selection strategy, aimed at increasing salt tolerance, was necessary to produce a culture of propionibacteria suitable for adding to a Gouda-type cheese.

Propionibacteria are microaerophilic and therefore thrive in an atmosphere with less oxygen than in air. For cultivation of the culture, it was therefore necessary to establish an environment that was as anaerobic as possible. In addition to the usual work of plating out on ordinary Petri dishes, various methods were introduced to the Dairy Institute by visiting Researcher Dr. Georg Reinbold from Iowa State University.

It was also important to investigate whether other strains of propionibacteria could produce cheese with the same characteristics. While visiting the Institute, Dr. Reinbold collaborated in cheesemaking experiments using another strain of propionibacteria from America. This new culture had a comparatively weak CO_2 production. However, the results were not promising as the cheese produced using this culture had an atypical taste.

A number of strains of propionibacteria had been isolated in the Dairy Institute's Section for Chemistry, Bacteriology and Market Milk Technology. Arne Henrik Strand conducted single cheesemaking experiments using ten of these isolates, but none of them resulted in a cheese with a desirable typical taste and eye formation. It was therefore decided that the development research should continue using the strain Sakshaug had used in his MSc research, but a more salt-tolerant variant was selected. This propionibacteria culture was maintained at the Institute's laboratories for many years and propagated for use in commercial cheesemaking. The Research Dairy at the Institute functioned as a "control dairy" for the culture up until the 1990s because one vat of Jarlsberg cheese (4,000 liters of milk) was produced daily in the dairy. This cheese production was closely followed, particularly regarding the propionibacteria culture's function and properties, and in this way acted as a quality assurance for Jarlsberg cheese production in the whole of Norway. The Institute continued with these "control productions" until June 1993, by which time TINE had taken over responsibility for production of the culture and the production of Jarlsberg cheese in the Research Dairy was therefore deemed no longer necessary.

studies of the technological factors important for the quality of jarlsberg cheese

During the ten years Ystgaard considered was the period it took to develop Jarlsberg cheese as a specific cheese type, a series of cheesemaking experiments were conducted. Not all of these were recorded with publication in mind, but laboratory records are available from at least eight experiments that took place between the autumn of 1957 and June 1958. This research aimed at discovering the optimum cheesemaking technology for Jarlsberg cheese. The experiments included the addition of salt and nitrate to the cheese milk, stirring and heating (cooking) of the cheese in the vat, various storage and ripening temperatures and the use of intermediate and refrigerated storage of the cheese before waxing. In addition, this topic was studied in several MSc research theses and other research projects. Some of these will be described in later chapters.

It gradually became obvious that it would be strategically unwise to publish too much of the work on the development of this new cheese type. Too many technological details would be made available, and it would be in the interests of the Norwegian dairy industry to keep these details secret from possible competition. (my bold font, for emphasis) For this reason, only some examples of how the pure developmental research was conducted will be described here and only published reports will be cited. First, a short introduction to the planning of the various experiments that comprised the actual developmental research of Jarlsberg cheese is needed.

the design of the experiments

The research experiments that were conducted to establish the optimum cheesemaking technology for Jarlsberg cheese took place at a time when experimental design, statistical data treatment and, not least, the technical equipment for doing the calculations were just developing. Of course, the statistical theories were established much earlier, and some of these theories were in fact treated as "Top Secret" by the Americans during World War II. During the 1950s, however, several good statistical textbooks were published that made statistics accessible to researchers who did not have much of a mathematical background. Books such as *Experimental design. Theory and application* by Federer (10), *Statistical Methods* by

Snedecor (36) and *Experimental Design* by Cochran and Cox (9) were examples of statistical textbooks that opened up this field. These books were used as reference books for planning the research at the Dairy Institute in the 1950s and 1960s.

At the Agricultural University of Norway, two people who were particularly involved in the development of statistical mathematics and experimental design were Professors Per Ottestad and Oyvind Nissen. Ottestad was Professor of Mathematics and was particularly concerned that experimental data be treated in a way that was as mathematically correct as possible. Professor Nissen, who was Professor of Horticulture, was perhaps more practically orientated than Ottestad. His modification of certain statistical methods resulted in new statistical programs, including the internationally known FDB-pro and M-stat. Both Ottestad and Nissen made valuable contributions to the design of the relatively large cheesemaking experiments at the Dairy Institute.

At the same time as statistical and experimental design methods were being developed, there was an enormous development in the technology for performing the necessary calculations and large amounts of data could now be analyzed relatively quickly. The advance was first mechanical, as more advanced manual calculators were developed, and later data could be analyzed electronically. During this period, a program for variance analysis was written in Fortran II at the Dairy Institute. The program was designed for the enormous card-punch machine used by Professor of Animal Husbandry, Harald Skjervold. Using this program and the available calculator equipment, it was possible to considerably shorten the length of time necessary to calculate the sum of squares for up to five variables. A number of the cheesemaking experiments that were conducted in the first half of the 1960s were designed to study the effect of several cheesemaking factors on the quality of cheese with eyes.

All of these experiments used the same design concepts and were based on the new expertise in experimental design and data analysis of multivariate experiments at the Agricultural University of Norway and the Dairy Institute. The work is published as reports from the Dairy Institute: Four of the reports concern the making of Gouda-type cheese, and one describes the technology of making Swiss-type cheese from pasteurized milk.

It quickly became obvious that the quality of Jarlsberg cheese was dependent on how well the metabolism of the propionibacteria culture was controlled during the cheese ripening. It was therefore important to gain an understanding of how this could be regulated by technological factors during cheesemaking. Propionibacteria are sensitive to both salt and acid, and thus regulation of the salt, water and acidity levels in the cheese would optimize the desired propionic acid metabolism. In a large cheesemaking experiment, the effect of the following factors on propionic acid fermentation, and thereby cheese quality, were studied: dilution of whey with water calculated as a percentage of the cheese milk volume; addition of salt to whey calculated in g/100 liters of cheese milk; addition of nitrate to the cheese milk calculated as g/100 liters of cheese milk. Four levels of each of the three experimental variables were used, resulting in 64 combinations. The cheeses were made in random order. Four cheeses weighing about 10 kg were obtained from each vat containing 400 liters of milk. These were then brine salted for different lengths of time. The number of days in brine was therefore a sub-plot factor, a terminology used in agricultural research (36).

Results from this research were published in a memorial volume for Professor Ystgaard based on some of his writings which were not published due to his untimely death. Two hundred examples of the manuscript were printed and sent to close colleagues and friends of Ystgaard. In the following paragraph, a short summary of the work described in this manuscript will be provided. It is, however, important to use this work to illustrate how the cheese was developed. A more statistically orientated publication of this work comprises a statistical analysis of 256 cheeses produced in the factorial experiment outlined above (41).

An example of the use of Analysis of Variance in this experiment is shown in Table 1. The Table shows the effect of the experimental design factors on the scores given by four judges when assessing the general quality of the cheese. The table shows that the addition of nitrate, whey dilution and brining time had a significant effect on the general quality of the cheese. It can also been seen from the Table that there is a significant interaction between brining time and whey dilution. This means that the effect that brining time had on the score for general quality given by the judges was dependent on the degree of whey dilution during cheesemaking.

In the statistical data analysis, Mean Squares of the three and four factors interactions were used as an estimate for the error variance. Further, significant effects were divided into linear, quadratic and cubic components which were then tested for significance. However, because so many F-values were calculated using the same estimate for error variance, Ottestad's method for correction of F-values was used. The statistical analysis of the data also included regression

analysis where all effects significant at a 5% level were included as explanatory variables. This relatively extensive use of mathematical statistics for the analysis of experimental data made it possible to optimize the production technology of Jarlsberg cheese in a rational way. The method also made it possible to understand how the experimental factors affected the cheese quality in a way not previously possible in cheese research.

some results from the cheesemaking experiments

The cheesemaking experiments described above were conducted in 1961 and comprised 64 cheese vats and the analysis of 256 cheeses therefrom. The main experimental design factors were: the level of addition of nitrate to the whey, dilution of whey and the level of salt added to the whey. Brining time was a "sub-plot" factor. All of the factors were varied at four levels. The results that provided the basis for the statistical analyses were from the following analyses:

1. Analysis of whey and fresh cheese
    - °SH in whey (titratable acidity)
    - pH in fresh cheese
    - Kg fresh cheese per 100 l milk
2. Analysis of mature cheese
    - Cheese pH
    - % salt in the cheese
    - % salt in cheese moisture
    - Soluble nitrogen, as % of total nitrogen
    - Amino nitrogen, as % of total nitrogen
    - Total concentration of volatile organic acids (ml 0.1 N/200 g cheese)
    - Acetic acid content (ml 0.1 N/200 g cheese)
    - Propionic acid content (ml 0.1 N/200 g cheese)
    - Cheese diameter (cm)
    - Sensory assessment
        - General quality (scale 1-15)
        - Eye formation (scale 1-15)
        - Number of eyes (scale 1-5)
        - Size of eyes (scale 1-5)
        - Cracks (scale 1-5)
        - Consistency (scale 1-15)
        - Taste and aroma (scale 1-15)

The criteria assessed by sensory evaluation could be explained by the design variables and the various analyses performed. Some of the analysis results are described below to show how results from this kind of work can provide information on the quality characteristics of cheese and thereby be used to optimize the cheesemaking technology.

Titratable acidity, expressed as °SH, was measured in the whey at the end of cheesemaking and proved to be crucial for cheese properties such as consistency, eye formation, taste, aroma and general quality. However, the pH in the fresh cheese did not provide a satisfactory explanation of the variation in the quality of cheese from the different cheesemakings. These results showed that °SH was more important than pH as a parameter for predicting mature cheese quality.

experimental design factors

The experimental design comprised the production of cheese without the addition of nitrate and with nitrate added at three levels. Addition of nitrate is a well-known technical aid in cheesemaking to avoid butyric acid fermentation. Butyric acid fermentation in cheese is due to the growth of spore-forming bacteria in the genus *Clostridium*, so-called butyric acid bacteria, and the species *Clostridium tyrobutyricum* is the most common in cheese. Growth of such bacteria in cheese can render it totally inedible, mainly because large amounts of butyric acid are formed. In addition, so much hydrogen is produced that the cheese structure is destroyed. Unlike CO_2, hydrogen is not soluble in the cheese moisture and large holes and cracks are produced in the cheese. The effect of adding nitrate to the cheese milk was dependent on the presence of butyric acid bacteria in the milk and the potential for them to develop in the cheese.

Dilution of the whey during cheesemaking was another experimental factor. Whey dilution is used to reduce the amount of lactose in the cheese curd at the end of cheesemaking. This is done by draining off a specific amount of whey after cutting and stirring. Water is then added, usually about the same as the amount of whey removed.

Lactose is the source of lactic acid production by lactic acid bacteria added as a starter culture. Reduction of the lactose content by dilution of the whey is thus a way to regulate cheese acidity, measured as pH. The acidity of the fresh cheese is important for the development of cheese quality parameters such as taste and consistency. The microbiological and biochemical processes that occur during cheese ripening give the cheese its flavor, consistency and eyes (in those cheeses that are meant to have eyes). These processes are strongly affected by the pH of the fresh cheese.

Dilution of the whey as a method to regulate the content of lactose and thereby lactic acid in the cheese was first used in Norway in the 1930s. Before that, the cheese was prevented from becoming too acidic by employing a higher cooking temperature in the cheese vat, thereby limiting the amounts of whey and thus lactose that were retained in the cheese curd. This process produced a hard cheese with relatively high dry matter content. Emmental cheese is a typical example of cheese that are produced using a high cooking temperature at the end of the stirring period to expel more whey from each individual cheese curd cube. The ability of the cheese curd to withhold whey or its potential to contract and expel whey is dependent on temperature. Raising the cooking temperature results in less whey in the cheese curd and this gives a harder cheese.

The addition of water to the cheese whey allows for regulation of the cheese acidity without simultaneously changing the level of moisture in the cheese. Using such technology, a cheese with lower dry matter and a softer consistency is produced without the cheese becoming too acidic. In an acidic cheese, microbiological and biochemical metabolism of lactose, fat and protein proceeds at a much slower rate and can even be totally inhibited. These metabolic processes are essential for development of the characteristic properties of the cheese. In Jarlsberg cheese, the metabolic conversion of lactic acid to propionic acid, acetic acid and CO_2 by an added culture of propionibacteria is very important. In 1969, Ystgaard published an article from studies conducted at the Dairy Institute wherein he showed the importance of the degree of dilution of the cheese whey on the quality of Small Swiss, Norwegian Gouda and Jarlsberg cheeses (60).

The third experimental factor was the addition of salt to the cheese whey. The addition of salt in the early stages of cheesemaking affects the growth and metabolism of the lactic acid starter culture. The growth and metabolism of propionibacteria are not only sensitive to salt, but also to acid. Salt addition to the whey can therefore be expected to have an effect on the activity of these bacteria during cheesemaking, in the fresh cheese and during ripening. Butyric acid bacteria are considered to be relatively salt sensitive. In addition, although their vegetative cells are destroyed by pasteurization, the spores are not affected. It was therefore important to establish the conditions during cheesemaking and in the fresh cheese that reduce the spores' potential for germination and development into vegetative cells. Although the spores are very salt tolerant, their germination can be prevented by low salt concentrations. The addition of salt at an early stage in cheesemaking, for example to the whey, can therefore help control the growth and activity of butyric acid bacteria in the cheese.

The addition of salt to the whey can affect the production of lactic acid by the starter culture. This will affect the pH in the cheese mass (casein) and its ability to swell and bind water. Low levels of salt both stimulate the growth of lactic acid bacteria and increase water binding in the cheese curd and swelling of casein. Conversely, greater concentrations of salt will inhibit the lactic starter and reduce water binding and swelling of casein. Brine salting is usually used for semi-hard and hard rennet cheeses such as Jarlsberg cheese. After pressing, the cheese is transferred to brine that is almost saturated with salt, usually 20%, at about 10 °C. Brining time, however, varies according to cheese type and especially to the size of cheese. Large cheeses need a longer salting time in order to achieve the necessary final concentration of salt in cheese moisture. In the cheesemaking experiments described here, brining time is statistically considered a "sub-plot". Cheeses were removed from the brine at different times, following the same pattern for all cheese experiments.

the effect of nitrate addition to the cheese milk

In these cheesemaking experiments, butyric acid fermentation proved not to be a great problem. Among all the cheeses produced, only two were judged to be swollen, an indication of butyric acid fermentation. In both cases, this occurred in cheese to which nitrate had not been added. In cheeses where nitrate had been added, a clear connection was seen between increasing nitrate concentration and a reduction in the amount of volatile organic acids formed in the cheese. The propionic acid fermentation was also clearly inhibited. The analysis of data showed a statistically significant

interaction between the addition of nitrate and whey dilution. The addition of nitrate inhibited propionic acid fermentation, but when the whey was diluted, the concentration of nitrate in the whey and the cheese was also reduced. A further effect of whey dilution was an increase in cheese pH.

Whey dilution stimulated the growth of the propionibacteria to such an extent that the inhibitory effect of nitrate became less evident. Interaction between nitrate addition and whey dilution had no demonstrable effect on the production of propionic and acetic acids by propionibacteria, an important indication that this activity was proceeding normally. As a result, cheese to which nitrate was added obtained a better score for general quality and eye formation than cheese made without nitrate addition. The aroma and taste of the cheese were superior, with intermediate levels of nitrate addition and whey dilution. The conclusion was therefore that both too much and too little nitrate had a negative effect on the cheese quality.

In the production of Jarlsberg cheese it is important to note that the effect of adding nitrate is only evident if the milk used contains relatively large numbers of spore-forming butyric acid bacteria.

the effect of whey dilution

As expected, dilution of the whey with water during cheesemaking gave a higher pH in the fresh cheese. This increase was linear with respect to the dilution level and, in fact, approximately 70% of the variation of pH in the fresh cheese could be explained by the effect of whey dilution. The pH in the mature cheese was also significantly affected by whey dilution, but this relationship was quadratic. The difference between pH in fresh cheese and ripened cheese increased with increasing whey dilution.

Analysis of protein breakdown in the cheese during ripening showed that whey dilution had a significant effect on the ripening process. In this type of study, it was usual to follow cheese ripening by measuring the amount of so-called soluble nitrogen and amino nitrogen. The amount of soluble nitrogen, expressed as a percentage of the total nitrogen in the cheese, gives an indication of how much protein has been broken down to peptides, while the amount of amino nitrogen shows how much protein has been completely broken down to amino acids.

This study showed that the soluble nitrogen content increased with whey dilution. The results also showed that the amino nitrogen levels were similarly affected, except that this relationship was linear. Propionibacteria metabolize lactic acid to propionic acid, acetic acids and CO2. This is characteristic for Jarlsberg cheese and propionic acid was the volatile organic acid measured in greatest concentration. Certain lactic acid bacteria can also produce acetic acid from citrate naturally present in the milk. The amount of acetic acid in Jarlsberg cheese is therefore always slightly higher than would be expected from just the propionic metabolism of lactic acid. The study showed that the concentrations of propionic acid and acetic acid increased quadratically with whey dilution. This is to be expected, since propionibacteria are sensitive to acid and whey dilution is a useful technology to limit the acidity of the cheese. The study also showed that it was possible to achieve maximal propionic acid fermentation by combining a particular level of whey dilution with a particular brining time.

Whey dilution significantly affected all of the sensory properties of the cheese, and the consistency was best when moderate dilution was used. Too little dilution gave a hard and crumbly cheese; too high a dilution gave a rubbery cheese. The effect of whey dilution on the score for taste and aroma in the cheese followed similar trends on the whole, and the tendency to form cracks was clearly reduced by increasing dilution levels.

the effect of salt addition to the whey

The addition of salt to the cheese whey also had a significant effect on the results of the various analyses that were conducted.

As expected, the amount of salt in ripened cheese increased with increasing addition of salt to the whey. However, this resulted in slower ripening as the amount of soluble and amino nitrogen decreased linearly with increasing salt addition to the whey, indicating a weaker protein breakdown. The production of propionic and acetic acids was also strongly reduced by the addition of salt to the whey, indicating that the propionic acid fermentation was strongly inhibited.

In cheeses with a low pH, high levels of salt addition to the whey negatively affected consistency and flavor, but, if the cheese was less acidic, the effect on taste was positive and consistency was not affected. As the salt levels in the whey were increased, the graders noted that the cheese more often had a short and hard consistency and sour taste, but that it was less often bitter. The score for the general cheese quality did not seem to be affected by the addition of salt to the whey.

the effect of brining time

Naturally, the concentration of salt in the cheese increased with a longer brining time. The rate of salt uptake was greatest during the first hours in the brine. As the salt concentration in the cheese increased, the increase in pH during ripening was reduced and soluble and amino nitrogen decreased. A reduction in production of propionic and acetic acids was also observed, giving a clear indication that salt inhibited biological activity in the cheese during ripening.

These observations have a clear connection. If the propionic acid fermentation is inhibited due to increasing salt, then less lactic acid is metabolized. Since both propionic and acetic acids are weaker than lactic acid, a greater amount of remaining lactic acid will result in a more acidic cheese. In addition, inhibition of proteolysis during ripening due to increasing salt concentration leads to a less pronounced increase in pH than occurs in cheeses where proteolysis is more active. Thus, both weak propionic acid fermentation and reduced proteolysis will result in a more acidic mature cheese.

Brining clearly affected most of the sensory attributes. An inadequate brining time resulted in the formation of very large eyes, implying that the propionic acid fermentation was too active. This clearly shows that salt can be used to control the propionic acid fermentation at the desired level. Interaction was observed between brining time and whey dilution, and it was possible to identify the optimal combinations of these factors through this work. The combinations that gave optimal eye formation also resulted in the best scores for quality. An optimal combination was also found for the best cheese flavor.

All of this experimental work made it possible to arrive at combinations of whey dilution and brining time that produced the best quality Jarlsberg cheese and was therefore important for the further development of the Jarlsberg cheese technology.

some individual studies on jarlsberg

Both during and after the main research and development of Jarlsberg cheese technology, various smaller studies were conducted to solve problems that appeared during the main cheesemaking experiments.

The team that studied Jarlsberg cheese development was also interested in adjusting the technology to various new technological advances. Similarly, new methods of analysis were employed to study the cheese's quality attributes. Some of these smaller research experiments will be described in this section in order to give an indication of how the research environment at the Institute was concerned with solving a succession of questions of importance for the development and commercialization of Jarlsberg cheese.

an unusual taste and odor

In 1963, an article entitled "Investigations of an unusual odor and flavour defect in cheese" was published (40). Later, further work was done on this defect in order to clarify the cause of this unusual problem (39). A phenomenon had occurred for several years from 1958 – a very distinctive, bad odor and taste in hard and semi-hard cheese, including Jarlsberg cheese. This defect became a very serious problem for the dairies producing this type of cheese, and it was economically very important for them that the cause be identified and eliminated. For a period in 1958, all cheese produced in the Research Dairy had this defect, including all the experimental productions of Jarlsberg cheese. The defect was noticeable only after a while, and by the time the cheese was two to three months old, it was very distinct. An odor developed that was reminiscent of cat urine and was known in the trade as "catty flavor" (cf). When the "cf defect" was investigated, it was discovered that it had previously occurred in other countries. Several cheesemakers related that the defect cropped up from time to time and then disappeared just as abruptly as it had come. No one understood the cause of the defect or which chemical components were responsible. Professor Johns from the Department of Agriculture in Ontario, Canada visited the Institute in the autumn of 1962. He evaluated the "cf cheese" and said the taste was identical to a defect that had occurred in Canadian cheese. Later, in a letter from the same institution in Canada, Professor Irvine confirmed that the defect had often affected Export Cheddar from 1959–1960.

In addition to studying the Jarlsberg cheese produced at the Research Dairy, cheeses with the same characteristic flavor defect were submitted from other dairies. Documentation of the incidence of the defect showed that, even within one day, a single dairy could produce cheese both with and without catty flavor. It was also registered that the taste was strongest in the outermost layer of the cheese, but that the odor varied. The texture and consistency of the cheese were normal, but they noticed that cheese with the cf defect always had a darker yellow color. In trying to understand catty flavor, there had always been a suspicion that sulfur compounds could be involved. If silver chloride was added to grated cf cheese, the odor disappeared, an indication that sulfur played a part in this taste defect. Gas chromatographic analysis of steam distillates showed that cf cheese contained higher concentrations of volatile organic acids than normal cheese. More importantly, the chromatograms from samples of cf cheese also showed a large specific peak that was barely visible in samples from normal cheese, indicating that a specific compound was responsible. The taste could also be removed by vacuum distillation of the fat from cf cheese.

A strain of *Streptococcus faecalis* subsp. *Liquefaciens* and an unidentified yeast were isolated from several samples of cf cheese. Both of these microorganisms were then used in cheesemaking experiments to test whether they were responsible for the flavor defect. Although these cheeses were not of good quality, there was no hint of catty flavor.

Some of the results from these studies indicated that the cause of the defect had nothing to do with the milk, milk handling or the actual cheesemaking, and that the defect probably did not have a dairy-related cause. Studies on canned meat had showed that the compound mesityl oxide could react with sulfur and form the compound 2-mercapto-2-methyl-pentane-4-one, which gave the meat a typical catty flavor. It was shown that mesityl oxide was present in the varnish on the inside of the cans (29). Research was then initiated at the Dairy Institute whereby mesityl oxide was added to the cheese milk. Neither the milk nor the fresh cheese had a catty flavor, but after 14 days' ripening, the distinctive flavor developed in the cheese. An addition to the cheese milk of tiny amounts of mesityl oxide, as low as 0.1 ppm, resulted in cheese that was easily identified by 100 dairy personnel who were used as tasters.

At that time, one particular dairy had problems with catty flavor in Jarlsberg cheese. It was discovered that the dairy had recently re-varnished the shelves in the Ripening Rooms, and an analysis of the varnish showed it to contain mesityl oxide. The considerable incidence of the cf defect in cheese from 1958 to the beginning of the 1960s was later explained by traces of mesityl oxide in the plastic of the rennet containers. From then on, it was recommended that there be no contact between the cheese and varnish, paint and plastic materials that contained mesityl oxide so as to avoid the catty flavor defect in hard and semihard cheeses, like the newly developed Jarlsberg cheese.

the effect of copper on jarlsberg cheese

In Switzerland, Emmental cheese is traditionally made in copper vats while stainless steel vats are used for cheesemaking in other countries. As with Jarlsberg cheese, growth of propionibacteria is very important for the characteristic properties of Emmental. In the studies of Jarlsberg cheese technology it was therefore of interest to investigate the effect of copper on the development of propionibacteria in cheese. Knowledge was needed about the effect of copper on the conversion of lactic acid to propionic acid, acetic acid and carbon dioxide, and whether copper in the milk would have an effect on the cheese quality. Tronstad studied this in his MSc thesis at the Dairy Institute (53).

The problems associated with catty flavor were generally known at the time Tronstad's thesis research was conducted, although the cause was not yet elucidated. It is worth noting that it was suggested in an earlier study that the addition of copper to the cheese milk could possibly block chemical transformations that could lead to off-tastes in cheese (40). German studies had shown that the addition of small amounts of copper to the cheese milk improved the quality of Emmental because it prevented a flavor defect that was reminiscent of hydrogen sulphide (21). However, it was also possible that the addition of copper would negatively affect the quality of Jarlsberg cheese.

Tronstad's MSc thesis was not comprehensive enough to draw clear conclusions. Nevertheless, the results supported what was already known about the significance of copper for the quality of cheeses produced using propionic acid fermentation. Low concentrations of copper in the cheese milk, such as 2.3 and 8 ppm, did not have a negative effect on quality. When higher concentrations were added, the cheese showed no eye formation after three months' ripening, but it was satisfactory after 4.5 months. A tinge of blue color was registered in the outer layers of the cheese. The conclusion to this work was that copper most likely retarded the microbiological and biochemical changes in the milk such that the ripening was somewhat delayed. No connection was found between the addition of copper and catty flavor.

early brining

The period following 1960 saw great technological advances in molding and pressing equipment for cheese. These would save both time and work, but would require adjustments to the pressing and salting technologies. Due to the need for relatively large investment in the new expensive pressing equipment, it was important to discover whether the pressing time could be shortened and the cheese quickly transferred from the press to the brine. Studies were conducted at the Dairy Institute to find out whether, and if so, how, early brining of Jarlsberg cheese would affect the lactic fermentation in the cheese and its final quality.

In 1963, investigations were made into how variations in pressing time and in the time between pressing and transfer into the brine affected lactose metabolism in the cheese (7). Four cheeses from each of 11 cheesemakings were treated in different ways and then later studied for sensory quality and a series of chemical parameters. Two of the cheeses were pressed in a standard steel mold lined with cheesecloth and pressed at 2.5.10 5 Pa pressure for three hours. One of these cheeses was placed in 20% brine immediately after pressing and the other was rested in the mold for 24 hours before transfer to the brine. The two remaining cheeses were pressed in the then recently developed Perfora cheese molds (molds with a strongly perforated surface) at 1.5.10 5 Pa pressure for half an hour. As with the others, one of these was brined immediately after pressing and the other one was brined after 24 hours.

The experiment showed that lactose was not present in any of the cheeses when brining was complete, even though the levels of lactose in the cheeses had varied at the time of brining. At no time during breakdown of lactose was it possible to show the presence of glucose, confirming earlier work in Sweden (35). It was therefore possible to conclude that a spontaneous metabolism of glucose also takes place in Jarlsberg cheese, following cleavage of lactose. No differences could be perceived in the quality of the cheeses that were pressed in different ways and kept for different times before brining.

In a continuation of this work at the Dairy Institute, a pressing time of three hours for cheese in steel molds with cheesecloth and 30 minutes for cheese in Perfora cheese molds was used. As before, some cheeses were brined immediately after pressing and others were brined 15-16 hours after pressing. At the Research Dairy, such a resting period following pressing in steel molds was the standard treatment for Jarlsberg cheese, and these cheeses were therefore regarded as controls in the experiment (48). The texture of cheese that was brined immediately following pressing was significantly poorer if the salting time was as long as for the control cheese. However, if the salting time was reduced, the quality of the cheese improved.

The average salt concentration in ripened cheese showed that early brining led to a greater uptake of salt compared to cheeses that had been brined later provided the same brining duration was used. Cheese pressed in Perfora molds and brined immediately after pressing attained the highest salt content brining time was held constant. This showed that it was important to reduce the brining time if the cheese was to be brined immediately after pressing. It was suggested that for Jarlsberg cheese, a reduction of 24-hours' brining time was suitable.

bactofugation of cheese milk

As mentioned in the section "The effect of nitrate addition to the cheese milk" page 63, one of the challenges with the production of cheeses like Jarlsberg cheese is to prevent the development of anaerobic spore-forming bacteria such as *Clostridium tyrobutyricum* (butyric acid bacteria) during ripening as this can render the cheese unfit for human consumption. A well-known aid to this end was the addition of nitrate to the cheese milk or to the whey, but a possible alternative to this could be what was known as super-centrifugation, bacteria-centrifugation or bactofugation. Although the pioneer work on this technique was actually done in the early 1950s, it was further developed in the early 1960s to w the amount of bacteria in milk at the dairy. Many studies on the use of bacteria-centrifugation were conducted at that time and published in the mid-1960s.

Because the specific weight of bacteria is greater than any of the components of milk, it is therefore possible to separate the bacteria from the milk by centrifugal force. At an early stage, the company Alfa Laval constructed a bacteria centrifuge called a "Bactofuge". Since then, the separation of bacteria from milk in the dairy industry has often been called "bactofugation". In the bactofuge, the bacteria are continually removed from the milk through a special valve in the outside wall of the separator bowl. If optimal conditions are used, the bactofuge can reduce the number of bacteria in milk by about 90%. Bacteria spores, such as those from *Clostridium tyrobutyricum*, are heavier than vegetative bacteria

cells, and also cells containing spores are heavier than other bacteria cells. Because of these properties, the spore content in milk can be reduced by 99% by bactofugation.

Around 1964-65, the Dairy Institute began experimenting with cheesemaking from bactofuged milk. After preliminary investigations, a more comprehensive experiment was begun at the end of 1965, producing Jarlsberg cheese from bactofuged milk (45). The research comprised 23 cheese productions in full commercial scale, separated into two periods. The Institute was able to borrow a bactofuge from Alfa Laval with a capacity of 6,000 liters of milk per hour and a centrifugal force of nearly 10,000 x g. The centrifuge was mounted in the milk line in the Research Dairy's standard milk treatment line, immediately after the pasteurizer's holding cell. The milk was thus bactofuged immediately following pasteurization and at the temperature used for pasteurization.

The thermostat for the pasteurizer had a minimum temperature of 53°C. Thus, both this temperature and 73°C were chosen as the two alternative bactofugation temperatures in the preliminary experiments. In the main experiment, however, only 73°C was used. In the preliminary experiments, bactofuged cheese milk both with and without added nitrate was used. It was found, however, that cheese from bactofuged milk with added nitrate ripened too slowly, so this combination was not used in the main experiment. The control cheese was produced according to the Jarlsberg cheese technology that was normally employed in the Research Dairy. These studies provided many interesting practical results that were of use for production of Jarlsberg cheese from bactofuged cheese milk. It was demonstrated that pasteurization and bactofugation at 73°C reduced the number of bacteria by over 99% and that the number of anaerobic spore-formers in the bactofuged cheese milk was very low, usually under one bacterium per ml milk. The milk loss from the bactofuge varied between 1.7 and 2.4% of the amount of milk treated, which was unacceptably high. Further development of the bactofuge technique therefore included sterilization of the lost material so it could be returned to the cheese milk.

It was also discovered that bactofugation reduced the protein content in milk by about 0.2%, which resulted in a lower cheese yield. Bactofugation produced a cheese with fewer eyes. Despite this, however, sensory assessment of the general quality could not distinguish between the experimental and the control cheese. The conclusion was therefore that it was possible to make Jarlsberg cheese without the addition of nitrate to the cheese milk, provided bactofugation was used.

taste and flavor compounds in jarlsberg cheese

Various chemical analyses were important research tools at the Dairy Institute. When the work on the development of Jarlsberg cheese began, it was essential to be able to analyze the content of various compounds responsible for taste and flavor in both mature cheese and at various stages of ripening. Researcher Alf Svensen held a key position in the work with the chemical analyses. An important part of some of this work was analysis of the cheese by gas chromatography (50). The Institute owned one of the best gas chromatographs available at the time, but it soon became apparent that more advanced studies of flavor compounds in dairy products and cheese required access to mass spectrometry. It was difficult to progress quickly in the identification of all the chemical compounds that formed different peaks on the gas chromatograms unless gas chromatography was combined with mass spectrometry. Unfortunately, this equipment was not made available for research at the Dairy Institute.

Figure 2 is an example of a chromatogram from a gas chromatographic analysis of Jarlsberg cheese. The Figure shows the characteristic large peaks of propionic acid and acetic acid formed from lactic acid by propionibacteria. Lactic acid is produced by the lactic acid bacteria starter culture used to acidify the milk and to give the cheese its high content of bacteria that are so important for the cheese-ripening process.

scanning jarlsberg cheese with computer tomography

In the years following the end of the developmental period for Jarlsberg cheese, researchers and MSc students at the Dairy Institute conducted a series of studies on Jarlsberg cheese and propionibacteria. It is not possible to go into the details of all these studies, but one particular work must be mentioned because it represents the completely novel use of a new analysis methodology for cheese research (46).

Cheese researchers have always wanted to study eye formation in cheese without damaging the cheese by cutting or puncturing. A so-called non-destructive method for studying cheese eye formation has therefore been needed. The Department of Animal Husbandry at the Agricultural University had a computer tomograph that they used to study the

composition of animal bodies *in vivo*. The researchers at the Dairy Institute were interested to see whether this instrument could be used to study eye formation in cheese without damaging it.

Sampling a cheese during ripening, particularly cheese with rind, can have unfortunate consequences. First of all, there is a risk of mold infection at the point of cutting, and such an infection will influence the chemical conversions during the further ripening of the cheese. Second, puncturing the rind causes a change in the balance of gas pressure in the cheese and probably an increase of the redox potential. Such a cheese would therefore not behave normally during further ripening. It is possible to sample other cheeses from the same production, but there is no way to be certain whether these are identical in all respects to the cheese first sampled. Also, such an experiment is extremely expensive when so many cheeses have to be sampled. In some cases, the number of cheeses available for analysis from each production becomes a limiting factor for the size of the experiment.

In 1983, 12 cheese productions on different weekdays were selected. Cheeses from four different positions in the cheese prepressing vat were scanned, and the development of eyes was followed in exactly the same place in two cheeses from each production. For each cheese, six to seven scans were made at different times following production: once in the fresh cheese after brining, three times during the Warm Room period, when the eyes are formed, once immediately after transfer of the cheese to the refrigerated Ripening Room, and one or two scans after the cheese was exposed to temperature stress after 13 weeks. Computer tomography proved to be very useful because it successfully showed eye formation as the gas was produced in cheese and could thus be used to study the factors affecting eye formation. Figure 3 shows that it was possible to demonstrate that the greatest gas production took place in the second week in the Warm Room. In Figure 4, the development of eyes can be seen on the cut surface of five cheeses during 13 weeks following production.

a unique cheese type

As previously explained, the research and development of Jarlsberg cheese was originally based on the production technology for Gouda cheese. This technology is largely preserved in today's Jarlsberg cheese technology. However, in our opinion, Jarlsberg cheese should be categorized as a unique cheese type and not compared to either Gouda or any of the Swiss cheeses.

Jarlsberg cheese cannot be characterized as a Swiss cheese despite the fact that propionibacteria are responsible for the eye formation and the development of flavor in the cheese is reminiscent of Swiss. Nevertheless, in 1963, Professor Ystgaard wrote in a compendium that Jarlsberg cheese was a type of Swiss cheese (58). Others have also chosen to characterize it as a so-called "Swiss-type variety" (31, 37). However, this cannot be proved or disproved since there is no acknowledged international definition of a Swiss cheese variety that clearly distinguishes itself from other cheese types (37).

Jarlsberg cheese's consistency, dry matter content, lactic acid bacteria flora, ripening progression and other quality characteristics deviate from that in a Swiss cheese. In a comprehensive article written by Anders Oterholm in 2004, "Norwegian cheeses in a historical perspective", a good description is given of the sorts of considerations that were made in the USA when Jarlsberg cheese was categorized in the American cheese classification system. Here, too, the starting point was a comparison between Jarlsberg cheese and Emmental. The conclusion of these discussions was that Jarlsberg cheese differed from Emmental in several ways (27):

- Production techniques
- The microorganisms used in the production
- Chemical composition including dry matter content and volatile organic acids
- Sensory characteristics:
    - -Eye formation: even eye distribution with a diameter of 10 -25 mm, generally smaller than Emmental
    - -Consistency: hard to semi-hard, pliable and markedly softer and drier that Emmental
    - -Taste and aroma: mild, slightly sweet, sour and nutty, but different from the stronger, sweeter and more nutty taste of Emmental

The conclusion was that even though Jarlsberg cheese has certain similarities to Emmental, the production process, chemical composition and sensory qualities were so different that Jarlsberg cheese should be classified as a unique cheese

variant that would be better placed in another group in the American cheese classification system. The conclusion of this evaluation process was that Jarlsberg cheese was to be considered a unique and distinct cheese type in the USA.

The mesophilic cultures used for the production of the cheese contain the following types of bacteria:

- *Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis*
- *Lactococcus lactis* subsp. *lactis*
- *Lactococcus lactis* subsp. *cremoris*
- *Leuconostoc mesenteroides* subsp. *cremoris*

A culture such as this is responsible for the acidification of the cheese milk and the cheese, and produces a certain amount of CO_2 through breakdown of the citric acid in the milk and through the leuconostoc's heterofermentative breakdown of lactose in the milk and cheese. Some of the mesophilic lactic acid bacteria also produce volatile aroma components, primarily from citrate metabolism, and participate with their proteolytic enzymes in cheese ripening.

When using this type of culture, it is very important that the cheese cooking temperature does not exceed about 40 °C as this would inhibit the bacterial growth. In Gouda production, the cheese cooking temperature is usually between 36-39°C and because Jarlsberg cheese technology is in principle like that of Gouda, similar temperatures are used (47). Both this heating and the subsequent stirring are very important for controlling the cheese moisture content, and consequently for the consistency and the ripening that then takes place. Jarlsberg cheese and Gouda have approximately the same dry matter content: 58.5% (1, 2). Both Jarlsberg and Gouda-type cheeses in Norway are now produced in several varieties with different fat content, but originally both cheeses contained 45% fat in the cheese dry matter. Both Jarlsberg cheese and Norvegia (a Norwegian Gouda-type) with 45% fat in the dry matter will therefore have approximately the same amount of moisture in the fat-free cheese: 60-57%. Jarlsberg cheese must therefore be regarded as a semi-hard rennet cheese both with regard to the International Dairy Federation (IDF) classification and in relation to FAO/WHO cheese standard (47).

The true Swiss cheese is called Emmental and is traditionally produced from unpasteurized milk. However, if the technology for Jarlsberg cheese and Emmental are to be likened, we must compare with the production of Emmental from pasteurized milk because Jarlsberg cheese was developed with pasteurized milk as the starting point.

The technology for producing Emmental is considerably different from that used for Gouda. First, a different type of lactic acid bacteria culture is used, namely a thermophilic culture. This culture contains lactic acid bacteria that grow at, and tolerate, higher temperatures than the mesophilic cultures used to produce Gouda. Pure cultures of lactic acid bacteria for Emmental usually comprise two thermophilic cultures: *Streptococcus thermophilus* and *Lactobacillus helveticus* (47). Other sources mention the possibility of using other thermophilic cultures such as *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Lactobacillus lactis* (24, 26, 33, 37). Mesophilic species of lactic acid bacteria, such as *Lactococcus lactis* subsp. *lactis* and *Lactococcus lactis* subsp. *cremoris*, may be used in addition to the thermophilic cultures (33, 37). In comprehensive studies at the Dairy Institute of Swiss-type cheese produced from pasteurized milk, a mixed mesophilic culture was used, of the type mentioned earlier, in combination with *Streptococcus thermophilus* and *Lactobacillus helveticus* (62).

The use of a thermophilic culture enables the use of a higher cooking temperature during the production of Swiss-type cheese. Swiss Emmental is produced as a very large cheese weighing between 65 and 110 kg. A cheese of this size requires a high dry matter content in the fresh cheese curd in order to retain its shape, and this is achieved by using a high cooking temperature (31). Different sources quote different cooking temperatures. For Emmental, for example, a temperature of 52–54 °C may be used, and the temperature during pressing can remain as high as 50°C for several hours after hooping. The cheese mass will become considerably drier than if lower temperatures are used, and many undesirable microorganisms will also be largely eliminated. American researchers have quoted the use of cooking temperatures of 50–53°C for Emmental (24, 33). In the production of Finnish Emmental, a cooking temperature of 53–55°C is used (22).

In studies of Small Swiss cheese at the Dairy Institute, cooking temperatures from 37 to 46°C were used (62). Temperature was one of the experimental factors employed when developing the technology for producing a Small Swiss cheese with an average weight of 2.5 kg. With a cheese of this significantly smaller size, it is less important for their shape to have as high dry matter as Emmental. The researchers found that a cooking temperature of 46 °C combined with a 5% whey dilution and a Warm Room temperature of 19 or 22 °C produced the best flavor in Small Swiss cheese.

Good results were also obtained in relation to other cheese characteristics when a cooking temperature of 43°C was used. However, none of the temperatures that gave good results for Small Swiss can be used for Jarlsberg cheese production.

Emmental is usually produced with about 45% fat in dry matter. Based on published figures for Finnish (22), French (33), German (23) and Swiss (31) Emmental, this type of cheese contains 51.5–53.5% moisture in fat-free cheese. This places Emmental as a typical hard cheese in the classification laid down by the IDF and FAO/WHO, whereas Jarlsberg cheese is classified as a semi-hard cheese according to this classification (47).

The propionibacteria that are used in both Jarlsberg and Swiss-type cheeses give them a characteristic taste. The distinctive eye formation and taste in both these cheese types are partially ascribed to the propionic acid fermentation that occurs, and the taste profiles of these two cheese types will therefore naturally have certain characteristics in common. It is clear, however, that the biological changes that take place in Jarlsberg cheese and in Emmental differ on several counts. In Jarlsberg cheese, volatile aroma compounds are formed from the metabolism of citrate in the milk by mesophilic lactic acid bacteria, whereas the thermophilic bacteria used in the production of Emmental are citrate negative. Thus, in Jarlsberg cheese, a compound such as diacetyl can contribute to the taste of the cheese. It is also generally known that lactobacilli of the type normally used for Emmental production have far greater proteolytic powers than the mesophilic bacteria used for Jarlsberg production. These cheeses will therefore have a different protein breakdown profile and will thus be expected to have different taste profiles. The products are also noticeably different with respect to ripening time. Jarlsberg cheese is normally ready for sale after about three months' ripening, whereas Emmental is usually not considered mature until about six months (31, 47).

When we sum up all these differences between Emmental and Jarlsberg cheese, it is clearly wrong to characterize Jarlsberg cheese as a Swiss cheese type despite the fact that Swiss cheese is not a clearly defined type. This has led to occasional use of the name of "Goutaler" a new class of cheese, actually a cross between Gouda and Emmental (52). This type of cheese is now produced in several European countries, but has variable quality characteristics. Cheeses such as the Dutch "Leerdamer", the German "Alpsberg" and "Felsberg" are grouped as "Goutaler" cheeses and are in the same group as Jarlsberg cheese. Jarlsberg cheese, however, is considered the prototype for cheeses in the "Goutaler family" (52).