FLAVOR DEVELOPMENT AND MICROBIOLOGY OF SWISS CHEESE–A REVIEW

I. MILK QUALITY AND TREATMENTS[1, 2]

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Abstract

This review, appearing in four parts, deals with relationships between flavor development and the microbiology of Swiss cheese. Body and texture characteristics of Swiss cheese also will be discussed, however, to a lesser degree and, wherever possible, in association with the flavor of Swiss cheese.

The first section, presented here, discusses use of raw milk and how the bacterial content of raw milk influences Swiss cheese quality. Thereafter, other milk treatments used in the cheese industry are discussed. They include clarification, heat-treatment, homogenization, and H_2O_2-catalase treatment of cheese milk. Changes in microbial flora and subsequent effects on Swiss cheese quality are included. Production of Swiss cheese with desirable body, flavor, and texture characteristics depends on use of low bacterial count, properly clarified milk. Mild [68 C (154.4 F) to 72 C (161.6 F) for 15 to 18 sec] heat treatment is recommended. Homogenization of cheese milk is not used and the H_2O_2-catalase treatment is not necessary.

Of the different varieties of ripened cheeses, Swiss cheese is important ranking third in total production in the United States after Cheddar and Mozzarella cheese. Swiss or Emmentaler cheese is characterized by having an elastic body with smooth texture; uniform, smooth eyes; and a unique, nut-like, sweet flavor. These factors are so closely interrelated that poor texture and irregular eye distribution can arise from a poor body. Flavor also may depend, to a certain degree, on this relationship.

The name Swiss cheese implies that it was first produced in Switzerland. It is called Emmentaler cheese in Europe and originated in the Emme Valley, Canton of Bern, in Switzerland about the 15th century *(89)*. Other spellings of Emmentaler may be found in the literature. In the United States, production of Swiss cheese originated in the 1860's in Ohio. This cheese originally was made in wheels with firm rinds, individual wheels weighing up to about 100 kg (225 lb) each; large amounts now are made in rindless blocks weighing about 36.4 to 40.9 kg (80 to 90 lb) *(116)*. To facilitate cutting and packaging operations, some plants make larger blocks weighing about 91.0 kg (200 lb).

Traditionally, Swiss cheese was made from raw milk, but in 1938, a method to make Swiss-type cheese from pasteurized milk was developed in Iowa *(136)*. This method was closely related to those used in Denmark, but has since been further modified *(345)*. European countries other than Denmark also have developed Swiss-type cheeses. A variety closely related to Swiss cheese is Gruyére, originally produced in France since about 1288 *(70)*. This cheese is made in smaller wheels and undergoes surface ripening, therefore having a stronger flavor arising from the proteolytic activity of the surface-grown microorganisms. There are other cheeses whose distinctive characteristics depend on growth of propionibacteria. They all possess eyes of various sizes and have the related nut-like, sweet flavor *(345)*.

High-quality Swiss cheese is dependent on microbial fermentation of milk constituents. Propionic-acid bacteria are necessary to produce eyes and the typical flavor. *Streptococcus lactis* and *Streptococcus cremoris* are sometimes included for acid production, *Streptococcus thermophilus* to improve general quality, and *Lactobacillus* species to control abnormal fermentation *(141)*. Propionic-acid bacteria are the special microorganisms of Swiss cheese; their presence in large numbers is necessary to develop the characteristic flavor and eyes that distinguish Swiss cheese and related varieties from all other cheeses.

Traditionally, Swiss cheese flavor has been evaluated organoleptically. Chemical methods were not sensitive enough, and only the influence of compounds such as propionic and acetic acid could be evaluated with some degree of accuracy. With the development of chromatographic methods *(267)* to analyze for amino acids and fatty acids *(267)*, chemical analysis of Swiss cheese flavor compounds became possible *(165)*. These compounds, however, do not completely account for the unique flavor of Swiss cheese. In 1952, gas-liquid chromatography

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[2]This review will appear in four parts: I. Milk Quality and Treatments; II. Starters, Manufacturing Processes and Procedures; III. Ripening and Flavor Production; and IV. Defects. Literature citations will follow part IV.

was introduced *(177)* and was first used in flavor chemistry in 1956 *(85)*. Since then, development of flavor chemistry has been extremely rapid. Most flavor compounds are volatile, and careful methods of isolation are necessary *(460)*. The concentration of these volatile compounds usually is very low, and sensitive analytical methods, such as mass spectrometry and nuclear magnetic resonance, are now successfully used for identification *(427)*.

Identification of flavor components in Swiss cheese generally has been avoided by most investigators, but much work has been devoted to other cheese types, especially Cheddar cheese, and the literature concerning the flavor of Cheddar cheese is abundant *(72, 115, 125, 147, 262, 266, 349, 373, 376)*. Some of the more significant work on Swiss cheese flavor has been done by Langler *(241, 244)*.

This article will review how flavor of Swiss cheese is affected by milk quality, starter microorganisms, manufacturing processes, and ripening. Defects in Swiss cheese also will be discussed.

MILK QUALITY AND TREATMENTS

Raw milk

Traditionally, Swiss cheese was made from raw milk, and it was recognized early that the bacteriological condition of milk was an important factor in cheese quality. Studies in the United States in 1939 showed that, if kettle milk had a methylene-blue reduction time of <3 hr, only one-third of the cheeses made from that milk would be of high quality. When the reduction time exceeded 3 hr, two-thirds of the cheeses were of excellent quality *(362)*. Therefore, raw milk used to manufacture Swiss cheese should have a reduction time between 3 and 6 hr *(116)*.

Both the bacteriological condition of the milk and the types of bacteria present are important. Presence of coliforms in large numbers will severely reduce quality. About 30% of different strains of coliforms isolated from milk inhibited lactic-acid bacteria; *Enterobacter aerogenes* generally inhibited lactobacilli, and *Escherichia coli* inhibited streptococci *(350)*. Presence of many coliforms generally led to failure of acid production and, therefore, production of cheese of inferior quality. Some micrococci promote, while others inhibit, growth of lactic-starter bacteria, with resultant diminished acid production. By reducing the numbers of these bacteria in cheese milk, defects in cheese related to inadequate acid production were eliminated *(350)*. Anaerobic spore-formers in raw milk may lead to "blown" cheese. Milk from silage-fed cows often is implicated in these instances. There are different opinions about the importance of milk from silage-fed cows, but most research workers believe that cheese made from milk of this sort is more prone to blowing. Constantinescu and Gondos *(63)* determined that feeding cows silage after instead of before milking resulted in a decrease in the number of anaerobic spores in the milk. In contrast, Kiermeier et al. *(196)* found no correlation between blown cheeses made of milk from silage-fed cows and of milk from cows not fed silage.

Because large quantities of milk are needed for cheese production, the manufacturing plant often stores milk overnight. Rapid cooling of milk to 10 to 12 C (50 to 53.5 F) instead of the usual overnight cooling usually improves cheese flavor with no effect on eye formation *(410)*. Now, modern technology dictates use of lower storage temperatures and necessitates use of much longer storage periods.

In collection of milk from the farm, procedural changes have occurred; a primary example is the shift from can to bulk collection. Refrigerated farm-storage of milk for 2 or 3 days before collection may produce changes in the physical, chemical, enzymatic, and microbiological conditions of the milk. Multiplication of psychrotrophic microorganisms may sometimes be severe enough to partly destroy fat-globule membranes and promote lipolysis. Coagulation by rennin also is retarded; this problem, however, can be remedied by *(a)* adding soluble calcium salts, usually calcium chloride, *(b)* adding more rennet, *(c)* using a somewhat higher renneting temperature, *(d)* acidification, and *(e)* using a somewhat higher cooking temperature *(357)*. Properly conducted refrigeration has advantages that outweigh the disadvantages, and Swiss cheeses made from refrigerated milk are whiter and have fewer but larger eyes, but otherwise show no difference in quality *(425)*. To assure uniformity in make procedure and cheese quality, larger manufacturing plants prefer commingled storage in large silo tanks and use "holdover" milk.

In experiments in Switzerland, Emmentaler cheeses were made from milk with a normal somatic cell content (10,000-50,000/ml, CMT-negative) and from milk with increased cell content (310,000-650,000/ml, CMT-positive). Curd elasticity and firmness developed slower and to a lesser extent in cheeses made from CMT-positive milk. The cheeses needed a longer ripening period, and more flavor defects were noted. Yield also was lower *(87)*.

Clarification

Clarification of raw milk leads to marked and consistent improvement in cheese quality. A decrease in cheese moisture content and yield may be noticed after clarification, and the percentage of fat

in the whey may increase *(430)*. Clarification decreases the tendency of fat to form aggregates on standing. Most leucocytes, some bacterial cells, and about 98% of the clostridial spores are found in the slime. This treatment leads to an increase in multiplication rates of starter organisms and improvement in the methylene-blue reduction test. The oxygen content of the milk is increased, and carbon dioxide content is decreased. Clarification causes the oxidation-reduction potential to decrease more rapidly in milks held at 30 C (86 F). Clarified milk also has a slightly lower stability to alcohol *(268, 423)*.

Removal of extraneous and cellular materials and more uniform distribution of bacteria are the most important contributions of clarification. Removal of these materials from milk leads to a decrease in eye number and an increase in eye size and uniformity. Swiss cheeses made from clarified milk also were found to contain fewer anaerobic spores, but formation of lactic and propionic acid and other aspects of the ripening process were slower in cheeses made from clarified milk *(268, 408, 411, 423)*. Matheson et al. *(268)* mentioned that firmness of the cheese increased and the incidence of the "glaesler" (glass) defect also increased when cheese was made from clarified milk. Detrimental effects of clarification on cheese quality diminish through clarifying milk at a relatively low temperature [21 C (70 F) instead of 32 C (90 F)] and slow bowl speed (3500 rpm instead of 7000 rpm); but the quality of cheese improved by decreasing the flow rate of milk by one-half and by increasing the temperature from 21 to 32 C. Bactofugation, or bacterial centrifugation, lowers the number of eyes as well as the bacterial spore count in the cheese *(423)*. It may reduce yield. This process has been studied in the United States but does not seem to have been adopted by Swiss cheesemakers to any extent *(345)*.

Heat-treatment of raw milk

Pasteurization is defined by the U. S. Public Health Service as the heating of milk in approved apparatus to at least 62.83 C (145 F) for a minimum of 30 min (LTLH) or heating to at least 71.67 C (161 F) for a minimum of 15 sec (HTST) *(430)*. Pasteurized milk is used to manufacture many cheese types, but its use for Swiss cheese production has caused difficulties. Most Swiss or Swiss-type cheeses made today are manufactured from heat-treated milk. In Switzerland, much of the Emmentaler cheese still is made from clarified or unclarified raw milk.

The first experimental Swiss cheese made from pasteurized milk was manufactured by von Freudenreich and Orla-Jensen in 1899 *(122)*. They inoculated milk with various microorganisms and concluded from their experiment that pasteurized milk was unsuitable to produce Swiss cheese. Their negative results may be explained by the use of low quality milk, and by too little knowledge of the beneficial bacterial flora of Swiss cheese. Later experiments, in the 1930's, showed that pasteurization had a beneficial effect through destruction of pathogens and other harmful bacteria, but made it necessary to add pure cultures to obtain good-quality Swiss cheese. Flash-pasteurization is suitable for treating good-quality milk, but earlier workers considered the holding method better for milk of lesser quality *(124)*. It is extremely doubtful if any plants in the U. S. today use the holding method for milk heat-treatment for Swiss cheese manufacture.

One of the first successful methods to produce a Swiss-type cheese from LTLH pasteurized milk was introduced at Iowa State University in 1938 *(136)*. A modified cooking procedure was introduced and involved removing a portion of the whey and raising the temperature of the curd to 38.8 C (102 F) by addition of hot water. This process produced cheese of good quality and has been used successfully in other countries *(345, 469)*.

The most important advantage of pasteurization is the inactivation of much of the undesirable microbial flora, but it also has the adverse effect of reducing desirable flora if present. Milk, flash-pasteurized at 76 to 78 C (168.8 to 172.4 F) for 15 sec, was used by Demeter and Janoschek *(78)* to make Swiss cheese. They found that addition of a pure lactic-starter culture and a special *Lactobacillus casei* culture was necessary to produce quality cheese. From the viewpoint of flavor and aroma, the cheese was improved, although it was downgraded because of the development of splits. The effect on Swiss cheese quality of flash-pasteurization over a range of 64 to 94 C (147.2 to 201.2 F) was studied by Olšanský and Vychytová *(307)*. Their results showed that cheese of high quality could be made with milk pasteurized in the range of 68 to 74 C (154.4 to 165.2 F) and that 72 C (161.6 F) with 15-sec holding time yielded the most desirable cheese. By reducing the temperature under 68 C (154.4 F), survival of deleterious bacteria was excessive, and their presence interfered with the ripening process. At temperatures above 74 C (165.2 F), reactions between the casein and whey proteins took place, resulting in deterioration of consistency of the cheese body and eye development. This deterioration was noted by the development of an "unclean sweet" taste and splits or cracks in the body of the cheese.

In Switzerland, it is thought that pasteurization is too severe a heat treatment for cheese milk. Therefore, a low-temperature heat treatment, "thermisa-

tion," of milk in the range of 56 to 65 C (132.8 to 149 F) for about 3 sec is utilized. Heat treatment at 56 C (132.8 F) caused fewer eyes to form, but yielded cheese of high-quality flavor and texture as compared with cheese made from raw milk *(41)*. Even at 56 C (132.8 F), the numbers of bacteria were reduced. Coliforms showed strain differences in vulnerability, but at 61 C (141.8 F) for 5 min, all coliforms tested were greatly reduced in number. *Micrococcus* species were variably resistant, and some even survived pasteurization. *Streptococcus lactis* was not heat resistant, but S. *thermophilus* easily survived the treatment. The number of propionic-acid bacteria was appreciably reduced above 58 C (136.4 F) *(293)*.

The types of microorganisms present in raw milk before pasteurization severely affected the ripening process of Swiss cheeses. A "normal" milk flora slightly reduced the lactic-acid fermentation in cheese and enhanced defects in eye formation, such as splitting. Large numbers of coliforms stimulated lactic-acid production, but adversely affected eye formation and flavor production. Yeasts accelerated the lactic-acid fermentation, increased body elasticity, and augmented gas formation, but had a negative influence on flavor. Anaerobic spore-formers inhibited lactic-acid formation, caused production of blowholes and splits, and the cheese had an unpleasant flavor *(309)*. Therefore, the initial microbial quality of the raw milk has an influence on cheese quality, even with pasteurization or other less severe heat treatments.

Homogenization of cheese milk

The first experiments with homogenized cheese milk resulted in cheeses of low quality because body and flavor defects developed. Later experiments using homogenized-pasteurized cheese milk in comparison with nonhomogenized milk showed that the milk lost less fat into the whey, cheese yields were increased, and the fat leakage from the cheese was reduced. The highest-quality cheese was obtained from milk homogenized at 500 psi, while higher homogenization pressures resulted in cheese of lower quality *(328)*. With homogenization at 2000 psi and addition of propionic-acid bacteria and a *L. casei* culture, the quality was approximately the same as that of control cheese *(329)*. Again, it is doubtful if any manufacturing plants in the U. S. use this treatment.

H_2O_2 — catalase treatment of cheese milk

Another method to control the microflora of cheese milk is addition of hydrogen peroxide. Benefits of this treatment have been related to the supposed selective action of hydrogen peroxide on microorganisms commonly causing defects. Defect-forming types of microorganisms are claimed to be largely destroyed, while many of the desirable organisms are assumed to survive. Roundy *(364)* found that 0.02 to 0.05% hydrogen peroxide was sufficient to reduce the number of bacteria in cheese milk, while Demeter et al. *(80)* determined that a higher percentage of 0.2% was best for treatment of milk for cheese manufacture. This difference may have resulted because Roundy *(364)* heated the milk at 52 C (125.6 F) for 25 sec after addition of hydrogen peroxide, whereas Demeter et al. *(80)* heated the milk to 52 C (125.6 F) before hydrogen peroxide addition to destroy the natural catalase of milk. A hydrogen peroxide treatment of 30 min was used in both instances. Catalase was added to destroy the residual hydrogen peroxide.

A 0.2% concentration of hydrogen peroxide in the cheese milk reduced the numbers of acid-producing bacteria during the first 20 min, and the number then remained constant. Coliforms were completely destroyed in 10 min. The kill of propionic-acid bacteria was negligible according to Demeter et al. *(80)*, but Roundy *(364)* determined that *Propionibacterium shermanii* was adversely affected. Bacteria were not appreciably reactivated during catalase treatment. This treatment of cheese milk is easily effected and can improve cheese quality *(430)*. It is, however, expensive and should not be used as a substitute for farm sanitation and proper milk handling and cheese manufacturing procedures *(345)*. Use of the H_2O_2-catalase treatment for milk also is believed to interfere with typical flavor development in resultant cheese.