Cheese making transforms milk into either fresh or ripened cheese, with the aging process ranging from weeks to years. The first days establish the chemical characteristics of the cheese before it begins to age, setting the stage for microbial ripening. Of the plethora of organisms in new cheese, some remain viable and may proliferate during aging, others will be suppressed, while still others may be suppressed initially and then favored or vice versa, depending on the chemical environment to which they are subject. To add to this complexity, the chemical environment within the cheese may change dramatically as ripening progresses. Much of this complexity can be reduced to a few scientific principles that cheese makers vary systematically to achieve a wide range of outcomes. The historical development of distinctly different cheese varieties involved modulating these basic principles.

The goal of this two-part series is to paint a conceptual picture in which the microbiology of cheese making is seen to fit closely with other, basic cheese making practices and the scientific principles that underpin them. In part one, we focus on the early steps in making cheese, where the chemistry and physical properties are set for the subsequent microbiologically driven ripening phase.

The Basics of Milk Coagulation

Milk coagulation is the key first step in which casein, the major protein in milk, and fat combine to form curds, while most of the water and lactose form whey. Cheese makers of old discovered three ways to coagulate milk, and their use gave rise to three distinct families of cheese: acid coagulated, acid-heat coagulated, and rennet coagulated. Cheeses from the first two families are almost always consumed fresh because of their high moisture content and, in the case of acid-heat coagulation, high pH, that make them prone to spoilage and rotting as they age. In contrast, rennet coagulation yields cheeses with much lower moisture content that support desirable microbial transformations during aging.

Rennet enzymes, which derive from a variety of animal, plant, and microbial sources, are aspartic proteinases that preferentially hydrolyze and destabilize casein, leading it to coagulate. About 80% of the protein in milk consists of casein molecules that form spherical macromolecular micelles that each contains about 10,000 molecules. Casein micelles also contain abundantly dispersed nanocrystals of calcium phosphate.

Rennet coagulation is a two-step process that begins with the enzymes hydrolyzing casein, especially along the micelle surface. This activity triggers a nonenzymatic phase, during which the spherical micelles progressively lose their ability to interact with water molecules, forcing them to interact instead with one another to form aggregates and chains. As coagulation progresses, the micellar chains increase in length and thickness, interlocking to form a three-dimensional, net-like matrix that entraps water and other major components of milk, including lactose, fat, whey proteins, and minerals (Fig. 1).

A critical feature of rennet curd is its capacity,
called syneresis, to contract and expel whey. Indeed, cheese makers take pains to control syneresis precisely so as to achieve a wide range of moistures levels within their cheeses, opening the way to producing an extraordinary diversity of ripened cheeses. Thus, the discoveries of various means to control whey expulsion through innovations in cutting, cooking, pressing, and salting are major milestones in the history of rennet-coagulated cheese making.

Rennet coagulation produces curds that are rich in calcium phosphate, whose capacity to absorb and neutralize hydrogen ions explains its high buffering capacity. However, as lactic acid accumulates when starter cultures digest lactose, that buffering capacity decreases when micellar calcium phosphate dissolves into the whey and is lost from the cheese. Therefore, the greater the rate of lactic acid production during cheese making, the greater the loss of calcium phosphate to the whey, and the lower the buffering capacity retained in the cheese. Buffering capacity is extremely important because it helps to determine the cheese pH at the start of ripening. Cheeses in which acid forms slowly are rich in calcium phosphate and retain a strong buffering capacity.

Thus, it is possible to produce rennet-coagulated cheeses that range widely in both moisture content and initial pH by modulating the rates at which whey is expelled and lactic acid is produced. This wide compositional latitude makes possible an extraordinary diversity of ripening outcomes. Indeed, the overwhelming majority of cheeses are rennet-coagulated types.

The Basic Early Steps of Cheese Making

Rennet-coagulated cheeses can prove challenging because of the complex and unforgiving nature of the final ripening process. For ripening to go well, the newly made cheese needs to be at the right pH and have the correct moisture and salt contents. They set the stage for the complex physical, biochemical, and microbiological changes that follow.

Producers first need to expel the correct amount of whey from the curd to achieve a moisture content ranging from 60 to 30%, depending...
on the cheese variety being made. Second, the producer needs to control the rates of acidification and curd demineralization so that the buffering capacity of the newly made cheese is compatible with a pH ranging from 5.4 to 4.6. Finally, salt must be incorporated into the cheese at the correct rate to a content varying from 0.5 to 4.0% or higher. In short, the first step of cheese making is a series of steps to dehydrate and demineralize the rennet coagulum and then to add salt to the curd.

The pH, moisture, and salt contents of the unripened curd collectively shape the chemical environment of the cheese. The chemical environment and physical parameters such as temperature, humidity, exposure to oxygen and air movement, and physical handling such as rubbing, brushing, and turning determine which bacteria, yeasts, and molds within the cheese and on its surface will be favored or suppressed, as well as the timing and sequence in which they proliferate and die off. The microbiological progression, in turn, profoundly affects the development of cheese flavor, aroma, texture, and appearance.

The chemical environment also determines which of the many enzymes within the cheese are switched on or suppressed, and sometimes their specificities. Finally, the chemical environment and microbiological and enzymatic changes also determine physical and chemical changes, especially those that involve casein-water interactions such as structural swelling and casein solubilization. Therefore, if the moisture, pH, or salt contents fall outside their target ranges, the cheese cannot ripen along the intended path, thus leading to a different cheese with different characteristics.

**More Detailed Look at First Steps in Cheese Making**

The basic steps used to make rennet-coagulated cheeses have changed little over thousands of years. Cheese makers of old learned to control moisture, pH, and salt contents by varying conditions during different steps and by using innovative equipment and techniques to produce cheeses that were suited to their needs. The basic steps of rennet-coagulated cheese making include setting, cutting, cooking, draining, knitting, pressing, salting, and finishing, or affinage.

The earliest step, called setting, includes inoculating milk with a starter culture containing lactic acid bacteria (LAB), incubating briefly, adding rennet, and then allowing more time for the milk to coagulate. In ancient practice, LAB entered milk as adventitious contaminants and grew quickly at ambient temperatures.

By the end of the 19th century, microbiologists began isolating and identifying the sources for rennet as well as the microorganisms responsible for fermenting milk during cheese making. Soon thereafter, microbiologists began characterizing in considerable detail many LAB strains for their contributions to cheese making. After identifying the best-acting and reliable LAB strains, microbiologists developed means for freezing or freeze-drying them, and then preparing precise blends to deliver specific outcomes.

First and foremost, the role of the starter LAB is to deliver a predictable rate of acidification during cheese making. Starter LAB strains used for making cheese fall into two broad categories based on temperature sensitivity. Those called mesophiles include *Lactococcus lactis* subsp. *lactis*, *Lactococcus lactis* subsp. *cremoris*, while others, called thermophiles, include *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Lactobacillus helveticus*, *Lactobacillus delbrueckii* subsp. *lactis*, and *Streptococcus thermophilus*. The mesophiles are inactivated at temperatures higher than 40°C, whereas the thermophiles remain active to about 65°C.

Renneting follows the addition and ripening of the starter culture. Generally, enough rennet is added to cause the liquid milk to form a gel within 60 minutes. After the gel forms, it needs cutting to expedite the separating of whey from the curd (Fig. 2). Cutting greatly expands the curd surface area, acting as a gateway for whey release. The greater the surface area to volume ratio of the cut particles, that is, the smaller the curd particles, the greater the release of whey, and the lower the moisture content of the cheese.

The step after cutting—cooking—includes heating and stirring the curds and whey. If this step involves no heat, the cheese is called uncooked. Cooking to higher temperatures, longer times, and with more stirring allows the curd to contract and expel more of the whey. Moreover, cooking influences how rapidly LAB strains produce lactic acid and that, in turn, affects syneresis because curd particles contract and expel whey more readily as the pH decreases. The effects of cooking temperature can be complex, affecting...
not only lactic acid production rates but also curd
demineralization and buffering capacity. Thus,
cooking times and temperatures need to be deli-
cately balanced to shrink, dehydrate, acidify, and
demineralize the curd particles as they are pre-
pared for ripening.

Before ripening begins, however, the whey is
separated from the curd particles, which are then
fused, or knitted, to form a larger entity. Early on,
cheese makers developed two approaches for sepa-
rating whey from curds. The more ancient
method is referred to as dipping, whereby the
mixture is scooped or poured from the coagula-
tion vessel into a draining vessel (Fig. 3). The
other more recent approach, draining, involves
leaving the curd in the coagulation vat while the
whey is drained off through a valve fitted with a
strainer.

The knitting of curd particles begins as the
whey is removed. Knitting proceeds, often for
several hours, until the fusing curd forms a con-
tinuous mass. Knitting continues the dehydra-
tion and demineralization processes that began
during cooking.

Knitting is often accompanied or followed by
pressing—applying pressure to the curd to re-
lease additional whey. Early cheese makers used
their hands to push or piled stones on the curd

Cutting the coagulated milk by hand with wire knives in artisanal cheese making. Cutting creates new surface area
that promotes the separation of whey from the resulting curd particles. (photo courtesy of The Cellars at Jasper
Hill, Greensboro, Vt.)
mass to remove further whey. Some cheeses are referred to as unpressed when gravity alone is relied on to knit the curd particles. However, pressing helps to expel whey and promotes more complete fusion of the curd particles, resulting in a more closed texture and a surface with fewer openings.

Dry salt can be rubbed onto the surface of an unfinished cheese at this stage, and it dissolves into the water phase and gradually diffuses into the cheese interior (Fig. 4). The cheese also can be submerged in concentrated salt brine, or the curd can be broken into particles and mixed with salt.
before pressing the now-salted curd into a block of unripened cheese.

**Conclusion**

These steps are completed within one or a few days, whereas affinage, or finishing, unfolds over the next weeks or years. Depending on the cheese variety being sought, the initially bland cheese is microbiologically, enzymatically, physically, and chemically transformed into true greatness. However, unless the cheese maker successfully builds the correct chemical composition into the newly made cheese during those first early steps, ripening will either be for naught due to spoilage or will shift away from the intended outcome, for better or for worse.

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**Suggested Reading**


