Making Great Cheeses, Part 2

During affinage, microorganisms gradually ripen cheese to its fully mature state—a process that can take weeks or years

Paul S. Kindstedt

The first day of cheese making establishes its chemical composition. During affinage, or finishing, the unaged cheese is transformed or "ripened" to its fully mature state. Finishing depends on the cheese maker, or affineur, subjecting the cheese to specific environmental conditions and physical manipulations over weeks, months, or even years depending on variety. However, no cheese can mature to greatness unless it begins with the right chemical composition. Here we explore the microbiological, chemical, and environmental conditions during cheese ripening, with well-known cheese varieties as examples.

Ripening occurs in two distinct zones: the surface of the cheese and the body, or interior. From a microbiological standpoint, the cheese body and surface are radically different environments, the former becoming anaerobic during ripening, whereas the latter remains aerobic unless the cheese is covered with an oxygen-impermeable film, in which case both body and surface remain anaerobic. Surface ripening dominates some cheese varieties, interior ripening others, and still others rely equally on both.

Surface Ripening of Cheeses with Low pH

The specific microflora that dominate the cheese surface depend on the organisms introduced there; the chemistry of the cheese; the temperature, humidity, and oxygen levels in the ripening environment; and physical manipulations of the cheese such as rubbing, brushing, turning, and washing. Surface-ripened cheeses can be divided into two broad categories based on the initial pH at the cheese surface being either lower or higher than 5.0.

Low pH surfaces at relatively cool temperatures of 11–13°C, high relative humidity of greater than 90%, and a highly oxygenated atmosphere favor the sequential growth of yeasts, then molds, leading to bloomy-rind cheeses such as Brie and Camembert. Such cheeses are traditionally made with rapid acidification, which leads to extensive demineralization and low initial pH values of about 4.6. The making of bloomy-rind cheeses also retains whey, producing initial moisture contents of 50% or higher. The resulting cheese surface proves hospitable for the growth of the white mold Penicillium camemberti, which in modern practice is added to the cheese milk before renneting or sprayed as a spore suspension onto the cheese at the start of ripening.

Yeasts such as Kluyveromyces lactis, Saccharomyces cerevisiae, and Debaryomyces hansenii, as well as the yeast-like mold Geotrichum candidum, typically colonize the surface of bloomy-rind cheeses ahead of P. camemberti. In modern practice, yeasts and G. candidum are added to the cheese milk as secondary cultures. By raising the pH slightly through catabolism of lactic acid and by producing peptides through secretion of extracellular proteinases, yeasts and G. candidum then stimulate the growth of P. camemberti.

Early during ripening, salt and moisture at the surface play a critical role through their influence on competing microbial populations. If the salt content is too low or the moisture content too

SUMMARY

➤ Cheese that is ripening can be broadly divided into two distinct zones: the aerobic cheese surface and the interior, anaerobic cheese body.
➤ Surface ripening dominates some cheeses, interior ripening others, while still other cheeses depend equally on both.
➤ The chemical composition of a cheese, environmental conditions such as temperature, humidity, and oxygen content, and physical manipulations that include rubbing, washing, brushing, and turning all affect surface ripening, which typically depends on bacteria, yeasts, and molds.
➤ Interior ripening involves mainly bacteria, which are selected by the chemical composition of the cheese, anaerobic conditions, and storage temperature.
AUTHOR PROFILE

Kindstedt: Passionate about Rural Landscapes and the Inner Workings of Cheese

During high school, Paul Kindstedt worked baking pizzas with mozzarella cheese that behaved differently from one batch to another. The experience “opened my eyes to the huge technical challenges that mozzarella cheese makers were facing,” he says. Later, in the 1980s, on the faculty at the University of Vermont, “mozzarella research was wide open and begging for a food scientist to give it the attention it deserved;” he says. “I happened to be in the right place at the right time.”

Kindstedt is a professor in nutrition and food sciences at the University of Vermont and, until recently, was codirector of its Institute for Artisan Cheese. His research focuses on how cheese is put together, chemically and microbiologically, and how, for example, “mozzarella cheese flows, stretches, and releases free oil upon melting, or how cream cheese spreads and sometimes weeps whey, or how crystals form in or on cheese and their effect on visual appearance and mouth-feel,” he says.

Kindstedt, 56, one of three children, grew up in eastern Massachusetts amid dairy farms and fruit orchards, “at a time when the high-tech industries outside Boston were transforming the landscape with unbridled development,” he says. As a child, he enjoyed roaming pastures near dairy farms and nearby stands of forest. By the time he was seven, however, many of the farms were replaced by housing developments. “This had an enormous impact on an impressionable seven-year-old lad, and I carried a longing for rural life with me from that point forward,” he says.

His father worked for IBM for 35 years, while his mother was a homemaker. “Our family was part of the great influx of new workers who were attracted by the high-tech boom that transformed the landscape west of Boston into sprawling suburbs,” Kindstedt says. He began college at the University of Chicago, expecting to study medicine. However, he says, “I hated the city, and decided to transfer after one year to the University of Vermont, land of dairy farms and magnificent rural working landscapes.” A dairy technology major, he received his B.S. in 1979, studied animal science for his M.S. in 1981, and completed a Ph.D. in food science in 1986 at Cornell University.

“I’m convinced that functioning agriculture adds value to quality of life beyond the obvious contribution of fresh, flavorful, and wholesome food, and it behooves us to maintain a healthy balance between economic development and rural conservation for the sake of my kids and those to follow,” he says.

A committed Christian, he is deeply troubled by the current culture wars. “I grieve that there is such polarization over this in America,” he says. “The message that I desire to articulate and defend to my colleagues in the academy and the members of my faith community is that science and Christian faith are not in conflict.”

He and his wife, an insurance company executive, have two daughters and a son, ages 16, 13, and 11, respectively. He likes to hike, backpack, and kayak, and appreciates “getting out and enjoying God’s wonderful creation, which he wondrously brought into being via his elegant evolutionary mechanisms.”

Marlene Cimons

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high, *G. candidum* may out-compete the white mold and form a wrinkled surface defect known as “toad skin.” Alternatively, contaminant *Rhizomucor* molds may gain a foothold and cause spoilage. However, if the salt content is too high, *G. candidum* is suppressed and *P. camemberti* may grow excessively in the absence of competition. Too much white mold growth in turn can lead to oversecretion of extracellular proteinases that break down casein to produce bitterness. *P. camemberti* aggressively catabolizes lactic acid, rapidly deacidifying the cheese surface, which may approach pH 7.0 by the end of ripening. This rise in pH has two important implications for ripening. First, when the pH rises above 5.8–6.0, the surface favors the growth of acid-sensitive strict aerobic bacteria known as the coryneforms, including *Brevibacterium* spp., *Co- rynebacterium* spp., *Arthrobacter* spp., and *Microbacterium* spp. These orange and yellow coryneforms, which may be added as secondary cultures, are highly proteolytic and prone to produce volatile sulfur compounds and ammonia, which contribute to pungent cheese flavor and aroma and further elevate the surface pH. Thus, traditional bloomy-rind cheeses sometimes display rust-like patches amid a lawn of white mold.

Second, high surface pH leads dissolved calcium phosphate to crystallize, which sets up the migration of calcium and phosphate ions from the cheese center to the surface along concentration gradients, where they continue to crystallize,
leading to a casein matrix that is zonally depleted of calcium phosphate. Under these conditions, high pH along with extensive proteolytic breakdown of casein strongly promotes casein-water interactions and thus a softening at the cheese surface, which gradually works its way towards the center during ripening as the interior pH increases. Consequently, bloomy-rind cheeses display a characteristic zonal pattern of ripening from surface to center (Fig. 1).

Molds cannot grow in the anaerobic cheese interior unless oxygen diffuses into the body. For most varieties, interior mold growth is a defect to avoid. However, for blue-veined cheeses such as Roquefort, prolific internal growth of the mold Penicillium roqueforti is requisite to ripening. For this reason, blue-veined cheeses may be pierced with needles to create shafts that allow carbon dioxide to vent and oxygen to reach the interior (Fig. 2). Furthermore, these varieties deliberately employ practices that favor incomplete curd particle fusion and an open porous texture that facilitates diffusion of oxygen throughout the cheese. For example, citrate-fermenting bacteria such as Leuconsostoc cremoris and Lactococcus lactis subsp. lactis bivoor. diacytvlactis that produce carbon dioxide may be used to enhance the open texture of cheeses. P. roqueforti grows at comparatively low oxygen and high carbon dioxide levels, thus rendering this mold particularly well adapted for the cheese interior. In modern practice, adequate blue mold growth is assured by inoculating milk before renneting or by spraying...
the curds with a spore suspension of *P. roqueforti* before knitting.

In addition to requiring oxygen, blue-veined cheeses must begin ripening with a chemical composition that favors the growth of *P. roqueforti*. Although composition varies, in general moderate to high moisture of 38–50%, salt of 2–5%, and low pH of 4.6–5.0 characterize the blue-veined cheeses. Within these ranges, the selective pressures that are exerted on the cheese microflora can vary considerably, which contributes to some characteristic differences among different blue-veined varieties such as Roquefort versus Gorgonzola. Cool storage temperature from 5–10°C and an oxygenated atmosphere are necessary for selective mold growth, as is a high relative humidity of 85–92% to prevent excessive dehydration, especially at the surface.

During ripening, *P. roqueforti* secretes extracellular lipases that release fatty acids from the triglycerides of fat globules. Adventitious yeasts within the cheese body also contribute to lipolysis, though to a lesser extent. Prolific lipolytic release of volatile short-chain fatty acids contributes to intense piquant flavor notes, but their impact is dampened through subsequent conversion of the fatty acids to methyl ketones by *P. roqueforti*, as well as to nonvolatile calcium salts as the pH rises. The blue cheese flavor depends very much on the balance between piquant volatile free fatty acids and methyl ketones.

Cheese pH rises substantially during ripening because *P. roqueforti* catabolizes lactic acid to carbon dioxide, which deacidifies the curd. This mold also secretes proteolytic enzymes that help to produce ammonia. Therefore, pH increases most in regions of the cheese where mold growth is most prolific. As the surface pH rises, coryneforms may proliferate, much as they do on bloomy-rind cheeses. Adventitious yeasts, starter lactic acid bacterial (LAB), and nonstarter bacteria also contribute to proteolytic changes in the cheese body that affect flavor and texture.

### Surface Ripening of Cheeses with High pH

Surface-ripened cheeses with a pH that is more than 5.0 at the start of ripening, primarily the washed-rind varieties, are produced under conditions of slow acidification that limit demineralization and retain high buffering capacity. Washed-rind varieties depend on some of the same microorganisms as the low-pH bloomy-rind cheeses. They ripen at temperatures between 13 and 15°C, 95–98% relative humidity, and under highly oxygenated conditions that favor coryneform growth. Like bloomy-rind cheeses, yeasts and *G. candidum* are the first to colonize the surface of washed-rind cheeses, catabolizing lactic acid and increasing the pH within a few days to 5.8–6.0. At that point, conditions favor the growth of coryneform species that, in modern practice, are applied in a step called washing as secondary cultures along with dilute salt brine.

Washing involves rubbing the cheese surface with dilute brine to favor coryneforms over competing molds. During washing, which is usually repeated every few days for two weeks, pin-
point coryneform colonies form and then spread across the surface, creating a continuous yellow-orange bacterial lawn. As noted earlier, coryneforms are highly proteolytic and produce volatile sulfur compounds and extensive ammonia, resulting in pungent flavors and aromas, while further elevating the surface pH. As with the bloomy-rind cheeses, the high surface pH causes calcium phosphate to crystallize and creates a zonal pattern of softening and ripening (Fig. 3).

An important side note is that the coryneforms can be coaxed through brine washing and proper temperature and humidity into growing on the surface of cheeses that are low in moisture, as long as the surface pH exceeds 5.8–6.0 (Fig. 4). Thus, their use as surface ripening flora extends from high-moisture soft and semi-soft varieties to include hard and semi-hard high-pH cheeses.

**Interior Ripening**

Apart from blue-veined varieties, most cheeses quickly develop anaerobic conditions in the interior as they ripen, preventing internal mold growth unless the surface rind is compromised. Under such anaerobic conditions, indigenous yeasts contribute little to interior ripening unless their populations are abnormally high due to inadequate cleaning and sanitation.

In contrast, both starter LAB and nonstarter bacteria play central roles in determining flavor and texture in the anaerobic interior of cheeses such as aged cheddar, Gouda, and Parmesan. Of particular importance is the capacity of those microorganisms to digest casein through proteolytic cascades that convert casein into progressively smaller peptides and free amino acids that, in turn, are converted into flavor compounds. Proteolytic cascades are very sensitive to the chemical environment within the cheese. For example, abnormal pH, moisture, or salt levels can affect proteolytic rates and specificities to yield atypical or off flavors such as bitterness. Abnormal chemical composition can also trigger undesirable fermentations by nonstarter bacteria, such as in cheddar cheese when low salt com-

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**FIGURE 3**

An artisanal washed-rind cheese with the surface rind partially removed to show the soft creamy layer beneath. Washed-rind cheeses display a zonal pattern of ripening from the surface inwards due to the surface growth of orange-pigmented coryneform bacteria and yeasts. (Courtesy of The Cellars at Jasper Hill, Greensboro, Vt.)
combined with high pH favor the growth of Propionibacterium freundenreichii or Clostridium tyrobutyricum, yielding abnormal flavors and gases.

Although Propionibacterium freundenreichii’s production of carbon dioxide as well as propionic and acetic acids is considered a defect in cheddar cheeses, their production is essential for Swiss or other alpine cheeses such as Emmental. Because propionibacteria are salt and pH sensitive, alpine cheeses are intentionally made with low salt and under conditions of delayed acidification, yielding a mineral-rich, highly buffered cheese that maintains an initial pH of 5.0–5.4.

When alpine cheeses are stored at 20–24°C for several weeks, their low salt and high pH strongly selects for the growth of propionibacteria, which convert lactate to carbon dioxide and propionic and acetic acids. Traditional alpine cheeses are made with a dense rind that slows the diffusion and venting of carbon dioxide, thus enabling it to supersaturate the water phase of the cheese. As the gas bubbles expand, the protein matrix expands elastically around them and they become embedded within the cheese body as round holes or “eyes” (Fig. 4). The protein matrix can expand instead of fracturing because the body of alpine cheeses is very closed and free of mechanical openings due to the pressing conditions employed. Furthermore, the high mineral content and pH of the curd render the structure very resilient.

Conclusion

Examples here illustrate the complex relationships between the chemical composition of a cheese at the start of ripening and the pathways that unfold over weeks, months, or years under controlled storage conditions. Deviations from the appropriate moisture, pH, and salt of a cheese alter the course of ripening and thus the final cheese, for better or for worse.

Such deviations, stumbled upon historically, led to new cheese varieties as well as disappointing or inedible batches of cheese. The great diversity of cheeses that we enjoy today is a testament to the tenacity and ingenuity of cheese makers throughout history. They adapted tools and developed practices that let them deal effectively with constraints of climate, culture, and economy while producing cheeses that satisfied their needs and continue to enrich our lives.

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Suggested Reading


Fox, P. F., T. P. Guinee, T. M. Cogan, and P. L. H.