Chapter 17
Mold-Ripened Cheeses

Marc Bates and Stephanie Clark

17.1 Introduction

Historically, mold-ripened cheeses likely came about by accident. But the mold-ripened cheeses of today are far from accidents—they are carefully crafted masterpieces of science and art. Broadly speaking, mold-ripened cheeses can be subdivided into two categories: those characterized by bloomy rinds (or surface mold-ripened cheeses) or blue-veined. Within each of those categories, great variability exists throughout the world, which will be further discussed in subsequent sections, along with general make procedures, expected characteristics and defects, and explanations for the sources of such characteristics.

The German scientist Weigmann (1906) reported that "It has long been known that the characteristic rancid, sharp taste of French Roquefort, English Stilton, and Italian Gorgonzola cheeses is caused by the green Penicillium." Much of the early published science on mold-ripened cheeses was conducted as a result of American consumers' desire for imported Roquefort, which was restricted after the First World War. Some of the premier American blue cheese research pioneers included Charles Thom, James Currie, and Kenneth Matheson (1900s–1920s) at the United States Department of Agriculture (USDA), Bernard Hammer and Clarence Lane at Iowa State College (1930s–1940s), and Samuel Coulter and Willes Combs at the University of Minnesota (1930s–1940s). Thom was the first to describe the importance of *Penicillium camberti* and *P. roqueforti* in mold-ripened cheeses. Thom and colleagues at the USDA were instrumental in defining the taxonomy of Aspergillus and Penicillium genera (Thom, 1906) and for determining microorganisms

M. Bates
Bates Consulting LLC, Cannon Beach, OR, USA

S. Clark (✉)
Department of Food Science and Human Nutrition, Iowa State University, Ames, IA, USA
e-mail: milkmade@iastate.edu

S. Clark et al. (eds.), *The Sensory Evaluation of Dairy Products*,
https://doi.org/10.1007/978-3-031-30019-6_17

responsible for proteolysis and lipolysis (Thom, 1906). Currie (1914) stated that "Every cheese connoisseur is familiar with the peculiar pepper or burning effect of well-ripened Roquefort cheese on the organs of taste." Currie went further to elucidate that *P. roqueforti* produces a water-soluble lipase, which is the chief factor in causing fat hydrolysis and subsequent formation of the primary volatile fatty acids responsible for typical blue cheese flavor: caproic, caprylic, capric acids.

Microbiologists Lane and Hammer are credited with establishing and patenting the method later used to produce Maytag Blue Cheese in Newton, Iowa. Their method involved separation of cow milk, homogenization of the cream (14–24 MPa of pressure), and blending back in raw skim milk to promote milk fat hydrolysis by the native lipase during ripening. Their research revealed that pasteurization of homogenized raw milk more rapidly developed volatile acidity, yielded more typical flavor than cheese made from non-homogenized raw milk, but was inferior to cheese made from raw homogenized milk (Lane & Hammer, 1938). Subsequently, Coulter and Combs (1939) reported that the addition of a lipase enzyme (called steapsin) enhanced flavor development in blue cheese, but cheeses had a bitter taste. Later still, Parmelee and Nelson (1949) showed that addition of select microorganisms that produce lipase (*Candida lipolytica*) to pasteurized, homogenized milk improved blue cheese flavor, with no bitter taste.

Later, Morris, Jezeski, and Combs, from the University of Minnesota, created the white-veined mold-ripened cheese called Nuworld cheese. The scientists induced mutants of *P. roqueforti* from a parent Minnesota strain by irradiation with ultraviolet light, then Morris et al. (1954) made "Minnesota Blue cheese" with the standard and mutant strains. Their experiments revealed that "Excellent cheese can be made with a white mutant… color, body, texture, and comparatively milder flavor are different enough from Blue cheese to constitute a new cheese, which may be classed within the semi-soft, mold-ripened group of cheese."

The classics among the surface ripened or bloomy cheeses are Camembert and Brie in the United States. Valencay and Poligny should also be considered if we look to include other styles originating from France. One legend credits Marie Harel, a farmer's wife from Normandie, France, with the origin of Camembert de Normandie (AOC) in 1791. Brie de Meaux and Brie de Melun, both French AOC cheeses, are made from raw milk. Here in the United States, we will likely only see a modern Brie made from pasteurized milk due to the short aging time and the 60-day aging requirement for raw milk cheeses. In France, the raw milk versions would be marketed prior to 60 days of age.

Dupont/Danisco Technical Manual (2014) tells us about the flavor compounds found in bloomy rind cheeses in Table 17.1.

These early works were instrumental in setting the groundwork for understanding and producing high-quality mold-ripened cheeses worldwide.

Table 17.1 Flavor compounds associated with bloomy rind cheeses

Families	Compounds	Associated flavors
S-compounds	Dimethyl sulfide (DMS) dimethyl disulfide (DMDS)	Sulphur, cabbage-like
Esters	Ethyl acetate, ethyl butanoate, ethyl propanoate, ethyl lactate, ethyl valerate, isoamyl acetate, isobutyl isobutanoate, ethyl hexanoate	Fruity, apple, pineapple, sweet, banana
Ketones	Acetone, 2-butanone, 2,3-pentanedione, 2-heptanone, acetoin, diacetyl	Solvent-like, etheric, buttery, blue cheese
Aldehydes	Acetaldehyde, 2-methyl butanal, isovaleraldehyde	Green, malty
Alcohols	Ethanol, 1-propanol, isobutanol, 2-methyl, 1-butanol	Ethanol-like, pungent, solvent-like, malty

Source: 2014, TM 2106-2e Dupont-Danisco

17.2 Bloomy Rind Cheeses

17.2.1 Definitions and Standards of Identity

The U.S. Code of Federal Regulations (CFR) includes a standard of identity for soft-ripened cheese at 21CFR133.182. While nowhere in the standard is the term "bloomy rind" used, this is the standard which provides for the production and marketing of such cheeses in the United States. Key elements of the standard include a minimum of 50% butterfat on a dry basis and the provision to be made from raw milk only if such product is cured at a temperature of not less than 2 °C (36 °F) for not less than 60 days. While the standard allows for the production of these cheeses from raw milk, the requirement to age for at least 60 days uses up much of the potential market suitability for the cheeses noted in the introduction.

The surface ripening cultures necessary for production of bloomy rind cheeses are provided for in the standard as follows:

A. Harmless flavor-producing microorganisms may be added.
B. The cheese is cured under conditions suitable for development of biological curing agents on the surface of the cheese, and the curing is conducted so that the cheese cures from the surface toward the center.
C. The word "milk" (in this particular standard) means cow's milk, goat's milk, sheep's milk, or mixtures of two or all of these.

Internationally, the Codex Alimentarius for Milk and Milk Products (FAO & WHO, 2011) has been established for Coulommiers, Brie, and Camembert. Some main differences between these three international standards and our U.S. soft-ripened standard are:

A. The harmless flavor-producing cultures include named cultures.
B. Each of the three cheeses must be made from cow or buffalo milk or mixtures thereof.

Additional international standards are prevalent in the European Union. Union-wide is the Protected Designation of Origin (PDO), while national systems like the French Appellation d'Origine Côntrolée (AOC) and the Italian Denominazione di Origine Protetta (DOP). The intent of these standards is to tie the production of a particular named cheese to both methods and a geographic area or region, thus protecting the production of local foods.

The fat content of bloomy rinds may lead to different naming conventions, such as double or triple-cream designations. Fat content is expressed as percent fat in the dry matter, also called fat on a dry basis. The soft-ripened cheese standard 21CFR 133.182 requires a 50% minimum fat in dry matter (FDM) with no maximum, which allows for the higher fat cheeses to be made under this standard. Codex standards for Brie and Camembert (FAO & WHO, 2011) show a minimum of 40% FDM and 30% FDM, respectively, and further indicate a reference range of 45–55% as being normal. While there is no legal definition in the United States, the French require double crème to have 60–75% FDM and triple crème to be greater than 75% FDM.

17.2.2 Production of Bloomy Rind cheeses

The surface mold-ripened cheeses, also called bloomy rinds, are characterized by the surface growth of white or off-white *Penicillium camemberti* and some yeast-like cultures of Geotrichum and Debaromyces. The bloomy category, with its common white rind or crust, can have a variety of curd production methods (Table 17.2). Lactic cheeses, more common in Europe and in the goat cheese industry, are distinguished by being acidified before coagulation. This technology may be referred to as 'traditional." At the other extreme are what are referred to as "stabilized soft

Table 17.2 Comparison of bloomy rind technologies

Technology Parameter	Traditional technology	Mixed technology	Stabilized technology
Acidifying cultures	Mesophilic	Blends of mesophilic and thermophilic	Thermophilic
Coagulation	Late-primarily caused by acidification	Intermediate-aided by both acidification and rennet	Early- caused by rennet
Mechanical steps of cutting and stirring	Neither	Large cut and little stirring	Smaller cut with modest stirring
pH at unmolding	≤4.45	4.65–4.85	4.95–5.20
Ripening cultures	Geotrichum + *P. camemberti* or *P. album*		
Culture ratio	2:1	1:1	1:2
Optional adjuncts	Corynebacteria	Corynebacteria, *P. roqueforti*	Corynebacteria, *P. roqueforti*
Marketing window	2–9 weeks	6–10 weeks	7–15 weeks

Source: 2014, TM 2106-2e Dupont-Danisco

cheeses" or "enzymatic," whose coagulation is caused by rennet action early in the process with most acidification occurring after coagulation. Additionally, the cheese makers get creative and use methodologies of production in between, referred to as "mixed technology."

It is no wonder that with all the possible technology variations for white surface-ripened cheese there are so many different cheeses available. Considering milks from different species, and mixtures of milks (e.g., goat and sheep), there are even more cheeses in the mold-ripened cheese category. As we think of cow's milk, we have the classics, including Camembert, Brie, Coulommiers, and triple creams. For goat milk, it would be the small crottins, bloomy logs, and pyramid shapes. Ewe's milk provides such classics as Perail de Brebis and Le Brebio. The American Cheese Society Judging & Competition provides category B – Soft Ripened Cheese, where makers can enter cheeses in the bloomy or white molded style. Subcategories include opportunities for milk from each major species plus mixed milk subcategories.

We will summarize the production steps of a classic bloomy rind such as Camembert from cow's milk. Bloomy rind cheeses are uncooked, meaning there is no step beyond pasteurization that requires any further heat.

Milk Supply We need to have fresh, high-quality milk. Milk can be from a farm's own herd or be purchased from other approved dairy farms or companies.

Receiving/Storage The milk must be evaluated for quality, composition, and free from contamination such as antibiotics during this step of the process. Its temperature must be kept below 4 °C (40 °F) to preserve quality and prevent outgrowth of any pathogens.

Standardization Standardization is the process of adjusting the composition of the milk's fat:protein ratio. If done, it is usually done by separation/addition of cream to achieve the desired composition. Not all makers have the ability to do this step, so it may be a point of differentiation.

Pasteurization The milk is pasteurized as a critical food safety process. While the standard allows for making from raw milk if aged for 60 days, it is typically not done in the United States for reasons discussed in the introduction.

Pre-fermentation Post pasteurization, the milk is tempered to approx. 32 °C (90 °F) and starter cultures or bulk starter are added so that they can become acclimated to the warm milk from the dry or frozen state the cultures may have come from. This is also called ripening the milk, as the starter work through their lag phase to growth phase and prepare to rapidly reproduce and ferment the lactose to lactic acid. Depending on the source and amount of starter culture, the duration of this step can be from 30 to 90 min.

Renneting/Coagulation The amount of rennet to use will be determined by whether the cheesemaker is following a traditional technology or stabilized technology (previously discussed). Coagulation in the traditional technology is primarily acid driven, so very little rennet is required and it is more an aid to draining than functioning as a coagulant. Stabilized technology depends on a rapid and complete coagulation early in the process, with fermentation occurring mostly post-coagulation. The stabilized technology uses enough rennet to coagulate the milk in approximately 30 min. Rennet comes in single and double strengths so it is important to know this when determining how much to use. The maker may also choose several sources of rennet, including animal, plant, and fermentation-produced sources. Calcium chloride may be added to aid/improve the rennet action, especially in milk that has been pasteurized significantly above minimum requirements.

Cutting Traditional technology may not employ cutting as such but just ladling the curd into the forms or molds ("dipping"). Stabilized technology would likely cut the curds into ½–1 inch cubes according to the needs of their particular process. Ladling and cutting increase the surface area available for moisture to escape or syneresis from the curd to reach a desired firmness and moisture content.

Stirring Stirring is not used for the traditional technology because the cheese is dipped into the form and drained. Stabilized technology uses some combination of cut size (above) and stirring to aid in getting enough whey out to reach desired moisture content and firmness. Stirring might be done with a few strokes every 3–5 min over about 25–30 min in a manual method. Mechanical stirring would only be used for very large-scale production where it could be managed with programmable automation.

Draining This step begins with the curd and whey separation. About 1/3 of the whey is pre-drawn or removed from the vat before transferring the remaining curds and whey to the molds for further draining while also being shaped.

Molding Molding has the purpose of creating uniformly shaped and sized wheels or discs of cheese. It also allows for continuation of drainage for as long as overnight.

Salting Salt may be applied to Camembert by either dry salting the curd or by placing the discs into a brine solution. Salting is usually done the next day, with parameters designed to achieve about 1% salt in the finished cheese. Dry-salted cheeses may rest with occasional turning for about 24 h or longer before proceeding. Brine salting for these small-format cheeses may take only an hour or two depending on the salt concentration of the brine.

Ashing This optional step is done for two reasons. First, it helps neutralize the surface acidity, making it a better environment for the ripening cultures to grow. Second, it provides a striking visual appearance of the finished product (Fig. 17.1).

Ripening We are now at day 3 since the start, and moving the cheese to a controlled temperature and humidity space where the *Penicillium camemberti* will literally 'bloom' on the surface over the next 10–12 days. Hence the name bloomy rind. The Geotrichum or other yeast cultures will grow first, de-acidifying the surface and making it more hospitable to the Penicillium. Penicillium blooms best at a humidity level above 90% and temperatures in the 10–12 °C (50–54 °F) range. The ripening cultures could have been added directly to the milk in the cheese vat. They could have been delivered to the surface by mixing with salt and applying the dry salting method. Otherwise, they would need to be applied to the surface by spraying or wiping methods. Uniform development of the bloom is aided by turning the cheeses every 3–5 days during this ripening step.

Packaging After a full bloom has developed over the surface of the cheese pieces, they may be wrapped in appropriate materials such as sulfurized paper, cellophane, or other patented wraps made especially for these cheeses. Depending on the technology used, desired product characteristics, and the market preferences, the product could be ready in as little as in 2–3 more weeks.

17.2.3 Sensory Evaluation

17.2.3.1 Preparing Samples for Evaluation

Tempering bloomy rind cheeses takes a bit less time than large-format cheeses (e.g., Gouda) due to the small size of the cheese and the consequently greater surface area to volume ratio, especially of the flat disc formats. Piece sizes of a pound or less would likely temper from refrigeration to the mid 10 °C (50 °F) range in as little as

Fig. 17.1 Goat cheese with bloomy rind, exhibiting surface mold and layers of ash (S. Clark image)

30 min. Tempering helps the evaluator to sense and appreciate the volatile components of the cheese, and having a set standard is best for comparing one cheese to another and one occasion to another. A full-size Brie or Coulommiers, on the other hand, will need 1–2 h to temper, as they may weigh as much as 6–8 pounds (Fig. 17.2).

Knives or wire harps (Fig. 17.3) are both acceptable to cut or open the cheese for visual inspection and portion it for tasting. When deciding how to portion the cheese, it is important to consider that there may be variations in the cheese from the exterior to the inner core of the cheese. Thus, we want to cut or slice so as to best expose a representative cross-sectional view to allow one to see from the rind all the way to the center of the cheese mass (Fig. 17.4).

17.2.4 Bloomy Rind Cheese Sensory Characteristics

Ideal Characteristics

Roustel (2020) described modern Camembert as having a rind with a fine white bloom that may develop brownish striations when fully mature. Its flavor should be mushroomy and earthy, with slight ammonia towards the end of its life. The paste should be homogenous, supple, and slightly elastic, with occasional fermentative openings. Mushroomy and earthy are terms that seem to be associated with most cheeses in this category. As the milk source changes from cow to other species, we expect to sense more animal notes associated with the shorter-chain fatty acids characteristic of the milk from sheep and goats.

When evaluating samples, we use all our senses in some sequence. We first see the external appearance and get some aroma. When cutting or slicing, we may get more volatile aromas and a visual of the interior of the cheese. Decorative shapes, leaves, spices, and/or condiments may be occasionally used on top of or inside some bloomy rind cheeses (Fig. 17.5). We note textural characteristics as we slice and handle the cheese, bringing it to our mouth. In the mouth, it gets really busy as we continue to evaluate the mouthfeel, tastebud responses, and even more volatile aromas via retro-nasal olfaction. A good product leaves us wanting more. If we are evaluating more than just a couple of samples, it is important to expectorate each sample to avoid satiation, which will dull our senses and fatigue us.

17.2.4.1 Defects in Bloomy Rind Cheeses

Bloomy rind cheese defects can be segmented into three categories: Appearance, color, and mold development, Body and texture, Aroma and flavor. Defect descriptions are included in subsequent pages. Many of the terms are also found in the American Cheese Society's T.A.S.T.E Test® scoresheets found on their website, https://www.cheesesociety.org/ccse-scoresheets/.

Fig. 17.2 A full-size Brie or Coulommiers may need 1–2 h to temper, as they may weigh as much as 6–8 pounds (S. Clark image)

Fig. 17.3 Cheese knife and small wire harp tools for working with bloomy rind cheese (Image by Bates Consulting)

17.2.4.1.1 Appearance, Color, and Mold Development

Cracked or Disturbed Rind A jagged, cracked, or split rind may be due to excessive drying or physical damage.

Discolored/Dull Color/Uneven Color Multiple terms are used when the color is not a fine white bloom with only some fine tan striations.

Excessive Mold Coat/Rind The term is used when the mold coat or rind is quite thick and upon further examination may even be tough or leathery when cutting or in the mouth.

Greasy/Free Butterfat Sometimes when a bloomy cheese is temperature abused such as in shipping or distribution the butterfat will come to the surface to yield this defect.

Fig. 17.4 A disc and a pyramid shape cut to display a good cross section of each cheese (S. Clark images)

Fig. 17.5 Examples show the presentation of the cheese may be enhanced by the addition of a colored spice or condiment (left), wrapping with bark and adorning with leaves (center), or using a unique shape (right) (S. Clark images)

Malformed/Crooked /Lopsided The terms are used to describe a lack of symmetry.

Slipped Coat/Rind/Skin The terms are used when the rind is found to be separating from the cheese itself (Fig. 17.6).

Undeveloped/Immature Mold Coat If the bloom is very thin and/or does not fully cover the cheese, or patchy coverage appears, these terms are used (Fig. 17.7).

Wet/Free Whey The terms should be used when the cheese has a wet appearance or actual free whey or moisture on the surface.

Undesirable Mold Type The term is used with the appearance of obvious growth of unintended or undesirable mold types not associated with the category (Fig. 17.7).

17.2.4.1.2 Body and Texture

Crumbly The term is used when the center cheese falls apart or crumbles when sliced or pressure is applied, as with the thumb and forefingers or in the mouth.

Curdy In curdy cheese, the original, individual curd particles may be seen or felt as the cheese is manipulated.

Excessive Gassy Some openings due to gassiness from flavor-producing bacteria are expected, so this term is used when the structure of the cheese is threatened by excessive gas holes.

Mealy/Grainy/Sandy A mealy texture is one that appears like and has the mouthfeel of corn meal. Grainy might have randomly dispersed granules visible or that can be felt in the mouth. Sandiness is usually a mouthfeel that persists after the sample has been expectorated/swallowed. It can happen when excessive lactose crystallizes.

Gummy/Pasty/Sticky These terms are applicable when the cheese doesn't let go. It sticks to the roof of your mouth, your fingers, and/or the knife.

Open The term open refers to the angular openings in the mass of the cheese left when the individual curds have not compacted and knit into a smooth mass.

Short Short refers to the brittleness of the curd when manipulated with the fingers and it readily breaks apart. The curd is inflexible.

Weak The term is applied when the cheese lacks resistance to pressure by the fingers or tongue against the roof of the mouth. This lack of resistance may be associated with excessive moisture content of the cheese.

17.2.4.1.3 Aroma and Flavor

Ammoniated As bloomy cheeses ripen and the protein breaks down, some ammonia is produced. Usually, it occurs in fully ripe cheese, and it may be present in a slight amount but more than that it is a sign of overripe product.

Atypical The product does not contain the basic characteristics of the category (see Ideal above) or includes attributes characteristic of a different cheese.

Barnyard The aroma or flavor is reminiscent of the barnyard, animals, and/or manure.

Fig. 17.6 Examples of slipped coat defect (S. Clark images)

Fig. 17.7 Examples of ideal (left) vs. undeveloped/immature mold coat (center) and undesirable "Wild" mucor mold type (right) (S. Clark images)

Bitter Bitter is a basic taste, detected only in the mouth and mostly at the back of the tongue or pallet. It has no odor or aroma. One cause is bitter peptides forming during the proteolysis that occurs during ripening or aging. For persons not blind to bitterness, this is an undesirable attribute, as the flavor may linger or persist after the sample is gone.

Chemical Chemical flavors are also described as medicinal, phenolic, or band-aid like. They could be reminiscent of sanitizers like chlorine bleach or iodophors.

Feed Flavors from highly aromatic feeds like alfalfa or silage fed within 2 h of milking or during milking can impact the milk's flavor.

Flat/Lacks The descriptor is applied to products lacking the primary character of the category. It could be applied to a mild cheese in an aged category.

Fruity/Fermented Fruity esters often remind us of apple or pineapple or other sweetish flavors. Krautlike is a fermentation flavor associated with some particular cultures.

High Acid This term is applied when the acid is the only flavor characteristic noted or it is out of balance with other components of the product's flavor. Bloomy rinds are quite acidic in the first days, but as they bloom and begin to ripen the pH goes up and so they become less acidic when ready.

High Salt The term is used when salt is out of balance and noticeable as a primary characteristic.

Lacks Freshness/Old Milk If the product has a stale or old component that is slightly unpleasing, the terms may be used.

Metallic Metallic is both a flavor and a mouthfeel that is puckery or astringent. It is caused by the animals' diet, especially on poor feeds in winter or by the metal in the water system they drink from.

Moldy or Musty The flavor or aroma is very earthy or reminiscent of a damp basement. It is not particularly pleasant, and not like the characteristic mushroomy flavor of bloomy rinds.

Rancid The flavor is caused by the lipolysis of the butterfat splitting off butyric acid from the fat molecule. Highly aromatic and is a positive component of blue cheese or provolone flavors. Not expected in bloomy rinds. It is sometimes described as baby's breath.

Unclean This flavor is an unpleasant experience that may come as an aftertaste or linger long after the sample is gone. It can come from the animals breathing air from a dirty and poorly ventilated barn, or it may be caused by spoilage organisms impacting on the milk or poor sanitation practices in the cheese room.

Unpleasantly Earthy See also moldy/musty above. The term describes flavor or aroma that is very earthy or reminiscent of a damp basement. It may be associated with a cave-aged cheese. It is not particularly pleasant and not like the characteristic mushroomy flavor of bloomy rinds.

Whey Taint The flavor is often caused by excessive whey or moisture being left in the curd. It can be unpleasantly sour or unclean in nature.

Yeasty The flavor is reminiscent of rising or fresh baked bread. It can be caused by too much Geotrichum or other yeast in the culture system of bloomy rinds.

17.3 Blue-Veined Cheeses

17.3.1 Definitions and Standards of Identity

Blue-veined cheeses are made throughout the world from raw, heat-treated, or pasteurized milk of cows, goats, sheep, or mixed milk. Some of the most famous blue-veined cheeses include Roquefort (France, discussed in Chap. 18), Stilton (England), Gorgonzola (Italy), Cabrales (Spain), and Danablu (Denmark). Some blue-veined cheeses have Protected designation of origin (PDO), Appellation d'origine protégée (AOP, in French-speaking countries, Denominacion de origen (DOP, in Spanish-speaking countries), or Denominazione d'origine controllata (DOC, in Italian-speaking countries) status.

According to the U.S. FDA Code of Federal Regulations, Blue cheese "is characterized by the presence of bluish-green mold, *Penicillium roqueforti*, throughout the cheese. The minimum milkfat content is 50% by weight of the solids and the maximum moisture content is 46% by weight… is at least 60 days old" (USFDA, 2022a). Nuworld cheese has the same requirements, except that it "is characterized by the presence of creamy-white mold, a white mutant of *Penicillium roqueforti,* throughout the cheese…" (USFDA, 2022b).

17.3.2 Production of Blue-Veined Cheeses

As with any dairy food operation, strict sanitation practices and use of fresh raw ingredients are also essential for high-quality blue-veined cheese. Cream and/or milk used to make blue cheese in the United States may be raw or pasteurized, homogenized, or bleached. If benzoyl peroxide or a mixture of benzoyl peroxide with potassium alum, calcium sulfate, and magnesium carbonate is used to bleach the milk, the weight of the benzoyl peroxide must not exceed 0.002% of the weight of the milk, and the weight of the potassium alum, calcium sulfate, and magnesium carbonate, singly or combined, must not exceed six times the weight of the benzoyl peroxide used. Additionally, if bleaching is conducted, vitamin A must be added to the curd in a quantity sufficient to compensate for the vitamin A or its precursors destroyed in the bleaching process (USFDA, 2022b).

Fresh milk (approximately 3.5% fat) is warmed (to approximately 32 °C (90 °F)), then cultured with mesophilic (typically exclusively) lactic acid-producing bacteria (i.e., *Lactococcus lactis*) and chymosin. Some processors have encouraged aeration of blue cheese by adding gas-producing cultures (e.g., *Leuconostoc* species). *Leuconostoc* can expand the mechanical openings in blue-veined cheeses, allowing *P. roqueforti* to colonize the eyes formed (Pujato et al., 2014). In ideal conditions, CO_2 leaves via punch holes; in less ideal conditions, eyes are entrapped in the cheese body.

Upon cutting, curds are gently scooped into perforated forms (approximately 19 cm in diameter, 15 cm in height), for whey drainage. Care should be taken to maintain a somewhat open structure. Spores of *Penicillium roqueforti* may be added to the milk or to the curds while filling forms. The forms are turned several times during draining, then removed from forms when considered sufficiently dry. The wheels of cheese are salted with dry salt or placed into a brine solution. Subsequently, perforations (approximately 50 per cheese) are made with copper or stainless steel "needles," sufficiently long to penetrate through the entire wheel, to enable air circulation, essential for mold growth throughout the open internal structure of the formed cheese.

Punctured wheels are held at a temperature of approximately 10–12 °C (50–54 °F), 90–95% relative humidity, until the characteristic mold growth has developed (approximately 30 days). Mold-inhibitory compounds (antimycotics) may be applied to the surface of wheels to prevent surface mold growth (Fig. 17.8). Alternatively or additionally, cheese surfaces may be scraped to remove surface mold or yeast outgrowth prior to packaging and distribution. Additional affinage may occur in caves at 4–7 °C (40–45 °F), for approximately 60–90 days prior to distribution.

Under European Union law, Gorgonzola is a protected designation of origin (DOP) cheese, made only in specific Italian provinces of Lombardy and Piedmont. It is made with unskimmed pasteurized milk, spores of *P. roqueforti*, and calf rennet, though some producers add lactic cultures (e.g., *L. bulgaricus* and *S. thermophilus)* and even selected yeasts of the Saccharomyces species. Curds are separately made out of the morning and evening milk and then alternately layered in forms to facilitate the open structure needed for aeration (Fox et al., 2000). Gorgonzola is typically aged 3–4 months. Gorgonzola Piccante is aged longer (~3–12 months) than "Gorgonzola Dolce" (at least 60 days) and has at least 48% fat on a dry basis. Gorgonzola has a softer, more smooth, and less crumbly texture than Roquefort unless aged (Gorgonzola Piccante). The body is cream to yellow in color; the pink-to-grey rind is considered in-edible (DOP Italian Food Agency, 2022).

Under European Union law, Stilton (PDO) cheese can only be made in Leicestershire, Derbyshire, and Nottingham, England, from pasteurized local cow milk. *P. roqueforti* mold spores are added to the milk and renneted. Curds are allowed to settle to the bottom of the vat, and cut to facilitate whey drainage, which occurs slowly over a 12–18-h period (Fox et al., 2000). Curds are milled, dry salted, and drained, with turning, for about 7 days in cylinder forms, at 26–30 °C (79–86 °F), 90% relative humidity (Fox et al., 2000). A rind develops during incubation in a cooler room (13–15 °C (55–59 °F), 85–90% relative humidity) for 6–7 weeks. Subsequently, cheeses are pierced, allowed 2–3 weeks to grow mold, then moved to a cold room (5 °C/41 °F) (Fox et al., 2000). Stilton has a minimum of 48% milkfat in the dry matter and resembles a high acid, flaky Cheddar cheese with blue-green veining. Stilton cheeses typically harbor secondary microflora, including but not limited to the adventitious (not intentionally added) yeasts *Yarrowia lipolytica* and *Kluyveromyces lactis*, which contribute to the distinct aroma and flavor profiles in the paste, veins, and brownish outer crust (Gkatzionis et al., 2009; Price et al., 2014).

Cabrales PDO cheese is made from raw cow milk or blended with goat and/or sheep milk. Cabrales is made in a traditional artisan fashion by rural dairy farmers in a small production zone in northern Spain. It has a fat content of 45% on a dry basis. Cabrales is aged at least 75 days in natural caves with *P. roqueforti* spores present (none are added during cheesemaking). Regulation requires that the cheeses be sold in dark-green-colored aluminum foil with the stamp of the PDO Queso de Cabrales (Worldnews, Inc. 2022).

Danablu is made with pasteurized cow milk, *P. roqueforti* spores, and chymosin. Curds are cut and ladled into molds, drained, and then brined. Wheels are pierced, then aged at least 60 days. Danablu has 50–60% fat on a dry basis.

17.3.3 Sensory Evaluation

17.3.3.1 Preparing Samples for Evaluation

Blue cheese stored under refrigeration should be tempered at room temperature for approximately 30 min per pound prior to evaluation to facilitate release of volatile components. Observe the quality of the packaging and the surface condition of the cheese. A sharp knife or wire should be used to cut the blue cheese wheel in half (wire), then into wedges (wire or knife), or crumbles (Fig. 17.9). Begin by observing the aroma upon slicing. Pay attention to the overall impact and impression as it may reveal what is to come when tasting the product. Make note of the appearance of the mold after cutting and again after tasting, as color may change. Pay attention to the slicing properties of the cheese. Tasting should include quarter-sized samples representing the center, middle, and exterior of the wheel to obtain a complete picture of the cheese quality.

17.3.3.2 Blue Cheese Sensory Characteristics

Besides Swiss cheese, blue cheese is likely the most visually recognizable cheese to consumers. Surfaces of wheels of blue cheese may appear white- to cream-colored or may display surface ripening of varying colors; wheels may be bandage-wrapped or even foiled. Color loss may occur if blue cheeses are placed in retail packaging before they are fully ripened ("in-pack maturing"). The atmosphere in which *P. roqueforti* mature post-packaging affects not only conidial color but also the way in which conidiophores are produced and develop morphologically; lanose or "cotton-woolly" appearance forms in higher CO_2 environments (Fairclough et al., 2011). Upon cutting, abundant internal veins and pockets of vibrant blue-green mold should be distributed evenly throughout an open-bodied white- to cream-colored paste.

Blue cheese should slice cleanly, without excessive force or crumbling. The cheese should break down into a smooth paste relatively quickly during mastication.

Similar to other cheeses, blue cheese's body and texture is largely dictated by pH because of its effect on mineral solubilization and casein dissociation from casein micelles. The ratio of intact casein to moisture, manufacturing practices, and storage conditions are also key factors. Further, blue-veined cheese body is affected by proteolysis from fungal protease action as well as residual chymosin, plasmin, and non-starter microorganism enzymatic activity (Diezhandino et al., 2016).

Blue-veined cheeses should have recognizable lactic acid and acetic acid aroma upon opening. Blue-veined cheeses are expected to exhibit extensive, blue-green veining throughout the body (from interior to just below the surface) of the white-to-cream-colored open-textured paste (Fig. 17.10). Consumers associate more blue-green veining with more intensely flavored cheeses, and associate yellow-brown veins with over-ripening (Fairclough et al., 2011).

Blue-veined cheese aroma and flavor result from proteolysis and lipolysis during ripening, yielding pleasing as well as potentially unpleasant flavors (Lawlor et al., 2003; Diezhandino et al., 2015). The question of whether homogenization is necessary for blue cheese flavor development was investigated by Cao and others (2014). The findings indicated the facilitative effect of homogenization of milk fat to enable *P. roqueforti* lipase to release free fatty acids and formation of methyl ketones in aged blue-veined cheese. High et al. (2021) identified 172 volatile compounds that discriminated 17 international varieties of blue cheese, including alcohols (22), aldehydes (3), esters (38), free fatty acids (11), hydrocarbons (10), ketones (19), lactones (3), nitrogenous compounds (7), sulfurous compounds (4), phenyl compounds (5), terpenes (4), and other compounds (2). The study revealed that the esters, hydrocarbons, ketones, and alcohols did the most to distinguish different cheeses. Blue-veined cheeses are often characterized by words associated with the chemical compounds, including but not limited to "moldy flavor" (methyl ketones (i.e., 2-pentanone, 2-heptanone, and 2-nonanone), "musty"

Fig. 17.8 Antimycotic agents modify the surface appearance of blue-veined cheeses (left = with; right = without) (S. Clark image)

(2,4,6-trimethoxy-benzaldehyde), “mushroom” (3-octan-3-ol), “rancid” or “lipase flavor” (fatty acids (i.e., butyric, caproic, caprylic acids)), “waxy” (capric acid), “soapy” (lauric acid), and fruity (ethyl hexanoate) (Drake, 2007).

17.3.3.3 Defects in Blue-Veined Cheeses

Blue cheese defects can be segmented into three categories: Appearance, color, and mold development, Aroma and flavor, Body and texture. Defect descriptions are included in subsequent pages.

17.3.3.3.1 Appearance, Color, and Mold Development

Terminology related to deviations from ideal or appearance and color defects in blue-veined cheese are summarized in the next section.

Closed Properly manufactured blue cheese should possess an open body, enabling oxygen-dependent molds to germinate and spread throughout the body of the cheese. A closed body exhibits a lack of openings and lack of blue veining (Fig. 17.11).

Crystals Blue cheese with extended aging may display crystals (e.g., tyrosine crystals), resulting from extensive proteolysis.

Discolored Upon cutting, blue cheeses are expected to display vivid blue-green-colored “veins” of mold that contrast a homogenous white paste. White, yellow, brown, or gray mold is indicative of contamination by other mold species or inadequate ripening conditions (e.g., low pH, low salt concentration, low oxygen) (Fig. 17.12). A yellow paste may be indicative of grass-feeding and, in such cases, may not be considered objectionable.

Excessive Mold The term “excessive mold” may be used when the amount of blue-green mold predominates the interior and surface of the cheese, with very little white paste evident (Fig. 17.13).

Free Whey/Wet Free moisture inside the packaging or entrapped within the body of the cheese, released upon slicing, should be faulted as free whey or wet (Fig. 17.14).

Inadequate Piercing Approximately 30–50 needle channels are sufficient for a wheel of blue cheese. Fewer than 25 may result in a cheese with a lack of veining (Fig. 17.15).

Fig. 17.9 Two appropriate styles of blue cheese preparation for tasting (wedges (left) and crumbles (right)) (S. Clark images)

Lack of Veining or Undeveloped Mold Undeveloped mold and lack of veining are similar. In a fully ripened cheese, extensive, even vein distribution throughout the body of the cheese is expected. Lack of veining most commonly results from a closed cheese body, caused by packing molds with soft curds, inadequate piercing, excessive retained moisture in curds, and/or excessive proteolysis. Inadequate packaging, ripening conditions, or forgetting to add mold spores during manufacture are other causes (Fig. 17.16).

Malformed A cheese that does not display a uniform shape should be faulted as malformed.

Surface Growth Unexpected surface mold or yeast growth should be faulted (Fig. 17.17).

Uneven Mold Distribution Blue-green veining should be distributed evenly from the cheese center to within a centimeter of the cheese surface (Fig. 17.18). Cheese exhibiting uneven distribution or more than two centimeters of white paste at the cheese surface should be faulted for uneven mold distribution.

17.3.3.3.2 Aroma and Flavor

Terminology related to deviations from ideal or defects in blue-veined cheese are summarized in the next section.

Ammoniated Blue cheese that has undergone extensive proteolysis can exhibit pH above 6.5 and have an ammonia aroma which is associated with the formation of aroma from free amino acids. Ammoniated will also typically be associated with bitterness and soft body.

Atypical The defect atypical is used when the blue cheese lacks typical "blue cheese flavor." In contrast to flat, which is an overall lack of flavor, atypical is the presence of an unexpected flavor or a flavor not expected in blue cheese.

Bitter Bitter is one of the most common defects associated with aged cheese. Bitterness results from excessive proteolysis and is recognized, by some, at the back of the throat or tongue. It may be slow to progress, but it lingers for a long time.

Fermented Although some acetic acid aroma and flavor notes are expected in blue cheeses, the defect "fermented" is indicated when the cheese has an excessive level or predominant vinegar or fermented fruit aroma or flavor.

Flat or Lacks Flavor Flat may be used to describe young blue cheese or that which lacks typical, piquant blue cheese flavor (it may lack blue-green veining). The predominant flavor may be lactic acid rather than complex blue cheese flavors.

Fruity Although some fruity notes (e.g., apple, pineapple, or apricot) are expected and desired in blue-veined cheese, if fruity flavors predominate or are exclusive (no other flavors are noted), fruity may be considered a defect.

High Acid While lactic acid is formed in the production of blue cheese, with aging, other aromatic and flavorful by-products should also characterize blue-veined cheeses. When lactic acid predominates or is in excess of expected levels, the defect "high acid" should be pointed out.

Fig. 17.10 Classic, open body and bright, blue-green mold extending close to within 1 cm of the cheese surface (S. Clark image)

High Salt Blue-veined cheeses contain approximately 3.5–4.5% salt, which is higher than many other cheeses. However "salty" should not predominate the flavor profile of blue-veined cheeses. Salt should help to bring out the complex flavor of blue cheese. If it is out of balance, high salt should be noted.

Rancid Although some rancid (free fatty acid) aroma and flavor notes are expected in blue cheeses, the defect rancid is indicated when the cheese has an excessive level or predominant rancid (butyric, caproic, caprylic, or capric acid) aroma or flavor.

Unclean Unclean blue cheese may have a fecal aroma upon opening the package. Alternatively or additionally, it may have an objectionable flavor or aftertaste.

17.3.3.3.3 Body and Texture

Terminology related to deviations from ideal or body and texture defects in blue-veined cheese are summarized here.

Mealy/Grainy Blue cheese that is too dry and/or crumbly will likely also be mealy and grainy. During and after mastication, the cheese does not fully break down, and after swallowing, the mouth does not clean up.

Too Crumbly Blue cheese that falls apart during slicing is considered too crumbly. Although blue cheese crumbles have many applications (e.g., salads, dressings), the most valuable blue cheese is available in wheel and wedge forms.

Too Dry Young or over-salted blue cheese is sometimes characterized by a dry body. It may slice cleanly or crumble upon slicing.

Too Firm Blue cheese that is difficult to slice is considered too firm. It may also be too dry and mealy/grainy.

Fig. 17.11 Pronounced closed body, lack of veining (right cheese also displays discolored mold and surface growth (left cheese displays an ash coat)) (S. Clark images)

Fig. 17.12 Discolored mold (grey (left) and brown (right) mold formation) and crystals (left) (S. Clark images)

Fig. 17.13 Excessive mold, surface growth, and uneven mold distribution exhibited in a freshly cut wheel (S. Clark images)

Too Soft/Weak Blue cheese that is too soft will be difficult to slice and may crush or smear. Blue cheese that contains too much moisture or that has undergone extensive proteolysis will be soft, weak, and/or pasty.

Pasty Pasty blue cheese is commonly soft and sticky while slicing. The defect is characterized by a sticky mouthfeel and a film may remain in the mouth after swallowing.

Fig. 17.14 Moisture spots (left) and free whey exhibited on the surface (right) and exuding from openings (right) of blue cheese (S. Clark images)

Fig. 17.15 Inadequate (left) or improper (right) piercings. The cheeses also exhibit discoloration due to wild microbial growth and possibly mite infestation (S. Clark images)

Fig. 17.16 Blue cheese exhibiting piercings but a lack of mold development, likely due to the apparent closed body (S. Clark image)

Fig. 17.17 Blue cheese exhibiting unsightly surface growth (the right cheese also lacks veining) (S. Clark images)

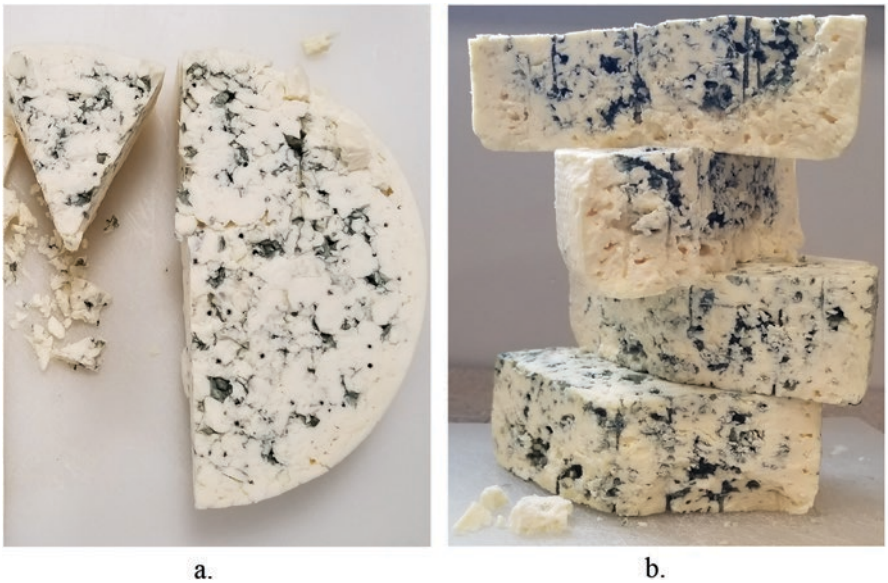

Fig. 17.18 Fully developed blue-green mold within cheese interior. (**a** even mold distribution; **b** uneven mold distribution (S. Clark images)

17.4 Conclusion

Readily recognized by their appearance, mold-ripened cheeses occupy a unique niche in the cheese case and food supply. These beneficial molds are not a sign of spoilage but of the delicate craftsmanship and maintenance of conditions allowing them to properly develop. Meticulous care in sanitation practices, cultivation of starter cultures and mold spores, production practices, and aging regimen yield a multitude of delightful bloomy rind and blue-veined cheeses worldwide, representing milk of cows, goats, sheep, buffalo, or mixtures of milk from multiple species.

A breakdown anywhere in the system may yield sensory defects as elaborated upon in this chapter. Both accidental and intentional changes to process or conditions have occasionally led to novel cheeses for this category. Training of personnel to recognize and combat sensory defects in mold-ripened cheeses will only improve our ability to ensure consumers have the best-quality mold-ripened cheese experiences.

References

Cao, M., Fonseca, L. M., Schoenfuss, T. C., & Rankin, S. A. (2014). Homogenization and lipase treatment of milk and resulting methyl ketone generation in blue cheese. *Journal of Agricultural and Food Chemistry, 62*, 5726–5733.

Coulter, S. T., & Combs, W. B. (1939). *The use of steapsin in the manufacture of blue cheese* (Journal Series Paper 1683) (pp. 521–525). Minnesota Agricultural Experiment Station.

Currie, J. N. (1914). Flavor of Roquefort cheese. *Journal of Agricultural Research, 11*(1), 1–14.

Diezhandino, I., Fernández, D., González, L., McSweeney, P. L. H., & Fresno, J. M. (2015). Microbiological, physico-chemical and proteolytic changes in a Spanish blue cheese during ripening (Valdeón cheese). *Food Chemistry, 168*, 134e141.

Diezhandino, I., Fernández, D., Sacristán, N., Combarros-Fuertes, P., Prieto, B., & Fresno, J. M. (2016). Rheological, textural, colour and sensory characteristics of a Spanish blue cheese (Valdeón cheese). *LWT-Food Science and Technology, 65*, 1118–1125.

DOP Italian Food Agency. (2022). *Gorgonzola Cheese P.D.O*. Available at: https://www.dopitalianfood.com/en/brands-dop-italian-food/cheeses-pdo-pgi/item/406-gorgonzola-cheese-p-d-o.html. Date accessed: 4 May 2022.

Drake, M. A. (2007). Defining cheese flavor. In B. Weimer (Ed.), *Improving the Flavor of Cheese*. CRC Press.

Dupont-Danisco. (2014). *Technical Manual 2106-2e, Solutions for White surface ripened cheeses*.

Fairclough, A. C., Cliffe, D. E., & Knapper, S. (2011). Factors affecting *Penicillium roquefortii* (*Penicillium glaucum*) in internally mould ripened cheeses: Implications for pre-packed blue cheeses. *International Journal of Food Science & Technology, 46*, 1586–1590.

FAO and WHO (Food and Agriculture Organizaioin of the United Nations and World Health Organization). (2011). *Milk and milk products* (2nd ed.). Available at: https://www.fao.org/3/i2085e/i2085e00.pdf. Date accessed: 12 Dec 2022.

Fox, P. F., Guinee, T. P., Cogan, T. M., & McSweeney, P. L. H. (2000). Chapter 17. Principal families of cheese. In *Fundamentals of cheese science*. Springer.

Gkatzionis, K., Linforth, R. S. T., & Dodd, C. E. R. (2009). Volatile profile of Stilton cheeses: Differences between zones within a cheese and dairies. *Food Chemistry, 113*(2), 506–512.

High, R., Eyres, G. T., Bremer, P., & Kebede, B. (2021). Characterization of blue cheese volatiles using fingerprinting, self-organiziing maps, and entropy-based feature selection. *Food Chemistry, 347*, 128955.

Lane, C. B., & Hammer, B. W. (1938). Bacteriology of cheese III. Some factors affecting the ripening of blue (Roquefort type) cheese. *Research Bulletin (Iowa Agriculture and Home Economics Experiment Station), 21*(237), Article 1.

Lawlor, J. B., Delahunty, C. M., Sheehan, J., & Wilkinson, M. G. (2003). Relationships between sensory attributes and the volatile compounds, non-volatile and gross compositional constituents of six blue-type cheeses. *International Dairy Journal, 13*(6), 481–494.

Morris, H. A., Jezeski, J. J., & Combs, W. B. (1954). *The use of white mutants of Penicillium roqueforti in cheese making* (p. 3093). Minnesota Agricultural Experiment Station.

Parmelee, C. E., & Nelson, F. E. (1949). The use of Candida lipolytica cultures in the manufacture of blue cheese from pasteurized homogenized milk. *Journal of Dairy Science, 32*(12), 993–1006.

Price, E. J., Linforth, R. S. T., Dodd, C. E. R., Phillips, C. A., Hewson, L., Hort, J., & Gkatzionis, K. (2014). Study of the influence of yeast inoculum concentration (*Yarrowia lipolytica* and *Kluyveromyces lactis*) on blue cheese aroma development using microbiological models. *Food Chemistry, 145*, 464–472.

Pujato, S. A., Guglielmotti, D. M., Ackermann, H.-W., Patrignani, F., Lanciotti, R., Reinheimer, J. A., & Quiberoni, A. (2014). *Leuconostoc* bacteriophages from blue cheese manufacture: Long-term survival, resistance to thermal treatments, high pressure homogenization and chemical biocides of industrial application. *International Journal of Food Microbiology, 177*, 81–88.

Roustel, S. (2020). *Soft cheese step-by-step*. France, Profession fromager.

Thom, C. (1906). Fungi in cheese ripening: Camembert and Roquefort. U.S. Dept. of Agriculture, Bureau of Animal Industry. *Bulletin, #82*, 1–39.

USFDA. (2022a). *Title 21—Food and drugs. Chapter I—Food and drug administration department of health and human services subchapter B – Food for human consumption. Part 133 – Cheeses and related cheese products. Subpart A – General provisions. 133.106 blue cheese*. Accessible at: https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-133. Date Accessed: 4 May 2022.

USFDA. (2022b). *Title 21—Food and drugs. Chapter I—Food and drug administration department of health and human services subchapter B – Food for human consumption. Part 133 – Cheeses and related cheese products. Subpart A – General provisions. 133.164 Nuworld cheese*. Accessible at: https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-133. Date Accessed: 4 May 2022.

Weigmann, H. (1906). Herkunft der Bakterien der Milch. In F. Lafar (Ed.), *Handbuch der technischen Mykologie* (pp. 155–189).

Worldnews, Inc. (2022). *Cabrales*. Available at: https://www.cheese.com/cabrales/. Date accessed: 4 May 2022.