4 Overview of the Brewing Process

4.1 Overview of the Process

A good friend of mine cooks a very tasty Persian saffron rice dish. It is creamy, buttery, savory, and unlike anything this Western palette has ever experienced. When I press my friend for how he makes the dish, his response is simply: "*First you plant the seeds*."

This is obviously a diversion to revealing the recipe, but there is some truth to recognizing, and revering, the beginnings of our culinary creations. The same is true for beer. We must recognize that this ancient brew begins with materials sourced from the Earth. Since the beginning of the agricultural age, humans have cultivated the materials and refined the process and the art associated with the production of this beverage. Historically, the raw materials used in the production of beer depended almost exclusively on what grew in the local area. If the brewer could not grow a particular ingredient, buy it from a local farmer, or trade for it in the market, it was not included in the process for making beer. And while this statement appears to only impact grains and flavoring ingredients, it also applied to the materials used within the process to make the beer (kettles, methods to cool or heat, how the beer was stored, etc.). In fact, many of the current styles of beer can be traced back to different local materials or processes that worked satisfactorily for our ancestor-brewers.

In this chapter, we explore the basics of the main ingredients used in the modern production of barley-based beer. Let us start by considering the source of the sugars we need to make our beer.

M. Mosher and K. Trantham, *Brewing Science: A Multidisciplinary Approach*,
DOI 10.1007/978-3-319-46394-0_4

4.1.1 Agricultural

First you plant the seeds In, most cases in the modern era, brewers did not plant, cultivate, or harvest the barley that they used. This still holds true today. But each brewer understood, just as we *must* understand, how barley is grown, harvested, and treated. Doing so, the brewer can recognize when the grain is suitable for brewing, and when the grain is substandard. After all, in order to brew beer worth consuming, one must begin with good ingredients. And it is always helpful to know where your beer ultimately comes from.

Barley (*Hordeum vulgare*) is a member of the grass family. It is likely that the barley plant was first cultivated in Mesopotamia around 10,000 BC, about the same time as wheat. Since that time, it has been cultivated, selected, and bred to produce the numerous different *cultivars* that are used currently. Each of these is grown for different purposes; barley destined for beer is often considered to be very high-quality grain.

Barley is typically grown in cooler climates since it has a relatively short growing season compared to other cereal crops. In North America, it is grown in the northern continental USA and Canada where corn does not grow well. Most—about half—of the US barley produced is used as livestock feed. About one-quarter of US barley is ultimately used for brewing. Around the world, the USA does not even crack the top ten in barley production when compared to the production levels in Russia, Germany, and many other countries in the world.

There are three basic types of barley used when classifying the grain. Depending on how the spikelets and seeds are arranged on the central spine of the seed head, the barley is known as 2-row, 4-row, or 6-row. Two-row barley has two rows of seeds on each spike, but has one fertile floret per node. Four-row barley has four rows of seeds. Similarly, 6-row has six rows of seed on each spike, but only three fertile florets per node. Wild barley is of 2-row variety. The 4-row and 6-row varieties were historically selected after domestication and grown for different purposes. As a malted grain, 2-row barley tends to have lower protein content. Four- and six-row barley varieties have higher protein contents. While four-row barley is typically not used in brewing, the six-row variety has found widespread use. With modern brewing and malting processes, the slightly higher protein content is not much of an issue as we will see in the next section (Fig. 4.1).

Once harvested, the barley is stored in silos and dried until it has less than 14 % water content. After the seed reaches that level of water content, the barley can be sold. Often, however, it is stored for 1–2 months (or longer in some cases). While the reasons are not entirely understood, this storage helps reduce the dormancy of the seeds.

Prior to sale, however, the seeds are cleaned. This involves running a magnet through the seeds to pick up small pieces of metal that come from the harvesting process. The seeds also enter a cleaning drum that removes small broken pieces and

Fig. 4.1 2-Row and 6-row barley. Photograph by Xianmin Chang (xianmin.chang@orkney.uhi.ac.uk)

stones. Finally, the seeds are sorted by size. This can be done using a screen sorter. In this machine, the seeds are poured onto a shaking screen. Seeds that are very large are shaken off of the screen and into a hopper. Seeds that are small enough to pass through the screen fall onto a second screen. If the seeds are too large to pass through the second screen, they are shaken into a second hopper. Those seeds that pass through the second screen are placed into a third hopper. In this way, the seeds are sorted into their relative sizes (large, medium, and small).

The larger, plumper seeds are perfect as base malts for the brewer. These seeds have a large amount of starch that will yield a lot of sugar per unit weight. The medium-sized seeds are still usable by the brewer, but are better used as specialty malts instead of base malts. Unfortunately, the smallest seeds do not have enough starch to make it worthwhile for the brewer. Instead of just throwing them away, these seeds are often sold as feed for livestock.

Given that the farmers do everything to maximize their profit, production is geared toward making the plumpest seeds possible. This practice is not always possible. Unfortunately, due to Mother Nature, the farmer sometimes struggles to correct for low rainfall amounts and temperatures that are not suitable for maximum yields. The result is that barley quality varies from year to year. The maltster and the brewer must account for this variability.

CHECKPOINT 4.1

What are the differences between 2-row and 6-row barley?
Draw a sketch of the seed size sorter outlined in this section.

4.1.2 Malting

If we try to use freshly harvested barley to make our beer, we notice that essentially no sugar is extracted from the grain. Early civilizations probably also noted this and conducted fairly elaborate techniques (such as allowing the grain to rot, or making barley dough and bread before making beer). We now know that the required sugars are packed away in the endosperm of the seed as starch. These are energy stores originally intended for a newly sprouting plant. To harvest that starch and convert it into sugars, the cleaned, sorted barley is sent to the maltster.

The maltster begins the process by soaking the seeds in water. This tricks the barley into thinking it is time to sprout. During this time, the "germ" part of the seed begins to grow into the acrospire; i.e., germinate (see Fig. 4.2). This process activates and develops diastatic enzymes inside the seed. It also starts the process of unlocking starches from the endosperm. In short, the seed begins to grow by converting its stored starch into sugars. Unless halted, however, the seed will continue to grow and consume all of the starches that are needed for brewing. Simply drying out the seed and heating it slightly halts the sprouting process. The rootlets that grew from the seed are then mechanically separated from the grain. At this point, the malted grain is ready for the brewer and is frequently called pale malt (Fig. 4.3).

Plain, pale malt accounts for up to 100 % of a brewer's grain bill depending on beer style. The purpose of the pale malt in the recipe is to provide diastatic enzymes and at least some of the fermentable sugars. *Diastatic power*, a measure of the malt's ability to convert starches into sugars, is a measure of the ability of the malt to do this job. But, pale malt, by itself, does not provide the brewer with enough variability to make all of the styles of beer. So, to provide different flavor profiles required for those different beer styles, the brewer uses specialty malts.

Specialty malts are made in many different ways. Some are made by heating the pale malt in a kiln until it browns (Fig. 4.4). The browning or toasting of the malts occurs via the Maillard Reactions we uncovered in Chap. 3. These reactions deepen and accentuate the malty-toasty flavor of the malt. As we will discover later,

Fig. 4.2 6-Row barley undergoing the sprouting process. From *left* to *right,* the seeds have been in contact with water for 0, 1, and 2 days, respectively. Rootlets begin to appear at the *bottom* of the barley seed

Fig. 4.3 After 4 days in water, the rootlets are approximately the same length as the original seed. Note the fine hairs attached to the rootlets in the *left panel*. The acrospire is not yet visible because it grows beneath the husk of the seed

different degrees of heat will yield different flavor profiles for the malted grain. The only downside is that the excessive heat required to toast the grain will denature the enzymes and reduce the diastatic power of the malt.

Other specialty malts are made by soaking the pale malt in warm water. This activates the malts to begin sugar production, but since the pale malt roots and shoots have been damaged, the seed cannot grow. Instead, the sugars collect in and on the seeds. When these seeds are then dried and kilned, they result in a great source of caramel, toffee, and roasty malt flavors. The kilning process, however, also reduces the diastatic power to essentially zero. These sugary malts are known as crystal malt (due to the presence of crystals of sugar on the surface of the seeds) or caramel malts (because of the flavors they provide).

A brewer has a wide variety of malted and toasted grains to design different beer taste profiles. But, malting and toasting grain often requires large, dedicated areas to spread out the grain, store the grain, and occasionally turn over the grains until the

Fig. 4.4 Chocolate Malt, Crystal-40L, and wheat Malt. Roasting the malted grain gives it deeper colors and flavors

germination process is complete. Additional machines and space are needed for kilning. Brewers leave this process to specialists known as maltsters; very few breweries will take on this time and space-intensive step themselves.

4.1.3 Mashing

The typical brewer begins their process at this point, purchasing malted grain from a maltster. The variety of malts that we discovered in Sect. 4.1.2 can be obtained from small boutique maltsters or large international maltsters. Once the malt is obtained, it undergoes mashing. Mashing can be considered an extension of malting, in that we are adding water again to the grain. This time, however, the maltster has removed the rootlets and kilned the malt. The result is that many of the enzymes needed for growth have been denatured, and the lack of the root makes the seed unviable as a plant. So the addition of water at this point does not result in growing seeds.

The malted grain is crushed to expose the white-starchy endosperm (see Fig. 4.5). The resulting *grist*, broken pieces of grain and husks, can be as fine as powder or only slightly crushed depending upon the brewers requirements. The grist and warm water are mixed and added to the *mash tun*, giving us the *mash*. There is some allowed variability to the water/grist ratio, but the mash typically has a consistency of fairly runny oatmeal.

In some cases, the brewer may take grains that have not been malted and harvest the starch from them for the mash. This involves a separate step where crushed grains are added to a separate vessel known as a *cereal cooker*. Water is added to the grist, and then the entire mixture is heated to the gelatinization temperature for the particular grain used (see Table 4.1). This step causes the starch in the endosperm of the grain to be released into the mixture. The entire mixture is then added to the mash tun. We will explore this process in greater detail in a later chapter. It is important to note that the unmalted grains used in this process do not have active

Fig. 4.5 Malted grain is gently crushed in preparation for mashing. Note the white-starchy centers of the malted grain and the largely intact husks

enzymes to convert the starches into sugars. Malt is required to provide those enzymes.

In the mashing step, enzymes developed during the germination (malting) process convert the available starches to sugars. The ultimate goal of mashing is to break down large starch molecules into sugars which can be digested by yeast, i.e., *saccharification*. The mashing process can involve several temperature rests depending on what process the brewer wishes to accomplish (create more sugars, reduce the amount of proteins, etc.). A *rest* is a period of time in which the mash is held at a specific temperature. These different rests are discussed in Chap. 6.

In the modern age of brewing, nearly all malted grain available on the commercial market is fully modified—meaning that the maltster has germinated the seeds until all of the endosperm has been acted upon by enzymes. The maltster does offer some partially modified malts that require special mashing rest steps to fully utilize. However, for most styles of beer, the brewer acquires fully modified malt and really only needs to execute the saccharification rest. The mash temperature typically is held constant at a value between 140 and 155 °F where it rests for 60 min. Programmed temperature running with multiple rests can reduce the time to as little as 20 min, but this requires specialized equipment to accomplish. During this rest, the starches in the endosperm of the malted barley are steadily converted into fermentable and un-fermentable sugars. With appropriate starting water chemistry, a pH in the range of 5–6 is naturally established in the mash. This pH is essential for the saccharification enzymes to work.

There are two saccharification enzymes that remain active in the malt after kilning at the malster's factory. These enzymes become activated again during the mash. It is possible for the brewer to fine-tune the final taste profile of the beer by adjusting the temperature within the 140–155 °F range. As discussed in Chap. 6, this can result in beer that is thin and alcoholic, thick and malty, or any combination of these profiles (Fig. 4.6).

At the end of the mash period, it is often desirable to halt the further conversion of long sugar chains to shorter, more fermentable chains. In this case, the brewer will execute a *mash-out* by raising the temperature of the mash just high enough to halt enzymatic activity, and preserve the sugar profile. This higher temperature also helps break down any proteins and glutens and helps reduce the viscosity of the mash significantly.

Table 4.1 Gelatinization temperatures of commonly used unmalted grains

Grain	Temperature (°F)	Temperature (°C)
Barley	140–150	60–65
Wheat	136–147	58–64
Rye	135–158	57–70
Oats	127–138	53–59
Corn	143–165	62–74
Rice	154–172	68–78

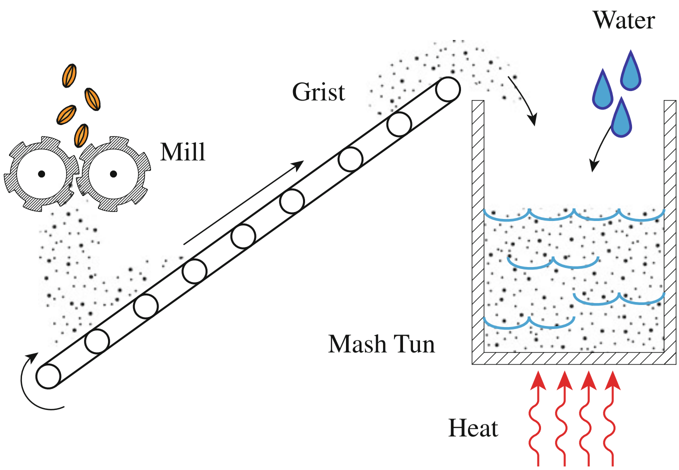

Fig. 4.6 Crushed grain (grist) is added to warm water and allowed to sit during the mash step. Typically, the mash is held at 155 °F for 60 min

CHECKPOINT 4.2
What is the purpose of malting?
If an unmalted cereal was used in a recipe with the intention of converting its starches into fermentable sugars, what process would be required prior to its use?

4.1.4 Lautering and Sparging

In this step, *the goal is to separate the sugar water from the grain.* There are a variety of approaches to accomplish this task. In some instances, the entire mash (grist and sugar water) is pumped into a different vessel known as a *lauter tun*. The water is then slowly drained from the grain while being gently rinsed with warm water (*sparging*). The lauter tun is wider and less deep than the mash tun. In addition, the lauter tun often contains a series of knives or rakes that can be rotated around the grain bed. By raising and lowering the knives, the grain bed can be gently stirred as it is being drained and rinsed. This helps ensure that all of the sugar is rinsed from the spent grains.

In some breweries, the grist has been ground into a relatively fine powder. This type of mash provides an increase in sugar production with a concomitant decrease in the time involved. One problem exists, though, in that filtering this type of mash using a lauter tun does not work. In this case, the mash is pumped into a *mash filter*. Inside the mash filter, bladders are used to squeeze the liquid away from the mash flour. Then, sparge water is added, and the mash flour squeezed again to remove all of the sugar water. This process, while requiring expensive equipment, is very efficient at extracting the sweet wort from the grist.

In smaller brewing operations, the mash tun and lauter tun are a combined vessel. In this case, the sparge water trickles through the deeper bed of grain and rinses it of the sugars. In both cases, the sparge water is often held at a fairly high temperature and relatively low pH. These characteristics help assure the brewer that all of the sugars are removed while reducing the possibility of extracting the tea-like tannin from the husks. Both vessels also have a false bottom with a large number of small holes that allow the sugar water to drain, but retain the spent grain.

The sugary, malty liquid that the brewer extracts from the mash is called *sweet wort*. It is a relatively thin liquid that contains some proteins, individual amino acids, metal cations (such as calcium, magnesium, and others), and a mixture of fermentable and unfermentable sugars. If the sweet wort was just drained away from the grains, a significant amount of sugar would remain in the nooks and crannies of the grist. The problem is that the majority of the sweet wort is held in the matrix of the grist owing to a relatively large surface tension of the water; much in the same way that water adheres in a sponge (Fig. 4.7).

As we have seen, *sparging* is the process of rinsing the sweet wort away from the spent grain. Ideally, the sparge water will rinse away the concentrated sweet wort, leaving behind plain water in the spent grain. However, there are two primary issues that arise with sparging. With excessive amounts of sparge water, the final batch of sweet wort becomes much less concentrated. Unless the brewer invests the energy to concentrate the wort, the final beer will be weaker, both in taste and in final alcohol content. And, as we discovered above and will cover in more detail in

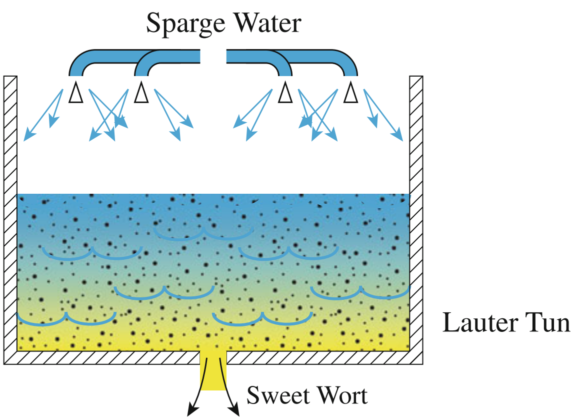

Fig. 4.7 General overview of the use of sparge water to rinse the mash. Sweet wort is separated from spent grain in the Lauter/Sparge step. This typically takes 20-60 min, or longer, to complete

Chap. 7, unless the pH of the sparge water is controlled, the extraction of tannin from the *chaff* (husks of the grist) becomes a very big issue.

For all but the mash filter process, there are a variety of process methods that can be used in the sparging step. Each type of sparging profile has its pros and cons and can be traced back to traditional procedures employed by different cultures. The three basic procedures are as follows:

Continuous (or Fly) Sparge As water is drained from mash, a continuous supply of warm water is sprinkled above the grains at the same rate that sweet wort is drained. The water level is kept above the level of the mash grains. This has the potential to extract more of the sweet wort, resulting in better brew-house efficiencies over other sparging processes. The largest issue with this method is that as the sweet wort is drained from the mash, the additional sparge water causes the runoff to become less and less concentrated. This, in turn, causes the pH to rise back toward the pH of the sparge water. If the pH rises above 6, the potential exists for tannin to be extracted from the husks. The process requires an attentive brewer and must be stopped when the sugar concentration of the sweet wort drops below and/or the pH begins to rise above a predetermined point.

Cleanup of the mash tun in a continuous sparge process is somewhat involved. The excess sparge water must be drained away from the spent grains as the first step. It is possible that this water, unusable as sweet wort, could be used to mash in the next batch, assuming the brewer is interested in making another batch that day and that the pH of the water was still below 6. Then, the spent grains must be scooped out of the vessel. The water that has been absorbed by the grains makes this process very laborious. Finally, the spent grains must be removed from the brewery. Many brewers sell or donate these to area ranchers to be mixed with roughage for their animals.

No Sparge Quite simply, the no sparge method is just that. The water from the grain bed is allowed to drain directly without addition of water. There is no risk of dilution of the sweet wort or extraction of tannin in this method. However, brew-house efficiency is greatly reduced, because a lot of usable sugars remain in the spent grains. This method is particularly useful for creating very-high-gravity beers. Cleaning the vessel after the no sparge method is very similar to the batch sparge, however, there is no, or very little, waste water from the process.

Batch Sparge Similar to the no-sparge method, the batch sparge method allows the sweet wort to be drained away from the grain bed until no more liquid is removed. This batch of sweet wort is called the *first runnings* and is very rich in sugars. The first runnings, as in the no-sparge method, can be used to make a high alcohol beer. Then, the mash-lauter tun is re-filled with sparge water, mixed to allow the water to rinse all around the grains, allowed to settle, and then re-drained. The *second runnings* can be used to make a lower alcohol content beer, historically known as a small beer. The first and second runnings can be combined into one batch or portioned out into two or more batches of different gravities. This is an improvement over no sparge approach in that efficiency improves with the second rinse. Again, care must be exercised to ensure that the pH in the second runnings has not changed to a point where tannin is extracted. In some cases, a third batch of sparge water could be obtained by adding more water, stirring the mash, allowing it to settle, and then draining off the liquid. Third runnings have very little fermentable sugars, but can still be fermented to prepare a very weakly alcoholic beer, or mixed in proportions with the other runnings to create beers of different alcohol content.

CHECKPOINT 4.3
Visit your local microbrewery. Which type of sparging system do they use? Describe its operation.
What is the purpose of sparging?

4.1.5 Boiling

The brewer then pumps the sweet wort into the *boil kettle*. It is then heated to boiling for a given period of time, typically 30–90 min. The exact time is determined by the outcome required by the brewer. In addition, there are several different types of boil kettles that can be used for the process, but we will cover them in much more detail in Chap. 10.

There are several reasons we boil the wort. We briefly touch on the main reasons here. Historically, the wort was boiled to kill harmful microorganisms and to allow the flavors of any other added ingredients to mix. This was important to early cultures as modern water purification procedures were non-existent. Early beer was relatively weak, but since it had undergone this boiling step, it was safer (and healthier) to drink than the primitive water sources of the day. Interestingly, these cultures did not understand the nature of microorganisms and did not understand *why* boiling made the drink safer—it just did. Likely, the main reason for boiling the wort was to meld the flavors and the resulting boiled wort tasted better than the wort that was not boiled.

We now understand that boiling the wort elicits several other primary functions. It is during the wort boil that the brewer will add hops. Depending on when the hops are added to the boil, they can contribute the characteristic bitter flavor, provide the characteristic aroma, or give flavor to modern beers. Again, the brewer has many options that determine the final profile of the hops in the beer. Hops give us the crisp, citrusy flavor found in pale ales, the bitter taste of a stout, and the characteristic aroma of India Pale Ales (IPAs). Even in beers such as browns and porters where hops are not as pronounced, the addition of hops help increase the shelf life of the final product and provide a taste balance with the alcohol in the beer. The chemistry behind the wort boil is discussed in Chap. 8.

Typically, a brewer will boil the wort with the first addition of hops for 60 min in order to provide the characteristic bitter flavor we associated with modern malt-based beers. There may be other hop additions later in the boil, but at the end of the boil period no matter when the hops were added, the liquid is now called *bitter wort*.

An important secondary effect of boiling the wort is to increase the relative sugar content as water is evaporated from the wort. This will eventually give us a higher alcohol content in the final beer, but with reduced volume. Another effect that occurs is the additional browning; the Maillard reactions. For the same reason that malts are toasted, this will give the beer a more robust, malty flavor (Fig. 4.8).

At the end of the boiling time, the bitter wort is pumped out of the vessel and then back into the vessel at an angle. This creates a *whirlpool*. During the whirlpool process, which can last as long as 60 min, the proteins and other coagulated materials fall to the center of the vessel forming a cone of sludge known as *trub*. The bitter wort is then pumped away from this sludge and through a chiller. As it moves through the chiller, it is cooled to the perfect temperature to begin fermentation.

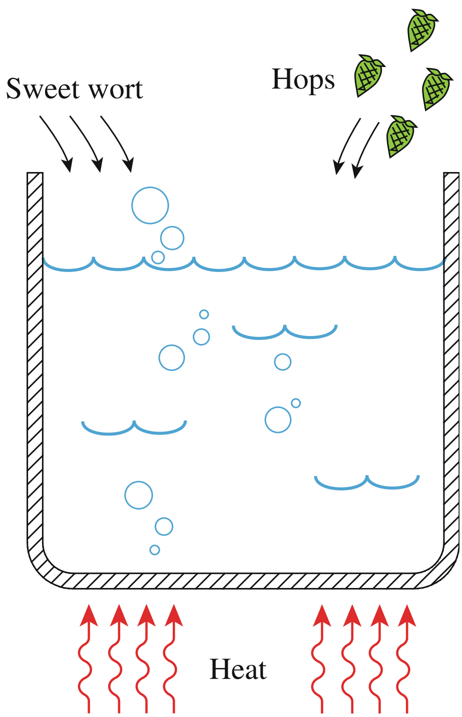

Fig. 4.8 The sweet wort is boiled with hops during the wort boil. Typically, this step takes 30–90 min

4.1.6 Fermentation

The cooled bitter wort is is pumped into a fermentation vessel. As it moves into the fermenter, oxygen gas is added to the stream of fast moving liquid. The process of moving liquid around in the brewery is often called *racking*. So, using the brewer's vernacular, the bitter wort is racked to the fermenter. Then, the cool oxygenated bitter wort is inoculated with yeast, known as *pitching* yeast into the wort.

It has been said that brewers make wort, but yeast makes beer. The importance of these microscopic fungi was not well understood in the early days of brewing. Even the German purity law, the *Reinheitsgebot*, did not initially recognize the importance of this ingredient in the overall process. It was not until the work of Louis Pasteur (1822–1895), and others, that we began to understand just how important yeast was to brewing. The biological metabolism of sugars by yeast is quite complicated and will be discussed in detail later. But we summarize the yeast's function from a macroscopic, if not empirical, point of view here. The purpose of the yeast from the perspective of the brewer is to consume the sugars in the bitter wort and leave behind alcohol.

Again, as in every step in the process, the brewer has a wide range of strains and species of yeast to choose from. Due to subtle differences in the metabolism of each different strains of yeast, the composition of the bitter wort, and the temperatures used by the brewer, each yeast strain will yield different by-products and impart the beer with a distinct flavor. For example, the banana and clove flavors common to hefeweizen are due to minute by-products excreted from certain yeast strains during fermentation. Fermentation temperatures can also influence the final taste profile of the beer.

Fermentation can take 2–14 days for ales, and lagers may take multiple months to complete the fermentation cycle. During the process, the dormant yeast falls to the bottom of the vessel and is removed. Yeast falls out of the beer by flocculating. This process, requiring calcium ions in the beer in order to be most effective, clumps the single-celled organisms together causing them to become too heavy to stay dissolved in the beer. Different yeast strains have different propensities for doing this and are often characterized by their ability to do so. For example, highly flocculating yeasts will tend to settle and clump together very quickly after fermentation. Highly flocculating yeasts may need to be re-suspended in the beer ("roused") to complete the fermentation cycle. On the other hand, low-flocculation yeast tends to remain in suspension. This is the cause of the cloudiness we see in Hefeweizen and some Belgian style beers. In between, medium-flocculating yeast tends to produce a cleaner beer because they stay active long enough to re-absorb diacetyl and other by-products. They take some time, but will eventually settle to the bottom of the vessel making it easier to separate and filter from the beer.

After the fermentation cycle is complete, we have what brewers refer to as *green beer*. Green beer is drinkable, but the refined flavors have not stabilized. So, the green beer is racked to a conditioning tank to allow that process to be accomplished. In some cases, the fermentation tanks are pressurized allowing the carbon dioxide that is formed by the yeast to carbonate the beer. In other cases, the tanks are open to the atmosphere and the addition or adjustment of the carbon dioxide level must be accomplished during conditioning.

CHECKPOINT 4.4
Outline as many reasons as you can why the modern brewer boils the wort before fermentation.
Louis Pasteur was responsible for more than just the recognition of yeast as a requirement for brewing. What other process in food production was he responsible for (hint: the process bears his name)?

4.1.7 Conditioning and Bottling

At this point in the process, the green beer that we have is not very tasty. The biological process of fermentation has produced a number of by-products such as acetaldehyde, diacetyl, and dimethyl sulfide. Combined, these flavors will give our beer an unpleasant "green" taste. If given sufficient time, the yeast that inhabits the beer may eventually re-absorb many of these compounds, so we allow time for the product to sit and "condition."

During this period of rest dormant yeast, heavier and larger proteins, and other debris continue to precipitate from the beer. This helps to further clarify the beer. In the conditioning tank, the brewer also can adjust the beer. Gelatins can be added to help proteins and yeast precipitate, flavoring agents can be added to adjust the flavor, coloring agents can be added to increase the color, and reduced hop iso-acids can be added to adjust the bitterness of the beer. Each of these processes adjust the beer so that the final product is within the brewer's specifications.

Bright beer refers to beer that has gone through this process and is ready to serve. In the case of natural conditioning, the yeast will eventually settle to the bottom of the storage vessel to make bright beer. Or, the brewer could mechanically filter the beer to separate the yeast. There are a multitude of possibilities for separating proteins and yeast from the beer, including plate filters, leaf filters, and centrifuges. Unfortunately, mechanically removing the yeast before the yeast has had time to reabsorb by-products could lead to beer that is permanently out of specifications.

Naturally conditioned beer takes between at least a month for ales, depending on overall alcohol content, and up to 6 months or even more for lagers. This difference is due to the temperatures at which the yeast prefers to work. Lager yeasts grow and ferment at cooler temperatures, so the metabolism of the by-products takes longer. Because the natural process is relatively slow, the brewer often intervenes.

Since the transition from the main activity of fermentation to conditioning is very gradual, it difficult to draw a line and say when the latter starts and the former ends. Bright beer, even though it has been allowed to sit, will still have active yeast dissolved or in suspension (typical yeast counts of one million cells per milliliter are common). It is at the packaging point where the process is different based on the size of the brewery. Larger breweries that distribute beer across the globe will tend to filter and pasteurize their beer. Smaller microbreweries that serve at their own taproom or keg their beer for local sales tend to avoid the added expense of filtering or pasteurizing.

In cases where the beer is not filtered and pasteurized, the yeast still suspended in the bright beer will continue to condition the beer. This greatly reduces the shelf life of the beer, as the flavors continue to change as time and temperature allow the yeast to continue their work. The length of the shelf life is highly dependent upon the style and strength of the beer. Some imperial stouts may be naturally conditioned and be best for consumption in year 2 of their life. In addition, since the beer is not pasteurized, growth of flavor-impacting bacteria and other organisms is possible. For these reasons, commercial breweries prefer to stabilize the flavor once the flavor profile has been established by filtering and pasteurizing. And just to be sure, many breweries also indicate the "best by" date on the label to ensure that the consumer has the best experience with the product.

4.2 Cleaning and Sterilizing

Just as it is important to start with quality ingredients, it is imperative to maintain a clean brewery. This is particularly true for any equipment that is used post-wort boil, since the boil will kill any microorganisms acquired during the mashing process. The issue is that other microorganisms that are ubiquitous in nature will be just as happy consuming the fermentable sugars in the bitter wort as yeast will. The uncontrolled fermentation by foreign microorganisms will output a significant amount of undesirable off-flavors, mouthfeel, and visual appearance.

In our casual discussion of removing unwanted microorganisms, several terms tend to be used interchangeably: sterilize, disinfect, and sanitize. However, these have very well-defined and different definitions in the brewing and food industries. To sterilize something means to completely kill all microorganisms. This generally requires excessive heat applied to the brewing equipment for an extended period. For example, a surgeon will sterilize scalpels and other operating tools in an autoclave. Unfortunately, killing all microorganisms is nearly impossible to do. In nearly every process, some microbes survive. Disinfecting means to kill all *unwanted* microorganisms which could cause spoilage. Unfortunately, this also does not often mean that all microorganisms are eliminated. Finally, sanitization just means we will eliminate most of the unwanted organisms.

It is just not practical, or necessary, to completely sterilize brewery equipment of all indigenous, wild microorganisms. After all, beer has been successfully brewed long before the role of yeast or other wild microorganisms were understood. In those days, it was pure chance that a “good” strain of wild yeast would inoculate the wort and start fermenting the beer. In fact, stirring sticks from successful batches were carefully saved and reused so that a particular “house flavor” would be passed to the next brew.

Rather than sterilizing, we clean the brewery and equipment as best we can and sanitize with a chemical agent, eliminating most of the undesired microorganisms. The goal of the brewer then is to get the fermentation started with *our* selected yeast before the other microorganisms have a chance to build a significant population. Called “microbial antagonism,” the yeast is able to build sufficient numbers such that it interferes with the normal growth of the other, undesirable microbes. And once the level of alcohol in the beer has reached a certain level, the alcohol itself serves as an antimicrobial agent.

Unfortunately, the dirtiest place in the brewery is the floor. The floor of the brewery is always wet, walked upon by the workers, and spilled upon with sweet wort, green beer, and other compounds used in brewing. Reduction in brewery contaminants is a result of those brewers that make sure to clean the entire space where the brewery exists. This may even include the outside walls of the brewery, and making sure that vegetation does not grow too close to the brewery itself.

Safety is a significant issue that all brewers must adhere to when using chemical agents to clean the brewery. For this reason, all brewers and workers in the brewery must know and understand the principles and processes for cleaning equipment. For example, some chemical agents will react with carbon dioxide. Many examples exist of cleaning agents being added to a freshly emptied fermenter and seeing the reaction of carbon dioxide and cleaning agent cause the fermenter to implode. Other examples exist of untrained workers entering a vessel to clean it using toxic chemicals and expiring inside the confined space. Care and safety are necessary when using these agents.

For the safety of workers, most equipment is fitted with spray balls. In these cases, cleaner is cycled through the vessels using a pump that pushes the liquid through a spray ball. The result is known as *clean-in-place* (CIP). This allows the brewer to clean a vessel in the shortest amount of time possible, while reducing the exposure of workers to harmful chemicals.

CHECKPOINT 4.5
Assume the brewer wishes to NOT clean the boil kettle between batches of beer. Describe what you might expect to happen to the beer in later batches. Outline at least three things that the brewer could adjust in the conditioning phase of the beer.

4.3 Inputs and Outputs

The most important part of brewing is making sure that the ingredients used in the process are the highest quality that they can be. In essence, a good beer can arise from good ingredients. It is very difficult to make a good beer from inferior ingredients.

4.3.1 Water

In the past, brewing ingredients and procedures were developed using local ingredients. This is still true today considering the first main ingredient, water. By percent volume of the final product, water is the most significant ingredient in beer, and, with the largest total weight, an ingredient that is difficult to ship from place to place. So even today, brewers source their main ingredient locally. Since clean water by itself has very little taste, it is easy to overlook the contribution of water as an ingredient. But just as one must "plant the seeds" to start with quality grain, one must also consider the importance of water. We will look more closely at water and its makeup in Sect. 5.4.

Early brewing culture drew water from the ground (well water) or from the surface (lakes, streams, springs, rivers, etc.). As it happens, groundwater contains a significant amount of dissolved salts and minerals from the surrounding bedrock—all of this depending on the geology of the area. It is quite fortuitous that many of the naturally dissolved minerals contributing to the hardness of groundwater are essential for brewing.

Owing to the different geology of different areas, brewing evolved differently depending on the water chemistry in the area. For example, regions with higher levels of bicarbonate, such as London or Dublin, are known for their darker beers. High levels of bicarbonates tend to make the pH of the water too high, affecting both mash efficiency and yeast metabolism. Adding highly roasted grain—darker roasted malt—tends to lower the pH back to the optimum acidic values. So, by accident or by trial and error, the brewers with this type of water who brewed darker beers such as porters and stouts noticed that the beer tasted very good. This style of beer is *appropriate* for the local water chemistry. On the other hand, the water from wells near Burton-on-Trent is high in gypsum (calcium sulfate). And coincidentally, this type of water is very efficient at enhancing hop aromas and flavors. Thus, the early brewers in Burton-on-Trent developed a very characteristic Pale Ale.

Early brewers brewed beers appropriate for their local water chemistry. Today, we have the option to start with purified water, obtained by either distillation or reverse osmosis (RO), and adding measured amounts of minerals and salts appropriate for the beer to be brewed. In the brewery, this means that city-provided water is often treated prior to its use. Or, a brewer can start with water that is available, either from a well or from a municipality, and make small corrections. However, an accurate accounting of the starting water chemistry is required. One step is clear, though. City water supplies that are treated with chlorine, fluoride, or other compounds must be treated at the brewery to remove these agents. In addition to their ability to alter the flavor of the finished product, the action of some of the disinfecting agents during the brewing process can result in the formation of potential cancer-causing agents. No brewer wants to make beer with that on the label.

4.3.2 Grains and Malts

The maltster provides the brewer with a large selection of malts to use in designing a beer. The variety of flavors available to the brewer is primarily due to the process used to dry and roast the malts, and to some extent the species (2-row or 6-row) and cultivar of grain used. We will consider the basic process differences and the type of malt each yields in this section. In Fig. 4.9, the overall processes and the products that are produced by each are outlined.

Roasted Barley The first distinction comes by examining Fig. 4.9. Roasted barley is simply barley that was toasted, almost burnt, without executing the malting process. The kilning at very high temperatures not only denatures the saccharification enzymes, but browns and burns the starches originally in the grain. Roasted barley is not malt; this ingredient is used sparingly for adding a dry roasted, distinct coffee-like flavor. It also adds a significant amount of color to the final beer. Roasted barley is frequently used in Stouts and some Porters.

Pale Malt On the other hand, pale malt has undergone the basic malting process by germinating the grain in the presence of water. The malting process starts the process of saccharification, as well as the development of needed enzymes. The growing process is halted by drying the malt. Typically, the malt is dried at around 100 °F (40 °C) with very high levels of ventilation. This drying step rapidly removes the water but does little to damage the enzymes in the malt. Once the water content reaches about 10 %, the malted grain is cured by raising the temperature to

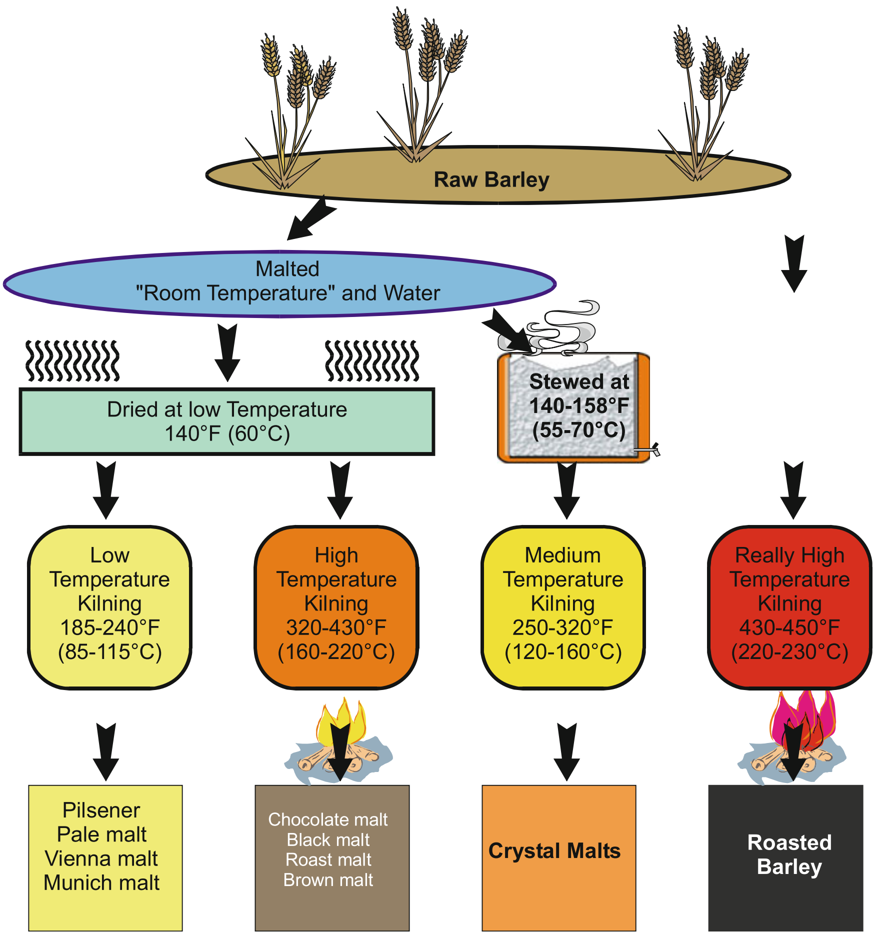

Fig. 4.9 Schema for producing a wide variety of malts from a single type of grain

about 175 °F (80 °C) with continued ventilation. The drying process is monitored by measuring the temperature of the air pushed into the grain (*air on*) and comparing it to the temperature of the air that passes out of the grain (*air off*). Once the temperature of the air on and air off becomes the same, the malt is considered cured. Typically, this leaves about 4 % moisture in the malt (Fig. 4.10).

Different cultivars, slightly different temperatures, and the amount of ventilation will yield different malts such as Pilsner malt and Vienna malt. The main point here is that the temperature used to dry the grain is low enough that the scarification enzymes are not denatured. The grain is said to have sufficient diastatic power needed to convert starches into sugars during the mash process.

Fig. 4.10 2-row pale malt

A grain bill must contain a significant amount of grain with diastatic power to execute the starch–sugar conversion. A grain used for this purpose is frequently called the *base grain* and makes up 70–95 % of the grain bill. Munich and Vienna Malts are initially dried at slightly higher temperatures with much lower amounts of ventilation. Then, they are cured at slightly higher temperatures than pale malt. This process helps protect most of the enzymes, but the higher temperatures increase the number of Maillard reactions. They have a darker, richer flavor and are an ideal base grain for Bock or Oktoberfest styles. Since they are dried at a higher temperature, they do not have as much diastatic power as pale malt, but enough that they can still be used as the base grain.

Dark malts Dark malts, such as brown malt and chocolate malt, have been kilned at higher temperatures. Again, a variety of temperatures are responsible for the biggest differences in these types of malts. The freshly dried pale malt is first cured at the standard pale malt temperature and then kilned typically in a drum roaster at higher temperatures. The higher temperatures increase the rate of Malliard reactions inside the malt and begin to change the flavor of the grain.

Malliard reactions, as we discovered in Sect. 3.3, are non-enzymatic browning reactions initiated by the condensation of amino acids and sugars in the grain. The products of the reaction are increased amounts of nitrogen and oxygen heterocycles and the formation of melanoidins. The process gives very distinct enhanced flavors and a significant increase in the intensity of brown colors.

While the elevated temperatures enhance the malty, biscuit-like flavors, this also denatures the enzymes and makes them unable to perform the reactions needed in the mashing process. Thus, these malts have very little diastatic power. This is primarily why these malts are not used as a base grain. Furthermore, a beer made exclusively with brown or chocolate malt would have a very strong and unbalanced taste profile (Fig. 4.11).

Fig. 4.11 Chocolate malt. The name of the malt arises from the color of the malt, not from the flavor. Although the use of this malt does increase the chocolaty flavors in a brew

Crystal malts Crystal malts initially skip the drying step in malting. As soon as the germination of the barley is complete, the wet grain is placed in a rotating drum and heated to about 150 °F (65 °C) for 30 min. During this initial heating, additional water is sprayed onto the malt. This is the normal temperature for conducting a mash, so it is like conducting a miniature mash right inside the barley seed. The result is that the enzymes in the grain become activated and convert the starches of the malt into sugars. Once the process has completed, the temperature is increased to 300 °F (150 °C) and the malt is ventilated for an hour or more. This higher temperature caramelizes some of the sugars and increases the flavors of toffee, caramel, and brown sugar. This also increases the Maillard reactions that further enhance the flavor and color of the malt.

The amount of time that the malt is left at 300 °F (150 °C) determines the level of browning that occurs. In this way, the maltster can prepare lightly colored crystal malts (known as Crystal 10L) or even very dark crystal malts (such as Crystal 90L) (Fig. 4.12).

Fig. 4.12 Crystal 40L malt. Note the exposed center of the malt has been caramelized. Compare this color to the white-starchy interior of pale malt (Figs. 4.5 and 4.10)

Crystal malts cannot be used as base malts. Even though the enzymes were initially active in the malt to convert the starches in the malt, the kilning process at 300 °F (150 °C) sufficiently denatures the enzymes such that none remain. These malts have no diastatic power. However, because the starches in these grains have been converted into fermentable sugar, crystal malts do not need to be mashed. The brewer can add them to the mash, but this is often just done to help increase the permeability of the filter bed when the mash is sparged. It is entirely possible that the brewer could simply steep the crystal malts in warm water to extract the sugars and add that directly to the sweet wort.

CHECKPOINT 4.6

Is it possible for the temperature of the air off to be lower than the temperature of the air on?

Crystal malts do not need to be mashed. Do they need to be ground into grist in order to be used? If not mashed, how are they used in the brewery?

4.3.3 Hops

Early beers did not use hops. These historical recipes, however, often used additives to spice up the brew so that it was not so one-dimensional in flavor. Many different plants, herbs, fruits, vegetables, and spices found their way into the recipe. The list is quite extensive but includes ingredients such as heather flowers, bog myrtle, dandelion, and spruce needles. As we noted in Chap. 1, the use of gruit was common in Europe. And while hops were used in beers as early as the 800's, it was not until the thirteenth century that hops saw consistent use as a flavoring agent. Yet, in Britain, hops were condemned as a "wicked and pernicious weed" and ale, a drink made exclusively from water, malt, and yeast, was the preferred beverage. It was not until the mid-fifteenth century that beer was accepted as a drink in England; and until the mid-eighteenth century, the words ale and beer meant entirely different drinks. The prevalence of the use of hops in beer is tied to both the pleasant flavor it produces and to the preservative power of the hops (beer would last longer).

The hop plant (*Humulus lupulus*) is a climbing, herbaceous perennial, in the family Cannabaceae. Although it looks like a vine, it is actually a *bine*. The difference is in how the stem of the plant attaches itself to structures as it grows. A bine grows helically around its support and has downward pointing bristles to help it climb, while a vine uses tendrils and suckers to attach to the support as it climbs. Incidentally, hops are very closely related to cannabis (marijuana) in the relatively small Cannabaceae family. The hop plant is also *dioecious* meaning that it has distinct male and female plants. The flower that the female plant produces is the most desirable for brewing. But once that flower has been pollinated by the male plant, it begins to produce seeds. The production of seeds greatly reduces the utility of the flowers for use in brewing, so, the hop farmer works to make sure that only the female plant is grown in the field. While seeds do allow the plant to propagate, so too does the growth of the underground rhizome.

The rhizome of the hop plant is essentially a stem that grows beneath the surface of the soil. From the rhizome are perennial roots that can survive throughout the year, and in the spring, buds on the rhizome send annual shoots above the soil. Cuttings from the rhizome allow a genetically identical hop plant to be produced without use of pollination. Each year, the annual shoots rapidly grow from the rhizome during the spring and once they reach a given length, convert their growth spurt into the production of strobiles, also called cones.

The female hop cone contains lupulin glands, which produce the active bittering agents (Fig. 4.13). Hop resins, from the lupulin glands, contain alpha acids and beta acids. There a large variety of chemical compounds found in these resins, and their effect on the final taste of the beer depends on (a) the relative proportion of compounds and (b) the length of time these compounds are allowed to boil in the wort.

When hops are added to the boil, the components of the hop oils such as myrcene, humulene, and caryophyllene begin to effuse into the wort boil immediately. However, these lighter compounds will be quickly boiled away if allowed to boil for a significant amount of time. It is for this reason that if the brewer wishes to retain those compounds in the finished beer, hops are added at the last 5–10 min of the boil. Hops intended for this step are usually called the "aroma" hops.

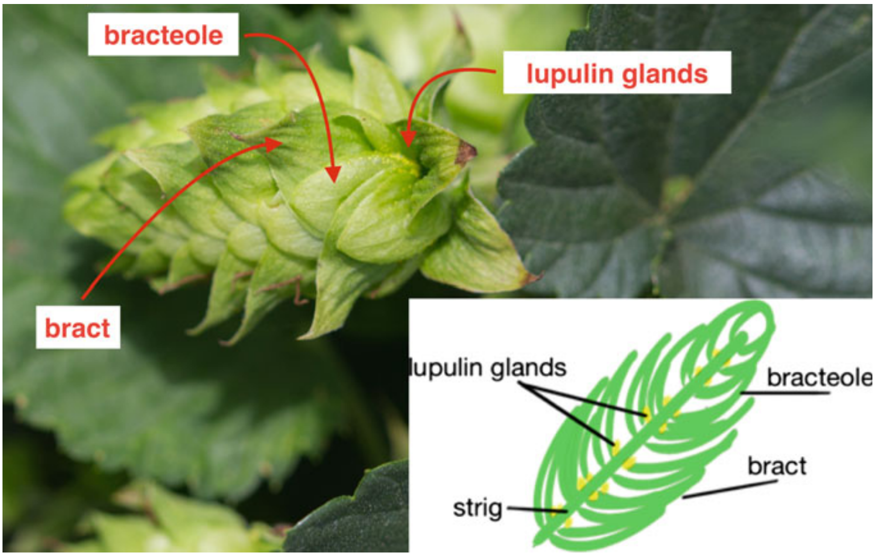

Fig. 4.13 Hop cone cross section

Different types of hops are specifically cultivated to have higher levels of the lighter compounds—and thus intended as an aroma hop.

Other compounds found in the hop oils also dissolve in the wort when the hops are added. Many of these compounds are less volatile and are not carried away so quickly. Hops added at this stage, about 20 min before the end of the boil, are called “flavor” hops. Flavors and aromas from these two steps include descriptors such as “citrus,” “piney,” “grapefruit,” “floral,” and sometimes “earthy” depending on the type of hop used.

Hops added near the beginning of the boil do not contribute much in the way of flavor and aroma since the flavoring and aroma compounds that are volatile will have evaporated away during the course of the boil. Hops added at very early, “bittering hops,” are intended to add the bitter flavor to the beer. As we uncover in Chap. 8, the alpha acids (humulones) isomerize in the hot wort. A hop with high alpha-acid content is intended as a bittering hop.

A hop intended for bittering would not necessarily be suitable for flavor or aroma—or vice versa. For example, Cascade hops are commonly used in pale ales and IPA’s because they have a larger proportion of the lighter compounds, such as myrcene and humulene, which gives these beers a characteristic “citrus” or “piney” flavor. But Cascade hops have a relatively low alpha acid content, compared to a bittering hop such as Chinnook that has up to three times more alpha acids. Chinook hops might be a good choice for bittering.

CHECKPOINT 4.7

Is it possible to use a “bittering” hop for aroma only in a beer?

Use the Internet to research at least two varieties of hops that are grown in New Zealand. Are each of these bittering, aroma, or flavor hops?

4.3.4 Yeast

Yeast is a single-celled eukaryotic organism and is technically a fungus. A eukaryote cell contains a nucleus and other organelles enclosed with a membrane. Most yeasts reproduce asexually by mitosis, but the species of yeast most common to brewing reproduce by an asymmetric division process called budding. We will explore this in much greater detail in Chap. 9.

Brewing yeasts can be loosely divided into “top-fermenting” and “bottom-fermenting.” They are classified into these categories based where they are typically active. The most common strain of top-fermenting yeast is *Saccharomyces cerevisiae* and typically most active at a temperature between 60 and 70 °F. This yeast is commonly used for ales and is colloquially known as "ale yeast." On the other hand, *Saccharomyces pastorianus* is bottom-fermenting yeast. This yeast, "lager yeast," *can* ferment at higher temperatures but, unlike *S. cerevisiae*, it remains active at lower temperatures, as low as 40 °F. Further, *S. pastorianus* is also able to hydrolyse melibiose into more fermentable monosaccharides—something that *S. cerevisiae* cannot do. This leads to more consumption of the available sugars for a drier, crisper flavor. Lager yeast can be used at higher temperatures, giving the characteristic flavor of "steam beer," or California Common beer.

Yeast has a significant impact on the final flavor of the beer. Their selection and use is another variable over which the brewer has control. Yeast, via its metabolism of sugars, will also produce small amounts of by-products. Some of these compounds, such as acetaldehyde, diacetyl, or dimethyl sulfide, are not typically desirable in large quantities. Individually, these compounds give the beer a green apple, buttery, or cooked corn taste, respectively. These undesirable compounds will be eventually re-absorbed by the yeast, which is why the natural conditioning step takes so long—and is so important.

On the other hand, some by-products are desirable in certain styles of beers. These compounds can impart a clove, banana, or fruit flavor such as one might encounter in a Hefeweizen. Ale yeast, because of the higher temperatures, synthesizes a host of flavor compounds, such as esters, during fermentation. Esters are the compounds that give fruits their characteristic flavor. In a Hefeweizen, the banana-like flavor comes from an ester called isoamyl acetate. The yeast also produces other esters such as ethyl acetate, which tastes like a flowery solvent. So how do we control which esters end up in the beer and in what quantities?

We will discover more about the production of esters and other by-products in Chap. 9, but as an overview, yeast do produce a variety of alcohols including ethanol. These fusel alcohols can be converted into esters through a process called esterification. The type of ester that is produced depends on the alcohol that starts in this process. So, if we start with ethanol, we might end up with ethyl acetate after the esterification. Or, if we start with isoamyl alcohol, we would expect to end up with the banana-like isoamyl acetate. To control the production of these esters, the brewer may select a specific strain of yeast known for its particular ester production. Temperature also has a large impact on the production of esters. Generally speaking, increased temperature will increase the amount of esters produced.

4.3.5 Finished Product

Once the beer has been conditioned, it is typically ready for packaging or serving. The flavors of the beer have been set, and the action of the yeast has reduced itself to almost nothing. The brewer has had time to adjust the color, the flavor, and the clarity of the product in the conditioning tank. As we will see in Chap. 10, clarifying agents may have been added, the level of carbonation has been adjusted, and the beer is verified as being within specifications for what the brewer had intended.

In some cases, this has taken months to achieve from the malted barley. In other cases, the process has only taken a week or two.

Whatever the case, the brewer now decides the way that the beer will be consumed. Will the customer buy it in a bottle, a can, or in a keg? Or, will the customer consume the beer at the brewery's taproom? These decisions determine the last few steps in the overall process.

Once to the consumer, the beer undergoes the true test. It is the consumer that determines whether the brewery makes good beer. As we will see in Chap. 12, the measure of quality is not determined exclusively by the brewer or a tasting panel. It does not matter whether the beer is "within spec" or "true to style." What matters most is that the customer enjoys the product and wants to consume it. And for that reason, it is important that the beer fits with what the customer believes is what a beer should look, taste, smell, and, yes, even feel like. If the beer strays too far from the public's perception of quality, sales will decline or stagnate. And the brewery will suffer.

The perception of a quality beer starts with how it is served. Whether it be from a bottle, a can, or a tap, the beer must "look" like a beer. In the USA, this means that a beer must be carbonated appropriately, have a thick head that lingers as long as possible, and be relatively clear. Obvious exceptions to this exist, and those exceptions depend upon the particular style.

In the taproom, bar, pub, or tavern, the way that the beer is handled is important. The glass should be tipped as the beer is first poured into it. And once the volume of beer has reached an appropriate level, the glass is held upright while the remaining beer is poured right into the center. This method of pouring allows the bulk of the beer to be added to the glass without a great loss of carbonation. Then, for the last few ounces, the beer is agitated with the pour into the center. This causes the head to rise and form on the top of the beer.

One of the more important indicators of good beer handling is how the beer is served. Servers should carefully present the glass to the customer so that the head still remains on the beer. Did the bartender spill it all over the glass and stick the receipt to the outside of the glass? Or did the bartender carefully pour the perfect

Table 4.2 Suggested beer serving temperatures

Style	Temperature	Style	Temperature
American Light Lagers	32–40 °F (0–5 °C)	Pale Lagers Pilsners	38–45 °F (3–7 °C)
Belgian Ales Abbey Ales	40–45 °F (4–7 °C)	Wheat-based beers Lambics	40–50 °F (4–10 °C)
American Pale Ales IPA's	45–50 °C (7–10 °C)	Stouts Porters	45–55 °F (7–13 °C)
Strong Lagers Cask and Real Ales	50–55 °F (10–13 °C)	Barley wine Wee Heavy	50–55 °F (10–13 °C)

Data taken from Randy Mosher, Tasting Beer: An Insider's Guide to the World's Greatest Drink, Storey Publishing: 2009 pint with as much care as a newborn infant? Did the beer get served to you right after pouring, or did the server go on vacation right after you placed your order.

The perfect pour should come to you while it still has the majority of the foam still remaining. It should be served in a glass that is appropriate for the style and dry to the touch, and the beer should still be at the preferred serving temperature (see Table 4.2).

If these steps are correctly accomplished, the customer has the best chance to enjoy the beer to its fullest potential. And if the brewer has done the task to provide the best product possible, the customer will repeat their business. That alone is a sure sign that everything was well done and done well.

Chapter Summary

Section 4.1

Brewer's barley is available in 2-row and 4-row varieties, and in a wide variety of cultivars.
Barley is sorted by size; the plumper seeds are sold to the maltster for making malt.
The seeds are then stored to reduce their dormancy and enable sprouting.
Malt is made by germinating the seeds until all of the starch has begun to be utilized by the seed for growth.
The malt is then dried and kilned to prepare a variety of different malt products ranging from pale malt to black malt.
The brewer mashes the malt using warm water until the starch is converted into fermentable sugars.
The sweet wort is boiled. This allows the brewer to add flavoring agents and hops while at the same time sterilizing the wort.
The hopped wort is cooled, oxygenated, and fermented using yeast.
The brewer conditions the green beer prior to packaging for sale.

Section 4.2

Brewing beer requires constant cleaning and sanitizing.
Safety and care must be taken into account when working with any cleaning or sanitizing agent.

Section 4.3

The four main ingredients used in beer production are water, malt, hops, and yeast.
While the overall process for making beer is relatively uniform, the options when using each of these ingredients give rise to an almost infinite number of flavor options.
The end result of the process depends entirely upon consumer approval.

Questions to Consider

1. For the brewer, what is the most important part of the hop plant?
2. What is the difference between a vine and a bine?
3. Distinguish between bittering, flavor, and aroma hops with regard to (a) time of addition to the wort, (b) effect on bitterness, and (c) effect on the finished beer.
4. What is diastatic power?
5. What is meant by the term "base" grain?
6. Outline the steps involved in brewing beer from malt.
7. Why is a plumper barley seed considered better for use as a base grain?
8. Is barley the only grain that can be malted? Explain your answer.
9. Why do some breweries utilize a cereal cooker?
10. Although beer is made with just four ingredients, the brewer/malster has significant control over the final taste of the beer. List as many things the brewer can change *in the process* to produce the beer which will influence the final flavor.
11. Why would it be important to make sure that the brewery floor is free of bacteria if the production of beer is inside sealed vessels?
12. Explain how crystal malt is prepared from barley?
13. What purpose would the addition of crystal malt have in beer manufacture? Why is this malt used instead of just adding sugar?
14. Why would a brewer use chocolate malt?
15. List some of the compounds that yeast can produce.
16. Use the Internet to determine the appropriate glass and temperature for serving a Belgian Ale.
17. What is meant by the term sparge?
18. If a brewer batch sparged, how many different "strengths" of beer could be made?
19. Why would a brewer prefer to use rain water over groundwater?
20. What is meant by these terms: lauter, sparge, mash, condition
21. What is meant by these terms: grist, chaff, pitch, malt
22. Why are hop yards (hop fields) made up of only female hop plants?
23. How are hops propagated?
24. What is meant by the statement: "the customer is always right"?
25. A brewer wishes to use lager yeast and ferment hopped wort at 75 °C. Based on the information in this chapter, what would you expect to be the outcome of this process?
26. If two brewers utilize the same exact recipe, will they make beer that has the same flavor profile? Explain why or why not.
27. Why is it not possible to make beer from unmalted barley? What would a brewer need to do to use unmalted barley as one of the ingredients in the production of beer?

Laboratory Exercises

Sketch the overview

This laboratory assignment requires the students to view videos from the Internet and then create a flowchart outlining the overall brewing process. The assignment can be made as a homework assignment, or can be a class assignment that requires students to discuss their outline and compare it to the rest of the class.
Sources for the video are easily found as brewery tours of local breweries. These tours are often uploaded to the Internet and can be found in YouTube, VIMEO, Google Play, and other sites. The students should watch one or two video tours of breweries that illustrate each of the processes found in the brewing of beer. Then, the students, working in small groups, should produce a sketch of the brewing process using the correct terminology. If each group produces a sketch of the process using a different video tour, comparison of the processes used in regional and local breweries can be made.

Research on Barley

This laboratory assignment requires the students to evaluate the commercially available varieties of barley to determine the key characteristics of their use in malting and brewing. The assignment can be given to groups of students for presentation to the entire class, or multiple barley varieties can be assigned to each student to complete compare–contrast reports.
Students are given a list of barley varieties to examine. The students then research the varieties on the Internet and in the library to determine key features of the varieties they have been assigned. Specific information that works well in this exercise includes (a) parents of the specific cultivar, (b) location where the cultivar was first grown, (c) percent of protein, starch, etc., (d) typical growing period, (e) information about performance in malting.