

# Chapter 1

## An Overview of the Brewing Process

**Abstract** The first chapter of this book has an introductory character, which discusses the basics of brewing. This includes not only the essential ingredients of beer, but also the steps in the process that transforms the raw materials (grains, hops) into fermented and maturated beer. Special attention is given to the processes involving an organized action of enzymes, which convert the polymeric macromolecules present in malt (such as proteins and polysaccharides) into simple sugars and amino acids; making them available/assimilable for the yeast during fermentation.

### A Brief History of Brewing

Beer has a strong bond with human society. This fermented beverage was most likely created by accident thousands of years ago. Despite the massive technological growth that separates ancient brewing from today's high-tech breweries, the process in its traditional version remains entirely unchanged. However, even though our ancestors could make primitive beers from doughs and cereals, they did not know the biochemical steps involved in the process.

Some historians suggest that beer-like beverages were brewed in China as early as 7000 BC (Bai et al. 2012), but the first written records involving beer consumption only date from 2800 BC in Mesopotamia. However, there is strong evidence that “beer” was born as early as 9000 BC during the Neolithic Revolution (Hornsey 2004), when mankind left nomadism for a more settled life. With this new lifestyle, came the need for growing crops and for the storage of grains. Thus, it is likely that natural granaries produced the first “unintentional” batches of beer.

From Mesopotamia, the beer culture spreads through Egypt around 3000 BC. Until shortly before the years of Christ (30 BC), beer was the beverage of choice among Egyptian people (Geller 1992). Thereafter, Egypt fell under Roman domain, introducing a wine culture into the region. However, even with wine as a choice, beer endured as the sovereign beverage among the Egyptian general population (Meussdoerffer 2009). Through the Roman dominion, wine was a drink for the nobles. At that time, beer was regarded as the drink of “barbarians” because

wine was the conqueror's beverage (Nelson 2003). In fact, before the expansion of the Roman Empire, beer was the queen beverage of all Celtic peoples in France, Spain, Portugal, Belgium, Germany, and Britain. Then, together with the expansion of the Roman Empire, came the development of the wine culture (Nelson 2003). When Romans lost control, mainly by Germanic conquering of Western Europe in the fifth century AD, beer took back the place as the sovereign drink.

The first evidence of commercial brewing is in the old drawings of a brewery, found in the monastery of Saint Gall, and date from 820 AD (Horn and Born 1979). Before the twelfth century, only monasteries produced beer in amounts considered as "commercial scale" (Hornsey 2004). Monks started to make more beer than they could drink or give to pilgrims, the poor, or guests. They were allowed to sell beer in the monastery "pubs" (Rabin and Forget 1998). The basis of the brewing industry, however, was born in the growing urban centers where large markets began to emerge. Brewers began to provide good profits for the pubs, and the independent inns became tied public houses. Thus, most of the fundamentals for manufacturing and selling of beer in our time were established in London by 1850 (Mathias 1959).

## The Ingredients

Beer holds one of the oldest acts in the history of food regulation—the *Reinheitsgebot* (1487). Most known as the "German Beer Purity Law" or as the "Bavarian Purity Law", it was originally designed to avoid the use of wheat or rye in beer making. This act ensured the availability of primary grains for the bakers, thus keeping bread's prices low. From that time forth, the law restricted the ingredients for making beer to barley, water, and hops. Naturally, this purity law has been adapted over time. For example, yeast was not present in the original text as it was unknown by that time. The current law (*Vorläufiges Biergesetz*) is at stake since 1993 and comprises a slightly expanded version of the *Reinheitsgebot*. It limits water, malted barley, hops, and yeast for making bottom-fermented beers, while to make top-fermented beers, different kinds of malt and sugars adjuncts are allowed. However, it is well known that breweries around the world often use starch and sugars adjuncts also for the production of bottom-fermented beers.

The basic beer ingredient will be described in the following chapters as well as the main technological steps with focus on bottom-fermented lager beer, the most widespread beer type in the world.

## Water

Water is the primary raw material used not only as a component of beer, but also in the brewing process for cleaning, rinsing, and other purposes. Thus, the quality of the "liquor," which is how brewers call the water as an ingredient, will also determine the quality of the beer. Thereafter, the brewing liquor is often controlled

by legislation. It has to be potable, free of pathogens as well as fine controlled by chemical and microbial analyses. In addition, different beer styles require different compositions of brewing liquor.

Water has to be often adjusted previously to be ready as brewing liquor. Adjustments involve removal of suspended solids, reduction of unwanted mineral content, and removal of microbial contamination. Thus, different mineral ions will affect the brewing process or the final beer's taste differently. For example, sulfates increase beer's hardness and dryness, but also favor the hop bouquet. High iron and manganese contents may change beer's color and taste.

Calcium is perhaps the most important ion in the brewing liquor. It protects  $\alpha$ -amylase from the early inactivation by lowering the pH toward the optimum for enzymatic activity. Throughout boiling, it not only supports the precipitation of the excess of nitrogen compounds, but also acts in the prevention in over-extraction of hops components (Comrie 1967). Furthermore, calcium also plays a crucial role through fermentation, since it is mandatory for yeast flocculation (Stratford 1989), as discussed in the next chapter. Yeast growth and fermentation are favored by zinc ions, but hindered by nitrites (Heyse 2000; Narziss 1992; Wunderlich and Back 2009).

## ***Malted Barley and Adjuncts***

The barley plant is, in fact, a grass. The product of interest for the brewers is the reproductive parts (seeds) of the plant known as grains or kernels displayed on the ears of the plants. Depending on the species of the barley, the plant will expose one or more kernel per node of the ear. Mainly, two species of barley are used in brewing: the two-row barley (with one grain per node) and the six-row barley (with three grains per node). To put it simple, the fewer are the kernels per node, the bigger and richer in starch they are. Conversely, the six-row barley has less starch but higher protein content. Therefore, if the brewer wants to increase the extract content, the two-row barley is the best option, whereas if enzymatic strength is the aim, the six-row will be the best choice (Wunderlich and Back 2009).

Worldwide, most breweries use alternative starch sources (adjuncts) in addition to malted barley. Adjuncts are used to reduce the final cost of the recipe and/or improve beer's color and flavor/aroma. The most common adjuncts are unmalted barley, wheat, rice, or corn, but other sugar sources such as starch, sucrose, glucose, and corresponding sirup are also used. The use of adjuncts is only feasible because light malts (i.e., Pilsener malt) have enough enzymes to breakdown up to twice their weight of starch granules. However, each country regulates the maximum allowed amount of adjuncts for making beer. Until the current days, the Bavarian Purity Law regulates the use of adjuncts in Germany, whereas "outlaw" countries such as USA and Brazil often exaggerate the use of adjuncts. In the USA, commercial breweries can use up to 34 % (w/w) of unmalted cereals of the total weight of grist. In Brazil, unmalted grains such as corn and rice are allowed in amounts as high as 45 % of the total recipe content. Poreda et al. (2014) assessed the impact of corn grist adjuncts

on the brewing process and beer quality under full-scale conditions. The use of corn in up to 20 % of the formula affected some of the technological aspects of wort production and quality, but caused no significant effect in the physicochemical properties of the final beer. Nonetheless, the impact on beer's flavor profile was not considered. The abuse of maize and/or rice is known to impair the beer with a predominant aroma of cooked corn or "popcorn aroma" (Taylor et al. 2013).

## Malting

It is important to emphasize that unmalted grains are the dormant seeds of grass plants, i.e., *Hordeum* spp. (barley) and *Triticum* spp. (wheat). Through the malting process, the grains are germinated controllably to produce the corresponding malt. However, the correct extent of germination is the key for producing good malt.

During germination, the embryo grows at the expense of reserve material stored in the kernel. As soon as the grain makes contact with suitable conditions during steeping (moist and adequate temperature), all enzymatic apparatus is gradually activated to break the reserves of starch and proteins to form a new plant. Here lie the crucial roles of malting, which are enriching the malt with enzymes (amylolytic, proteolytic, etc.), modification of kernel endosperm, and formation of flavor and aroma compounds. Starch-degrading enzymes (such as  $\alpha$ -amylase,  $\beta$ -amylase,  $\alpha$ -glucosidase, and limit dextrinase) produced during germination are better characterized than the proteolytic counterparts (Schmitt et al. 2013).

It is easy to understand that the optimum stage for interrupting the germination is when the malt is rich in enzymes, achieved sufficient endosperm modification and have consumed as little reserve materials (starch, proteins) as possible during embryo development. At this point, germination is arrested by kilning (drying). After complete kilning, the pale-malted barley is known as Pilsener malt. All other varieties of malt derive from this point by kilning or roasting at different temperatures. However, the more the malt is heat treated, the greater is the damage to the enzymes. So, while Pilsener malts are the richest in enzymes, chocolate malt (thoroughly roasted) have no enzymatic activity at all.

## Hops

Compared to water and malts, hops are lesser of the ingredients used in brewing, but no lesser is the contribution it makes to the final beer. Hops influence to a large extent the final character of beer. Brewers use the flowers (cones) from the female plants of *Humulus lupulus*. As there are numerous varieties of this plant spread worldwide, it is predictable that the quality and characteristics of the flowers also vary. Thus, some hops are known as "aroma/flavor hops" while others as "bitter hops." The  $\alpha$ -acids are responsible for the bitterness of a given hop, whereas aroma

is tied to essential oils from hop cones. Thus, aroma hops are usually weaker in  $\alpha$ -acids but rich in essential oils. Conversely, bitter hops have higher contents of  $\alpha$ -acid but may lack on essential oils.

Nowadays, breweries rarely use cones, but pellets and hop extracts instead. Pellets are made from raw hops by drying, grinding, screening, mixing, and pelletizing. Extracts result from extraction with ethanol or carbon dioxide. The resulting product is a concentrated, resin-like sticky substance. The extracts and pellets are easier to be stored and have higher shelf life but also different chemical compositions than hop cones.

## ***Yeast***

Genus of *Saccharomyces* has always been involved in brewing since ancient times, but through the vast majority of the brewing history our ancestors had no idea that living cells were the responsible entities for fermentation.

Although Antonie van Leeuwenhoek was the first to see yeast cells through a microscope in 1680, it was not before the studies by Louis Pasteur that conversion of wort into beer was awarded to living cells. Pasteur made careful microscopic examination of beer fermentations and published the results in *Études sur la bière* (1876), which means “Studies about beer.” Pasteur observed the growth of brewing yeast cells and demonstrated that these were responsible for fermentation. Given the importance of the brewing yeasts to beer characteristics, the next chapter of this book is entirely dedicated to them.

## **Wort Production**

### ***Milling***

Before mashing, the malt and other grains must be milled in order to increase the contact surfaces between the brewing liquor and malt. The ground malt (with or without other unmalted grains) is called grist. Some traditional breweries still use lauter tuns for wort filtration and, in these cases, the grain’s husks should not be too damaged because it functions as a filter material. However, other breweries use mash filters as an alternative and thus no husks or coarse grits are necessary. The appropriate milling is usually attained either by roller or hammer mills.

The finer are the particles the better is usually the breakdown of the malt material into fermentable sugars and assimilable nitrogen compounds. However, the particle size directly interferes with the rate of wort separation. Unmalted grains also hamper the rate of wort recovery by increasing the proportion of insoluble aggregates of protein, hemicellulose, starch granules, and lipids (Barrett et al. 1975).

Although the vast majority of breweries perform a dry milling, Lenz (1967) suggested several decades ago an alternative wet milling and Szwajgier (2011) has recently discussed the advantages of the process. The author compared wet and dry millings, proving that the former improves the extraction rate of fermentable sugars from the filtration bed into the wort, thus reducing lautering time. Moreover, the author observed that the wet method can also reduce the amount of phenolic compounds extracted during mashing, which could enhance the colloidal stability of beer produced (Delvaux et al. 2001). However, the wet milling also increases protein extraction, which should be monitored to prevent haze formation (Szwajgier 2011).

## ***Mashing***

To initiate mashing, the grist is mixed with water (mashing-in) at a prespecified temperature to produce a slurry known as mash. Subsequently, the mash is heated to optimum temperatures of the technologically most important enzymes and allowed to rest.

There are two main mashing strategies. Either the entire mash is heated up according to a predefined pathway (infusion mashing), or the temperature of the mash is increased by removing, boiling, and pumping back parts of the mash (decoction mashing). A considerable breakdown of starch is only attained after the temperature is high enough to cause gelatinization, which broadly exposes the binding sites to the enzymes. As the temperature rises, enzyme activity accelerates, but also does the rate of enzyme denaturation. In addition to temperature, enzyme activity and stability is also influenced by pH and wort composition (Rajesh et al. 2013).

The breakdown of starch into fermentable sugars is quantitatively the most important task occurring during mashing. Although barley malts have four starch-degrading enzymes ( $\alpha$ -amylase,  $\beta$ -amylase,  $\alpha$ -glucosidase, and limit dextrinase), the heavy work of breaking starch to fermentable sugars throughout mashing depends on  $\alpha$ -amylase and  $\beta$ -amylase. The degradation of starch starts by action of  $\alpha$ -amylases (optimum temperature 72–75 °C, optimum pH 5.6–5.8), which have much broader work option than  $\beta$ -amylases (optimum temperature 60–65 °C, optimum pH 5.4–5.5). That is because  $\beta$ -amylases can only “attack” the non-reducing ends of starch and dextrin chains. Despite  $\beta$ -amylases have a higher affinity with long chains of starch molecules (Ma et al. 2000), the fast action of  $\alpha$ -amylases makes dextrin more accessible increasing the availability of binding sites for  $\beta$ -amylases. Therefore, the smallest product of action of  $\beta$ -amylases is maltose, while  $\alpha$ -amylases can virtually break an entire starch chain into glucose. Thus, the final wort consists of fermentable sugars (glucose, maltose, and maltotriose) and non-fermentable small (limit) dextrins. Simultaneously with enzymatic starch degradation, other processes such as protein breakdown,  $\beta$ -glucan degradation, changes in lipids and polyphenols, and acidification reactions take place.

At the end of the mashing, it is necessary to separate the aqueous solution of the extract (wort) from the insoluble fraction called spent grains. For this purpose, lautering (filtration) is carried out either in lauter tuns or in mash filters of different constructions. In lauter tuns, the complete separation of extract is achieved through sparging of the spent grains with water. In mash filter, the extract adsorbed in spent grains is recovered with the use of filter cloths.

The amount of solid malt (grist) transferred into soluble extract enables to calculate the brewhouse yield (efficiency of operations) and determines the “strength” of the wort. The wort concentration is usually expressed as the mass of extract (kg) per hl wort in % w/v.

## ***Wort Boiling***

After separation from the residual solids (brewer’s spent grains), the hot sugary liquid (wort) is boiled with hops. Additionally, some special recipes also use all kinds of “seasoning” to the wort on this step such as coriander seeds, orange peel, cinnamon, and cloves. Furthermore, it is also in this stage that sugar adjuncts as sucrose, malt sirup, and sugarcane may be added as “wort extenders” to increase extract.

The whole process takes from 90 to 120 min and according to Miedaner (1986), the crucial processes taking place during wort boiling are: inactivation of enzymes; sterilization; precipitation of proteins (hot break); evaporation of water and unwanted volatiles such as dimethyl sulfide (DMS); isomerization of hop  $\alpha$ -acids; and the formation of flavor compounds through Maillard reaction. After separation of hot break and cooling, the wort is aerated and it is ready for pitching.

## **Fermentation and Maturation**

After pitched into chilled and aerated wort, brewing yeast will initiate assimilating fermentable sugars, amino acids, minerals, and other nutrients. From this time forth, the yeast starts excreting a wide range of compounds such as ethanol, CO<sub>2</sub>, higher alcohols, and esters, as a result of cellular metabolism. Whereas the large cut of these metabolic by-products are toxic for the yeast cells at higher concentrations, they are the wanted products of beer fermentation at reasonable amounts.

After cooling and aeration, the wort must be pitched (inoculated with suspended yeast cells) as fast as possible to avoid contaminations. Common pitching rates are about  $15\text{--}20 \times 10^6$  cells mL<sup>-1</sup>. However, higher dosages are often used in high gravity brewing (HBG). While small to medium size breweries still may use open fermenters, large breweries mostly replaced them by closed stainless steel cylindroconical vessels (CCVs). These closed fermenters not only offer larger productivity and good hygienic standards, but also provide operating advantages through temperature and pressure control (Landaud et al. 2001).



The amount of fermented extract determines the attenuation of wort, which is the main parameter indicating the course of fermentation. Regular worts contain about 80 % of fermentable extract. At the stage of beer transfer, movement of the green beer from fermentation cellar to lager cellar, the green beer should contain approximately 10 % of unfermented fermentable extract in order to obtain sufficient formation of dissolved CO<sub>2</sub> during maturation. However, some breweries allow all extract to be utilized during primary fermentation and then add more of the original wort (or sugar adjuncts) for carbonation. A proper primary fermentation can be achieved usually in about 5–7 days, but the exact duration will strongly depend on the original wort extract, fermentation temperature (7–15 °C for lager beers), and yeast physiology.

Maturation further exhausts the residual extract to form CO<sub>2</sub>, which in turn helps at removing some unwanted volatile substances as aldehydes and sulfur compounds (“CO<sub>2</sub> wash”). During maturation, also other processes take place such as beer clarification (precipitation and sedimentation of cold break particles), yeast sedimentation, and flavor formation. The main parameter determining the state of maturation is the removal of diacetyl formed during primary fermentation. Although this process can take several weeks, modern breweries may use specific yeast strains, high pitching rates, and elevated temperatures to accelerate diacetyl removal. After diacetyl concentration falls below perception threshold (0.1 mg L<sup>-1</sup>), the temperature of the lager tanks or CCVs is decreased (–2 to 3 °C for lager beers) to clarify and stabilize the beer. Thereafter, beer is ready to proceed into final processing stages, which may include all or just some of the following operations: filtration, colloidal stabilization, packaging, and pasteurization.

The next chapter of this book thoroughly discusses yeast metabolism and fermentation.

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