Beer

(John Morrissey)

There are many different possible styles of beer, from dark Irish stouts to pale Czech pilsners. Some of these are ales, produced by the activity of the yeast *Saccharomyces cerevisiae*, whereas others are lagers, made by a related yeast, *Saccharomyces pastorianus*. The combination of the yeast strain and the production process is responsible for the style of the final beer produced.

What is beer?

Beer is a fermented alcoholic drink that is widely consumed all over the world. While there are different styles, all beer is based on cereals and is produced by fermentation with yeast.

It is an ancient product and archaeological evidence shows that 13,000 years ago – at the dawn of civilisation – humans were already making beer in the region of modern day Syria, Lebanon and Israel. Recipes dating back 5000 years have been also found from ancient Egypt, Iraq (Sumeria) and China, so we know that beer-making is one of the oldest forms of biotechnology – when humans deliberately use microbes to make a product.

How is beer made?

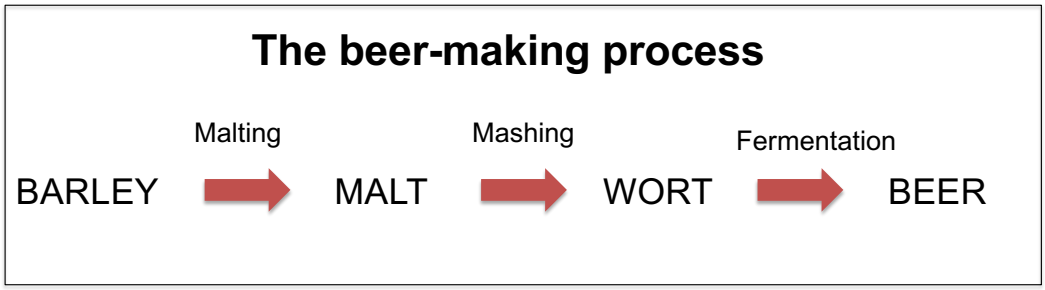
Although beer can be made from different cereals, modern beer mainly uses barley. To start the process, barley grains are steeped in water, allowed to germinate, dried and roasted in a process called malting. Next, this malted barley is milled, which means grinding it into a very rough flour which still has the barley husks.

The flour is mixed with water and heated up to a temperature of 50^{0}C - 60^{0}C where it is held for somewhere between 30 minutes and two hours. This step is called mashing and it allows the barley enzymes that were activated during germination to break down the starch that was present in the barely grains to simpler sugars. Starch (sometimes called amylose) is made up of a long chain of glucose molecules and when this is broken down by enzymes (amylases), the main products are glucose and maltose (a compound composed of two molecules of glucose).

After mashing, the solution is filtered (brewers call this lautering) to remove the barley husks; this clear, sugary liquid is now called wort. As well as sugars, wort contains amino acids, vitamins, minerals and all the other nutrients needed for microbial growth and metabolism.

The wort is boiled and during boiling, the flowers of the female hop plant are added. Hops contain certain acids that have a bitter flavour and these are important for the final taste of beer. They also help protect beer from being spoiled by bacteria.

The boiled wort is cooled, yeast are added and fermentation starts. This is really the most important part of the process because now the yeast grow and convert the sugars to alcohol. When fermentation is finished, we now have beer!



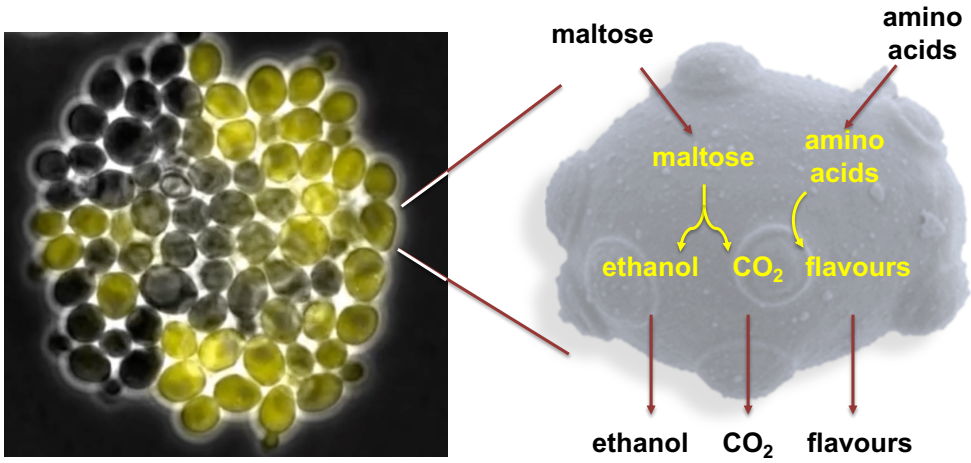
Beermaking can be divided into distinct steps. Barley grains are harvested by the farmer and transferred to the maltster. In the malthouse, seeds are steeped in water, germinated and then dried and roasted to make malted barley. Dark roasted barley is used to make stout, whereas light malts give rise to pilsners. The malt in transferred to the brewhouse where it is ground to a coarse flour. This is dissolved in water and then heated to 50°C – 60°C in a process called mashing. There are lots of variations possible in the mashing regime and this produces different styles of wort. Wort is transferred to the brew kettle and hops are added. The mixture is boiled, cooled and then transferred to the fermentation vessel. Here yeast is added and the real magic of fermentation takes place.

What happens during fermentation?

Without fermentation, there would be no beer – which is why it is the most important part of the entire process. Scientifically speaking, the term fermentation describes the metabolic process when sugars (or other organic compounds) are used to generate energy in the absence of oxygen (air). There are different types of fermentation depending on the end products but the type used by brewing yeast converts the sugars (mainly maltose and glucose) that are in wort to ethanol and carbon dioxide (CO_2).

The ethanol is what makes beer an alcoholic beverage and the CO_2 is what makes it bubbly. This fermentation process is exactly the same as what happens in bread-making – but in that case the CO_2 makes the dough rise and the ethanol just evaporates during baking.

But the yeast does not just make alcohol and bubbles – it also produces a lot of different flavours and aromas. These give beer its distinctive taste and smell and are vital for beer – without these, beer would be bland and uninteresting.



Fermentation by the yeast cell factory. A cluster of actively growing yeast cells is seen on the left – this is a photograph taken using a microscope because yeast are too small to see with the naked eye. On the right, there is a cartoon of a single yeast cell with the most important metabolic processes shown. The sugar (maltose) is converted to alcohol (ethanol) and CO_2 while amino acids that are also present in the wort are converted to wonderful flavours and aromas.

Is beer a food or a drink?

That is a good question! You saw in the earlier section that beer-making and bread-making are very similar – both start with flour and use yeast metabolism to convert it to another form. In fact, beer is very nutritious because it contains sugars, amino acids and vitamins – this is one of the main reasons that beer has been made for thousands of years.

In the past, beer was an import source of food for sailors, workers and the general public. Some say that beer was also safer to drink than water in former times because of the anti-bacterial effects of hops!

Beer was made at home in kitchens at the same time as people made bread for the family. Of course, one obvious difference between bread and beer is the alcohol and this is not healthy! So while beer can be a nutritious drink, it is important that it is only consumed in small amounts to avoid the bad effects of too much alcohol.

What about the yeast?

We already said that fermentation is the most important part of brewing and so we must talk about yeast – the hero of the process! Yeast is a general term used for a certain kind of microorganism – in fact, there are thousands of different types of yeast – all of which are fungi. In this case, though, the yeast that we use comes from the genus *Saccharomyces*. There are two different species of *Saccharomyces* used to make beer – *Saccharomyces cerevisiae* (*S. cerevisiae*) for making ale and *Saccharomyces pastorianus* (*S. pastorianus*) for making lager.

S. cerevisiae is the same yeast that is used to make wine, cider and bread. It is an ancient species and its origins can be traced back many millions of years. Its natural home is in the bark of trees, especially oaks, but the strains that we use have been cultivated in wineries and breweries for hundreds of years and, over time, have developed habits that are important for our processes. We call this "domestication" and one example of developed habits is that brewing strains of *S. cerevisiae* are much better at using maltose that their wild cousins.

It is important to know that pure cultures of yeast have only been used in brewing for the past 100 years or so. Before that, brewers started each batch of beer with yeast left from the

previous batch – a process called "backslopping" – and, during this continual cultivation, evolution led to the selection of strains that were particularly good for making beer – natural variants that fermented fast, produced a lot of alcohol, and had nice flavours!

S. pastorianus, the species used for making lager beer, is much younger and has a very interesting history. It is what we call a hybrid species – formed when its parents come from two different species. Hybrids are very common in biology – there are many examples of plants, including important crops like wheat. In the case of *S. pastorianus*, one parent was *S. cerevisiae* and the other parent was another *Saccharomyces* called *S. eubayanus*.

Scientists believe that *S. pastorianus* was born around the start of the 17th century when these two parents mated to give rise to a new species with special characteristics. This new species combined traits of both parents – like *S. cerevisiae,* it is very good at fermenting maltose to alcohol and like *S. eubayanus,* it is able to grow and low temperatures (4^{0}C – 8^{0}C). The ability to grow and ferment at low temperatures is important for making lager beer and it is believed that this style of beer emerged in central Europe in the 15th – 17th centuries.

Continual fermentation at low temperatures created the circumstances to select natural yeast variants that were better at performing under these conditions, including the hybrid *S. pastorianus*. This is a very good example of evolution – natural selection of fitter strains. Although, *S. pastorianus* arose in the 17th century, it was only isolated as a pure culture in 1883 and it was later named in honour of the famous yeast scientist Louis Pasteur – thus lager yeast is named *S. pastorianus.*

A rock cavern in Frankonia, Southern Germany. In the 15th and 16th centuries, a new style of beer making emerged in Central Europe. This took place in cool rock caverns in Frankonia and other regions and involved fermentation at lower temperatures, around 4°C - 8°C compared to the normal fermentation temperature of 16°C - 20°C. it is believed that this style of cold fermentation created the environmental conditions for the evolution of the lager yeast, *Saccharomyces pastorianus*. This yeast is a hybrid of the ale yeast, *Saccharomyces cerevisiae* and a wild yeast called *Saccharomyces eubayanus*. Image courtesy of Mathias Hutzler, TUM, Germany.

More on the microbiology of brewing

People with some knowledge of brewing often talk about "top-fermenting" and "bottom–fermenting" yeast. Although they often do not know it, by using these terms, they are distinguishing between fermentations carried out by *S. cerevisiae* (top-fermenting) and *S. pastorianus* (bottom-fermenting), and thus also between ales and lagers. In reality, yeast are distributed throughout the wort during fermentation but at the end, when the sugars are all consumed, they bunch together to form clusters, or "flocs", and these flocs either float to the top or sink to the bottom, depending in the yeast.

Either way, flocculation is very important as it enables the brewer separate the yeast from the beer. Even in modern brewing, these harvested yeast are pitched again into a new fermentation, though normally for only four – five cycles in case the yeast mutate and develop new properties.

The temperature of fermentation is important for the final beer. Yeast produce many flavours, some are considered positive but others less so. When growing at a lower temperature, fewer flavour molecules are produced and that is one advantage of cold-fermentation with *S. pastorianus*. This is the main reason why lager beers are less complex in flavour and considered easier to drink than ales, which are produced by warm fermentation and have much more diverse mixed flavours. It also explains why lager-style beer makes up about 90% of the global production – it is possible to make light beers with mild flavour that many people will find palatable. Of course, the connoisseur might be more interested in the complex nuances of British or Belgian ales, or even of the new craft ales now being produced.

Did beer change history?

Well, maybe it is an exaggeration to make this claim but it is certainly true that developments in human society and beer-making are closely intertwined. For example, beer was critical for the northwards expansion of the Roman empire 2000 years ago. While the Roman elites drank wine and considered beer a beverage of the barbarians (Celtic and Germanic tribes), they quickly recognised its value and all Roman frontier towns and forts became important brewing centres – making beer to sustain the legions and their supporters.

After the collapse of the Roman empire, much knowledge was lost but at the end of the Dark Ages (8th Century onwards) monks originating from Ireland, reintroduced knowledge and learning to Europe. They also brought brewing technology with them, and the monasteries they established were both centres of brewing and the first B&Bs in Europe. Some have gone so far as to claim that with these contributions, the Irish saved civilisation!

And later, the development of the powerful Hanseatic league of city states along the Baltic coast from the 13th to the 17th centuries was only possible by the industrialisation of beer production in these cities. This allowed production of beer of sufficient quantity and quality to nourish sailors plying these routes.

Still later, the innovations that led to the style known as India Pale Ale (IPA) in the 18th century were important for helping Britain establish in the Indian subcontinent. The key feature of the original IPA style was the addition of a lot of hops, which made the beer very bitter and preserved it against bacterial spoilage during the long voyage to India. Ironically, when the Californians reinvented "IPA" in the 1990's, there was a misunderstanding of the types of hops to be added and the American style of IPA uses hops that are very aromatic but low in bitter compounds. So American – style IPAs are very different to the original British style.

Personalities have also played an important part in brewing history. In the 16th century the Bavarian Dukes passed "purity" laws known as the *Rheinheitsgebot* that set rules for beer making. One of these rules was that only barley could be used in brewing but they later granted

a derogation to a brewer in a small town called Schwarzach near the Bohemian border to allow him use wheat. This was mainly to avoid losing tax to Bohemian imports but when in 1602 the owner of the Schwarzach brewery died without a male heir the Bavarian Duke, Maximillien I, confiscated the brewery and relocated it and its yeast to his court brewery in Munich. One theory is that it was here, in the Munich court brewery (*Hofbrauhaus*) that the lager yeast, *S. pastorianus*, was born at the start of the 17th century.

Another interesting story describes how in 1845, JC Jacobson, the founder of the Carlsberg brewery, travelled to Munich to study brewing methods and brought yeast back with him from the Spaten brewery to Copenhagen. He stored the yeast in a hat-box, and travelling by stagecoach, he stopped regularly to top-up the hat-box with ice to preserve the yeast. That yeast was used in the Carlsberg brewery until 1883 when their chief scientist, Emil Christian Hansen, developed methods for isolating the first pure cultures of yeast. And that started the modern method of using pure cultures to produce very consistent beer anywhere in the world. Maybe it also started the path to loss of diversity and homgenisaton of styles that is only now being reversed?

Are there new trends in brewing?

Yes, of course there are! Although brewing is an ancient form of biotechnology, it is also modern and scientists are continually carry out research to better understand yeast and to develop new styles of beer.

One example is making new hybrid strains. You remember that lager yeast is one case of a hybrid, but it is possible to mate other species together to make new hybrids that can have interesting features – for example, they might be able to make new flavours or might be more efficient at fermentation.

Another example of innovation is the use of different species of yeast entirely. There is a species called *Lachancea thermotolerans* that carries out a different kind of fermentation: instead of making alcohol, it makes lactic acid – just like the lactic acid bacteria used to make cheese. If *S. cerevisiae* and *L. thermotolerans* are used together, it is possible to make a beer that is both alcoholic and sour!

Yet another yeast called *Brettanomyces bruxellensis* is sometimes included to mimic the strong aromatic character of some Belgian beers and investigations continue with other yeasts that might also produce interesting beers.

The idea of using more than one microbe in a fermentation actually copies what would have happened before microbiologists developed the knowledge and methods for pure cultures. It is something that is also seen with other traditional fermented products, for example sourdough bread. Some people believe that using mixed cultures of two or more microbes gives a more varied and interesting final product, whereas others are concerned about the difficulty in controlling such fermentations to make a consistent product. In this case, both opinions are correct and the option that is chosen really depends on the producer and what product they want to make.

During the later part of the 20th century, there was tremendous consolidation in the brewing industry. While in the 1800's and 1900's, every town worth its salt had at least one brewery making a local beer, over time these closed, or were bought by larger brewers, who in turn were purchased by global brewing giants. This led to the loss of beer diversity, and while thankfully some yeast strains have been saved in culture collections, many have also been lost, so there has also been a loss in biodiversity.

The last decade of the 20th century and the start of the 21st century has seen a reversal of fortunes and the emergence of a new brewing sector, the craft breweries. These smaller

operations generally focus on making flavoursome beer, usually ales, as an antidote to the "sameness" of some global beers. While the big brewers are important for a lot of innovation in the sector, it is also true that the passion of craft brewers will help preserve the soul of beer.

One of the major developments in the past ten years had been the growth in the production of non-alcoholic beer. This comes from strong consumer demand – people want to drink beer because of all its positive features but at the same time want to avoid excessive alcohol consumption because this is known to be unhealthy, and to avoid driving under the influence of alcohol.

Non- or low-alcoholic beers can be made in different ways but it always starts by performing the brewing and fermentation process that was already described – if this is not done, then it is not beer! Low alcohol and non-alcohol beers have been around for many years but they were not popular because they did not taste much like original beer. They could be produced by stopping the fermentation before it was complete, or by heating the beer to evaporate off the alcohol. But in the first case the beer remained sweet and in the second, the heating process also had a very bad effect on the overall flavour.

The new methods that have been developed use a process called reverse osmosis to remove alcohol without heating and so most of the flavours are retained. In some cases brewers also add back flavours that were produced by yeast in separate fermentations to try to fully recreate the taste of the original beer. Although the technology that scientists have developed is very successful and make popular products, it is not possible to 100% replicate alcoholic beer as alcohol itself also contributes to the final flavour of beer.

And the conclusion.....

There are many styles of beer but all share common features – they start with cereals and use the fermentation activity of yeast to make a fermented beverage. The large diversity in beers comes from variation in the brewing process, the type of barley or other cereal such as oats or wheat used, malting styles, or mashing changes – and in the selection of one of hundreds of different brewing strains of yeast that are available, each with their own special personality.

The yeasts that are used are natural and ancient but they have been captured, and trained – domesticated – by humans to take advantage of evolution to give strains that are adapted for our use.

Brewing is one of the oldest forms of biotechnology but it is still an area where lots of exciting research is taking place. When consumed in moderation by adults, beer is a nutritious fermented beverage that has been enjoyed by human society since the dawn of civilisation. For this, we thank the, not so humble, yeast!

A typical brewhouse. The brewhouse uses a variety of different stainless steel vessels for mashing, filtering, fermenting and storing beer.