Dukes of Ale BJCP Preparation Course 2009
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Yeast and Fermentation

What are Yeasts?

Yeasts are unicellular fungi that are found commonly in natural environments. There are about 1500 species currently known to science and it is estimated that less than 1% of all species have been described. Of this multitude of species, only a handful are known to be useful in the production of alcoholic beverages.

Yeasts normally reproduce asexually – brewing yeasts achieve this through a process called "budding", in which a "mother" cell grows a "daughter" cell that eventually separates to become a fully independent yeast.

A relatively unique trait of yeasts that distinguishes them from most other life forms is that they are capable of both aerobic and anaerobic metabolism. This quirk turns out to have an important impact on brewing, as brewers need to leverage both forms of metabolism in order to achieve a high-quality finished product.

Yeasts were unwittingly used in the production of alcoholic beverages for thousands of years before their discovery. Northern European brewing families passed down their "magic" brewing sticks for generations. Nobody understood why, but if you didn't stir the beer with this magic stick the beer would not come out right. It was likely more common to rely on sediment from previous batches to ensure the next one came out right. In 1680, Leeuwenhoek came close to discovering the secret when he observed yeast under magnification. Unfortunately Leeuwenhoek did not recognize these "globular structures" as a life form and so it was not until 1857 that Pasteur published a paper showing that the alcohol in beverages was produced by living organisms.

An interesting side-effect of this lack of understanding in how beer was made is played out in the history of the Reinheitsgebot. Originally proposed in 1487 and passed into law in 1516, the Reinheitsgebot declared that no ingredients shall be used in the production of beer other than water, barley and hops. After Pasteur's work in the 1800s authorities amended the law to allow the inclusion of yeast.

Armed with the knowledge that yeasts are responsible for the fermentation of alcoholic beverages, brewers have greatly improved the process of maintaining pure yeast cultures and clean fermentations. This has resulted in the widespread availability of a very impressive variety of high-quality yeast cultures. Because these yeasts are available to most brewers in the form of high-quality cultures, today's brewers are able to make a large variety of beer styles. This variety and the quality of the cultures has greatly improved the quality of the beers we enjoy today.

Terminology

A couple of terms will be important in our discussion of yeast and fermentation:

Attenuation – Attenuation refers to the completeness of the fermentation. “Real attenuation” is the percentage of wort sugars that are fermented into alcohol. “Apparent attenuation” is used more commonly because it is easier to compute using just gravity readings. The formula for apparent attenuation is:

apparent attenuation = (original gravity-final gravity)/original gravity

The distinction between apparent and real attenuation exists because the density of ethanol is only about 80% of the density of water. Brewers cite apparent attenuation far more commonly than they do real attenuation, so bear in mind that when you hear an attenuation number quoted, it usually does not indicate the actual percentage of wort sugars fermented.

Flocculation – Towards the end of the fermentation process, individual yeast cells will clump together and sink to the bottom of the fermentation vessel. This process is called flocculation. Different strains of yeast contain different levels of “sticky” carbohydrates on the surface of their cell walls. Because some have stickier cell walls than others, strains vary in the degree to which they flocculate and the manner in which they do so. The flocculation tendencies of a yeast strain have important implications for the beer they produce. For example, highly flocculent strains will tend to produce lower attenuation levels and because the yeast will settle to the bottom of the fermenter earlier than will a less flocculent strain.

Kräusen or Krausen – Used as a noun, kräusen refers to the thick yeasty layer of foam on top of fermenting beer during the most active phase of fermentation. When used as a verb, this term refers to a way of naturally carbonating beer without the addition of corn sugar or cane sugar. Unfermented wort, or wort from a fermentation at “high kräusen” can be added to the beer immediately before bottling, thus ensuring adequate sugars and yeasts to properly carbonate the beer in the bottle.

Lag Time – The time elapsed between pitching of yeast and the first clear signs of fermentation. During this time, the wort will appear still and the airlock will not show much activity.

Varieties of yeast

There are two main species of yeast used in the brewing of beer. The oldest is *Saccharomyces cerevisiae*, also known as ale yeast. Ale yeast performs best at temperatures ranging from 60°F to 70°F, and most strains fall dormant below about 55°F. Ale yeast is also known as “top-fermenting” yeast because it tends to do most of its work from the top of the fermenting liquid. The warm fermentation temperature range causes most beers produced by *S. cerevisiae* to contain high amounts of fermentation by-products such as esters. This is why ales have fruitier tastes and aromas than beers produced at cooler temperatures.

The other major species used in brewing is known variously as *Saccharomyces pastorianus or Saccharomyces uvarum*. This species was first described in 1883 by an employee of the Danish brewery Carlsberg, who named the species *Saccharomyces carlsbergensis.* Any of these three names generally apply to the species that encompasses today's lager yeast varieties, though the name *Saccaromyces pastorianus* seems to be gaining favor. Lager yeast does its best work at cool temperatures, generally between 45°F and 55°F, and these cooler temperatures result in few fermentation by-products and a clean taste largely free of fruity esters.

In the 1400s, Bavarian brewers noticed that beer kept in cold places lasted longer before spoilage than did beer kept in warm places. The practice of cold aging and storage became popular throughout the region, and eventually cold fermentation became the norm. In 1553, Duke Albrecht V of Bavaria issued a law dictating that beer could not be brewed during the warm months. All Bavarian beer (except wheat beer) was brewed in this manner, and brewers quickly found that cold temperatures were now necessary for their beer to ferment properly. They didn't know it yet, of course, but their habit of fermenting in cold environments had isolated a new species of yeast. This illustrates an important concept in brewing. Yeasts are living organisms, and their life cycle proceeds rapidly. Yeast populations do quickly adapt to their conditions.

A few other species of yeast are used in the production of some types of beer. Most notably, yeasts belonging to the genus *Brettanomyces* are used to produce many Belgian beer styles.

Packaging and Storage of Yeast

Yeasts have the ability to enter a dormant stage, during which they do not require a steady supply of food or nutrients. This enables brewers and yeast labs to package and store yeasts in a variety of forms. The most important thing you can do to ensure continued viability of the dormant yeasts inside a package is to avoid subjecting them to extreme temperatures. Storage at a constant, cool temperature (in the refrigerator) is best but reasonable deviations from this ideal do not generally kill the entire population.

Yeasts are normally distributed to brewers by yeast labs in either a dried form or in a liquid form. Dried yeasts are packaged in small foil packets with very high cell counts. This is convenient because the yeast can be pitched into the wort without making a starter. In order to wake from their dormant state and resume metabolism yeasts must bring a certain amount of water through their cell walls and into the cell. If the first fluid into which they are pitched has a high amount of sugars, this osmotic process is inhibited. For this reason it is best to rehydrate dried yeasts in warm water before pitching into the wort.

Liquid yeasts are usually packaged as a slurry contained in a vial or a large foil pouch known as a “smack pack”. The smack pack contains an inner pouch with yeast nutrients inside. When the inner pouch is broken several hours before pitching, the yeasts begin to awaken from their dormant state. The outer pouch swells as the yeast cells produce carbon dioxide, providing the brewer with some indication that the yeasts are healthy and viable, and it also improves the health of the yeast cells before they are pitched. Most brewers prefer liquid yeast cultures to dried ones. The reasons vary, but most brewers cite the broad variety of yeasts available in liquid form, and a few also claim that the dry cultures are less pure than the liquid cultures.

Despite being more pure, liquid cultures have one disadvantage when compared to dry yeasts, and that is that they are packaged with lower cell counts. To ensure a quick, healthy start to fermentation, brewers using liquid yeasts normally make a yeast starter. The yeast starter is a small batch of beer that is used to activate the yeasts and grow the cell count up to a point where the yeast population will not be overwhelmed when it is pitched into the full batch of wort. Making a starter is easy, you just boil some dried malt extract in water, and optionally add hops. Cool the brew down to pitching temperatures and pitch the yeast culture. Within two or three days, the starter will be at high kräusen and ready to pitch. Though this process is easy, it must be performed with the utmost attention given to sanitation. For high volume or high gravity batches of beer, step-culturing is sometimes advisable, where you make a series of successively larger starters until you have grown the appropriate quantity of yeast cells.

Brewers wishing to store their yeast strains for the long-term often store very small numbers of cells in small vials. This is best done in something called a “slant”. Slants are so named because they contain a small amount of storage medium, usually dried malt extract in agar or gelatin, that is cooled at the bottom of the vial with the vial at an angle. The result is a slanted surface when the vial is viewed in its normal upright position. After preparing the medium, the brewer inoculates the vial with a small amount of the desired yeast strain. There will be some growth initially while the vial is kept at room temperature, and after a few days the slant should be refrigerated. The yeasts remain viable in the refrigerated slant for about three months. To use the culture, the slant should be step-cultured up to a viable size.

It is also easy to culture yeast from commercial beers, provided they are bottle-conditioned. Step-culturing is useful here to ensure you pitch enough cells. Just use the sediment from the bottom of the bottle to inoculate your first starter step. As always, sanitation is important, and one should also do this with the knowledge that some commercial breweries use a different yeast for conditioning than they do for fermentation.

Fermentation

Yeast Life Cycle
Beer fermentations can in general be divided up into three phases: Adaptive, Attenuative and Conditioning. To summarize, the adaptive phase is the aerobic growth phase, attenuative is the anaerobic alcohol production phase, and conditioning is a seemingly quiet but nonetheless important phase in which certain primary fermentation products are processed, often resulting in more pleasant flavors within the beer.

Adaptive Phase
During the adaptive phase, there is plenty of dissolved oxygen in the wort available for the yeasts to use their aerobic metabolic pathway. This phase involves uptake of oxygen, nitrogen and sugars. Nitrogen and sugar uptake requires a permeable cell wall. To achieve cell wall permeability, yeasts rely on their reserves of glycogen. As yeasts enter their dormant state, they build up glycogen reserves, and so this adaptive phase is when the cells begin to awaken from their inactive state. The reactions that synthesize sterols from for the purpose of making the cell wall permeable are also very dependent on oxygen. This is why it is crucial for brewers to aerate or oxygenate their wort after cooling it. A lack of oxygen will cause the yeasts to resort to far less efficient pathways to achieve cell wall permeability, such as those using wort trub proteins.

With the cell walls now permeable to sugars and to nitrogen compounds such as amino acids and peptides, the yeast cells now have all the necessary nutrients to enter a period of rapid growth and reproduction. The growth and reproduction will continue rapidly as long as there is sufficient oxygen. When oxygen is no longer available, the yeasts will be forced to use their anaerobic metabolic pathway, which is far less efficient. The result of this shift is that growth slows dramatically, and the transition to the attenuative phase begins. Under ideal conditions, this transition occurs within a few hours of pitching the yeast.

Attenuative Phase
During the attenuative phase, the yeasts process wort sugars anaerobically. This is when the majority of the alcohol is produced. In most beers, this phase lasts a few days. In many fermentations, a thick

kräusen will build up on top of the beer. The yeasts' main task during this phase is to break down sugars into ethanol and carbon dioxide. The large volume of carbon dioxide produced results in vigorous airlock activity during this phase. Other minor metabolic pathways produce small concentrations of chemicals such as fusel alcohols and fatty acids. Though the concentrations of these chemicals are usually low, their flavor thresholds are extremely low and many of them contribute harsh and undesirable flavors. Eventually the yeasts will have consumed all of the fermentable sugars, or they will find themselves awash in a bath of their own excrement (alcohol) and this rapid fermentation process will slow to a crawl. Yeasts with nothing better to do will begin to build up their glycogen reserves, flocculate, fall out of suspension and sink to the bottom of the fermenter. The transition to the conditioning phase is under way.

Conditioning Phase
During the conditioning phase there are far fewer yeast cells suspended in the beer than there was during the attenuative phase. With fewer yeast cells in suspension, the beer will appear clearer than the attenuating beer did. The few cells that remain active will slowly break down some of the heavier sugars, such as maltotriose, that were not metabolized earlier. Now is also the time when fusel alcohols, fatty acids and other byproducts of the primary fermentation are broken down into compounds such as esters, which generally have more pleasant flavors.

The conditioning phase can go awry if the yeasts begin to metabolize the compounds in the trub. This process will result in unpleasant flavors and so most brewers rack the beer off the trub once the attenuative phase is over. Another situation this helps avoid is autolysis of the yeasts – yeast death and decomposition. John Palmer's "How to Brew" has an especially colorful description of what this smells like. You will think something died in your beer, because in fact, something has.

Oxygen
Oxygen is a critical factor in the adaptive phase of fermentation. If the wort does not contain sufficient concentrations of dissolved oxygen, the yeasts will be unable to grow rapidly and fermentation will proceed slowly and inefficiently. This can cause a number of problems, among them the possibility of some other microorganism growing faster and becoming the dominant population in the fermentation – i.e. an infection. To ensure adequate wort oxygenation, brewers employ techniques ranging from splashing the cooled wort on its way into the fermenter, to shaking the fermenter once the cooled wort is inside, to pumping pure oxygen or filtered air into the wort through a diffusion stone. Once the attenuative phase has begun, however, brewers take great care to ensure they do not introduce oxygen to the beer. Though necessary to get the fermentation process off to a good start, oxygen is not a good thing to have in finished beer as it will contribute to stability problems, causing undesirable flavors to develop in the beer over time.

Temperature
Controlling the temperature is one of the most important factors in making good beer consistently. Each strain of yeast has its optimum fermentation temperature range, and staying within that range is important for a healthy fermentation. Ideally brewers only deviate from this temperature range intentionally, and for specific reasons. Chilling ale to near freezing shortly before packaging is known as "cold-crashing" and it is sometimes employed as a means of clarification. Another important temperature deviation is know as a "diacetyl rest". Many yeast strains produce large quanities of diacetyl during primary fermentation (attenuative phase), resulting in a buttery taste that is undesireable in many beer styles. At warm temperatures, the yeast will readily consume the diacetyl once primary fermentation is complete. Lagers, however, are fermented cool and then lagered cooler still. In order to allow the yeast a chance to do away with the diacetyl, the brewer can bring the beer up to a temperature

of 55-60°F for a day or two before lagering. This allows the yeast time to become more active and process the diacetyl.

Nutrients

In addition to sugar, yeasts need access to certain nutrients in order to remain healthy. These nutrients include amino acids, fatty acids and nitrogen. In beer fermentations, these compounds are usually readily available in the wort, originating in the free amino nitrogen and lipids that were in the barley malt. In mead fermentations, nutrients typically must be added, as honey does not contain the needed nutrients. Some malt extracts may be nutrient deficient, and so it is not a bad idea to add some yeast nutrient to your starter if using malt extract for your starter fermentables. High-adjunct beer recipes also benefit from the addition of yeast nutrients. There are several commercially available products that can be easily added if you suspect your recipe lacks certain key nutrients.

Calcium, magnesium and zinc are minerals that are important for yeast metabolism. These will be present by default in many brewing water sources, but some softened water might be lacking in these minerals. These minerals can be easily added if your brewing water lacks them.

Filtering

Yeast can be filtered off the beer to aid in clarity and to prevent a sediment layer at the bottom of the bottle. However, the presence of the yeast in packaged beer aids in stabilizing the product and protecting it from off flavors. Much commercially produced beer is filtered, homebrew is typically not filtered.

References

"Brettanomyces." *Wikipedia.* March 16, 2009. April 15, 2009 <http://en.wikipedia.org/wiki/Brettanomyces>

Draper, Dave. "Culturing Yeast and Using Slants." July 15, 2007. April 15, 2009. <http://www.unm.edu/~draper/beer/slantuse.html#Inoculate>

Fix, George. *Principles of Brewing Science.* Second Edition. Boulder, Colorado: Brewer's Publications. 1999.

Hanning, Chuck. "Yeast and Fermentation." *BJCP Exam Study Guide.* 2009. April 15, 2009 <http://www.bjcp.org/study.php#yeast>

Palmer, John. "Chapter 6: Yeast." *How to Brew.* 1999. April 15, 2009 <http://www.howtobrew.com/section1/chapter6.html>

Palmer, John. "Chapter 8: Fermentation." *How to Brew.* 1999. April 15, 2009 <http://www.howtobrew.com/section1/chapter8.html>

Palmer, John. "Chapter 10: What is Different for Brewing Lager Beer?." *How to Brew.* 1999. April 15, 2009 <http://www.howtobrew.com/section1/chapter10.html>

Papazian, Charlie. *The Complete Joy of Homebrewing.* Third Edition. New York, New York: Harper Collins. 2003.

"Saccharomyces cerevisiae." *Wikipedia.* April 7, 2009. April 15, 2009. <http://en.wikipedia.org/wiki/Saccharomyces_cerevisiae>

"Saccharomyces pastorianus." *Wikipedia.* April 5, 2009. April 15, 2009. <http://en.wikipedia.org/wiki/Lager_yeast>

Weix, Patrick. "Yeast Information and Technique Resource". May 26, 1994. April 15, 2009 <http://www.realbeer.com/jjpalmer/yeastfaq.txt>