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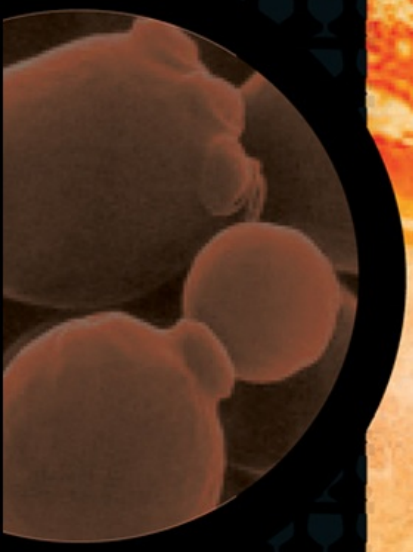

yeast

The Practical Guide to Beer Fermentation

Chris White with Jamil Zainasheff

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–Chris White

I could not have completed this book without the love, assistance, and support of my family: I do love them more than beer or brewing, but they never ask me to prove it. They know how hard I work on these books and how it takes away from family time as the deadline nears. For this book, they even put up with Dad furiously editing and writing during the family vacation to Disneyland. While my children, Anisa and Karina, are very supportive, my wife, Liz, goes much further and even helps edit all of my writing. I know my wife does not believe me when I tell her, "Dear, all homebrewers have their own yeast lab," but I really appreciate that she lets me spend money on and take up space with a lab, anyway. Yes, I know, I lead a charmed life.

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–Jamil Zainasheff

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You can find the latest version of the Beer Judge Certification Program Style Guidelines at the BJCP website, www.bjcp.org.

Foreword

"*We brewers don't make beer, we just get all the ingredients together and the beer makes itself.*"

— Fritz Maytag

"*Beer does not make itself properly by itself. It takes an element of mystery and of things that no one can understand.*"

— Fritz Maytag

I've always liked these two quotes, as I believe they perfectly illustrate the mysteries of fermentation, the least understood and often the most neglected part of the brewing process. If you read beer recipes provided on various brewing websites and in brewing books, you'll see that much attention is paid to things like grain bills, and more significantly these days, to hop bills. Yeast seems a bit like an afterthought, and maybe that's because it has been that way throughout much of history.

Read historical brewing books and you will find plenty of references to malting, malt quality, hop growing, hop quality, and even water quality. These processes were well understood fairly early in the game. But because most brewers believed fermentation was a spontaneous process, there are virtually no references to yeast in historical texts. This despite the fact the brewers realized how critical yeast is to the brewing process, calling yeast "godisgood," "berme," and "yeste." Yeast is often only mentioned in passing in recipes and procedural texts. Even the first version of the German purity law, Reinheitsgebot, failed to include yeast as an ingredient in beer. And on the occasions that yeast *is* explored thoroughly in historical texts, it's a tough read, because the information is painfully inaccurate.

What is even more amazing is that despite this lack of knowledge, understanding, or willingness to address the inclusion of yeast as a vital ingredient, brewers knew yeast was important, and they knew fairly early on that they had to harvest yeast and repitch it to the next fermentor to ensure the successful transformation of wort to beer. Yeast strains have survived for hundreds, if not thousands, of years, and have been successfully maintained and carefully selected to become the multitude of wonderful strains that are available to brewers everywhere today. Throughout history brewing processes evolved that favored the maintenance of yeast strains. Techniques such as top cropping, repitching, lagering, and seasonal brewing to maintain good fermentation temperature were all developed to ensure complete fermentations and delicious beer, despite brewers having no real understanding of what yeast was and how it worked. Even as recently as the late 1800s, after Louis Pasteur proved that fermentation is a result of metabolism by yeast, a living organism, brewing literature was chock-full of "marketing speak" references to yeast: "yeast must be of the *highest quality*," "yeast must be *excellent*," "yeast must be *exceptionally fine*," all of which really mean nothing, but do give the appropriate impression that the brewer treats his yeast with care.

Yeast research started in the late 1600s, shortly after the invention of the microscope, but really took off in the late 1700s and early 1800s. Several scientists came up with theories that were close to what we now know as reality, postulating that yeast were single-cell organisms and were responsible for alcoholic fermentation, but no one really landed on the key fact that yeast were metabolizing sugars to produce alcohol and carbon dioxide. In the late 1830s, yeast research was focusing in on the fact that yeast cell activity was the source of alcohol and CO_2 production. This promising thread of research was derailed slightly by the publishing of the following derogatory description of cellular fermentation by organic chemists Liebig and Wohler, who favored chemical reaction as the explanation for fermentation:

> *... Incredible numbers of small spheres are seen, which are the eggs of animals. When placed in sugar solution, they swell, burst, and animals develop from them, which multiply with inconceivable speed. The shape of these animals is different from any of the hitherto described 600 species. They have the shape of a Beindorf distilling flask (without the cooling device). The tube of the bulb is some sort of a suction trunk, which is covered inside with fine long bristles. Teeth and eyes are not observed. Incidentally, one can clearly distinguish a stomach, intestinal tract, the anus (as a pink point), and the organs of urine excretion. From the moment of emergence from the egg, one can see how the animals swallow the sugar of the medium and how it gets into the stomach. It is digested immediately, and this process is recognized with certainty from the elimination of excrements. In short, these infusoria eat sugar, eliminate alcohol from the intestinal tract and CO_2 from the urinary organs. The urinary bladder in its filled state has the shape of a Champagne bottle, in the empty state it is a small bud. After some practice, one observes that inside a gas bubble is formed, which increases its volume up to tenfold; by some screwlike torsion, which the animal controls by means of circular muscles around the body, the emptying of the bladder is accomplished. … From the anus of the animal one can see the incessant emergence of a fluid that is lighter than the liquid medium, and from their enormously large genitals a stream of CO_2 is squirted at very short interval. ... If the quantity of water is insufficient, i.e., the concentration of sugar too high, fermentation does not take place in the viscous liquid. This is because the little organisms cannot change their place in the viscous liquid: they die from indigestion caused by lack of exercise (Schlenk, 1997).*

Fortunately, some researchers continued on, and cell theory became more gradually accepted through the groundbreaking work of Pasteur. And groundbreaking it was; it completely changed the whole brewing industry. Pasteur traveled from brewery to brewery in the late 1800s and offered his services to inspect their yeast cultures, and gave the breweries a passing or failing grade. The story of Pasteur's influence on the Carlsberg brewery is well documented later in this book, but Pasteur didn't stop there; he traveled throughout Europe. When Pasteur indoctrinated the English brewers of the late 1800s on the importance of yeast, they hired chemists as senior level staff members. These brewing chemists became highly sought after and also became the highest-paid members of the brewery staffs.

As the field of biochemistry has grown, larger breweries have adopted scientific techniques to better understand their yeast strains. When I worked at Anheuser-Busch, we tracked yeast fermentation by-products like diacetyl, pentanedione, acetoin, and acetaldehyde at regular points throughout the lagering process. These maturation factors were quick indications of how healthy the yeast and fermentations were. But despite all the technology and research available, yeast still remains mysterious and unpredictable in many ways, and monitoring fermentations remains a very reactive type of situation. It wasn't uncommon for a team of experts from St. Louis to hop on a plane and visit a brewery that was having a problem with its yeast or its fermentations,

arriving with the dreaded statement, “We’re from Corporate, and we’re here to help.”

I remember a discussion we had as brewers at Anheuser-Busch several years ago regarding how much yeast contribute to the final flavor of beer. In general, the consensus was that yeast was responsible for nearly 80 to 90 percent of the flavor in an American lager. All you have to do is taste wort and beer side by side to understand the importance of yeast’s contribution to beer flavor. And if you consider the three flagship beers from the big three American lager brewers, which are brewed to the same style and use similar ingredients, you’ll realize the beers taste markedly different when compared side by side. And that difference is primarily due to yeast.

In a craft beer the impact of yeast on the final beer flavor may not be quite as pronounced, due to the increased quantities of specialty malts and hops, but I know at Stone Brewing Company we have fermented several worts with both our house ale strain and with Belgian yeast, and the beers taste nothing alike. In some cases we weren’t able to tell they came from the same wort, which we always found amazing.

So realistically, yeast can be the most active flavor ingredient in the brewing process, and it is certainly the most temperamental ingredient in beer. Yeast possess a tough combination of characteristics for a brewer to manage. As any experienced brewer knows, you must treat your yeast with the utmost care, or the beer can end up tasting horrible.

Chris White and Jamil Zainasheff have taken on the daunting task of explaining yeast and fermentation to us brewers. One of the difficulties in writing a comprehensive book on yeast and fermentation is that every yeast strain reacts differently to similar external conditions. Any brewer who has switched jobs or yeast strains knows that the conditions that make one strain perform well don’t always work for the next strain. It’s an inexact science, trying to manage this living organism and getting it to behave the way we want it to. Our job as brewers is to manage our yeast, keep it “happy” so that it only produces the flavor compounds we want in our beer, and not any of the “bad” flavors that yeast tend to produce when they are stressed.

Chris and Jamil have done a great job addressing these difficulties in this book. They have included loads of sound information and techniques that will work for brewers at all levels, from beginning homebrewers to production brewers at any sized brewery. Included are fantastic tips for working with all kinds of yeast strains and beer styles, introducing new strains, and how to use best brewing and lab practices to keep your yeast healthy and your beer tasting great. And even through the “dreaded” organic chemistry and biochemistry sections, the authors manage to keep the information conversational, which will allow brewers with varied educational backgrounds to take this information and use it effectively to improve their fermentations and their beer quality.

I hope everyone enjoys this book as much as I did. I think it’s a must for every brewer’s bookshelf. Welcome to the wonderful, mysterious, and complex world of brewer’s yeast!

Mitch Steele
Head Brewer/Production Manager
Stone Brewing Company

Introduction

Yeast is critical to beer, which makes it critical to brewers. Whether brewers fully realize it or not, yeast function involves much more than converting sugars into alcohol. More than any other fermented beverage, beer depends on yeast for flavor and aroma. Our goal was to write a yeast book that focused on the brewer's perspective, and we quickly realized that there are just as many perspectives about yeast as there are brewers. While one brewer may have an interest in exploring native fermentation with wild yeast, another is concerned with maintaining a pure culture and minimizing unusual flavors, and yet another wants to know every detail of yeast biochemistry. In the end, we did our best to cover as much information as possible from a practical brewer's view.

This is not a book for the highly successful regional or larger brewer who already has multiple labs and a doctorate in microbiology. This is a book for those who are in the early stages of their love of yeast and what it can do for their beer. And when we use the word "brewer," we are talking not just about professionals but also hobbyists. Homebrewers (who call themselves craft brewers in some parts of the world) love the process of making beer as much as their professional counterparts do. Just like professional brewers, they range from eccentric to highly scientific, but all share a passion to create something out of nothing. Of course, brewing successfully on a professional level takes a great deal of dedication and financial risk that homebrewers can avoid. Whether you are a professional or hobbyist, brewing great beer requires both an artistic flair and, at times, the ability to think like an engineer. In fact, engineers seem to enjoy homebrewing more than most and have a passion for taking the hobby to its limit. Perhaps this is why many professional brewers began as homebrewers. They wanted to take their creativity and passion to the public.

From the beginning, we decided that this would not be a yeast biology book. It is not a book on the basics of brewing, either. You should already know how to brew, and if you do not, get yourself a copy of *How to Brew* by John Palmer and come back to this book later. If your passion is for yeast biology, there are many fine yeast science books available as well. In some cases, we do discuss what is happening within the cell wall, but only to show how it affects your beer. We wanted to write a book that was accessible and useful for brewers of all experience levels. We cover yeast information from the basics to some advanced procedures and even beyond to some areas for further study. One thing we know about brewers is that they always want to know more, so we hope this book satisfies your interest, stretches your horizons, and has you thinking about yeast every time you think about beer.

Fermentor vs. Fermenter

Fermenter or fermentor, which is right? You see both words used interchangeably, but technically that is not correct. In this book we follow the differentiation found in many dictionaries:

We use fermentor when talking about a fermentation vessel, such as a cylindroconical fermentor.

We use fermenter when talking about the yeast itself, such as, “WLP001 is a strong fermenter.”

About Chris White

I have a peculiar resume. I graduated with a doctorate in biochemistry, but instead of joining a regular laboratory, I have spent my professional life immersed in the yeast and fermentation business.

The history of beer and yeast has been a fascinating subject for me since my college days, for many reasons. In the early 1990s I developed a passion for homebrewing while an undergraduate at University of California, Davis. My introduction to this fascinating world came through Michael Lewis’ Brewing and Malting Science course. I started homebrewing there and continued homebrewing while pursuing a Ph.D. degree from the University of California, San Diego. My thesis involved an industrial yeast, *Pichia pastoris*, which I had the fortune to work with in its early development. *Pichia pastoris* is now widely used in biotechnology. While wonderful in the science world, *Pichia pastoris* makes beer that tastes something like sweaty socks, so I started collecting brewing yeast strains from breweries and yeast banks worldwide. I experimented with these in my homebrewing, and at the same time, a surge of new breweries opened in San Diego. Pizza Port Brewing, Ballast Point Brewing, Stone Brewing, and AleSmith all got started in the early 1990s, which gave me an opportunity to understand the needs of professional brewers. I founded White Labs Inc. in San Diego in 1995. The company’s focus was large-volume liquid yeast cultures, based on technology that I learned with *Pichia pastoris* and later modified to meet the special needs of *Saccharomyces cerevisiae* brewing yeast.

Today, White Labs yeast is sold in homebrew shops and to professional breweries, and is also used in other industries, including winemaking. The thrill for me in those early years, and still today, was getting yeast of the highest quality to homebrewers and professionals. In this book I hope we show you how to maximize your fermentation experience by getting the most out of what can with good measure be called the most important ingredient in beer – the yeast.

About Jamil Zainasheff

“The yeast is strong within you.”

— Karina Zainasheff to Anisa Zainasheff

Since the age of eight, I have had an interest in foods that involve fermentation or similar processes such as bread, cheese, kimchi, and yogurt. Sourdough bread cultures fascinated me, and I quickly realized that the conditions I provided to the culture made a difference in the quality and flavor of the bread I made from it.

So it seems strange to me now that during the 1980s, as a biochemistry undergraduate at the University of California at Davis, the extent of my beer knowledge was centered around which day of the week was dollar beer night at the local watering holes.

It was not until later, when my wife, Liz, got me started with a Mr. Beer kit, that I added alcoholic beverages to my list of fermentation interests. I started brewing, but

through no fault of the kit, I had little initial success. I did have one advantage, though. While I had missed out on learning about beer, wine, or yeast like so many of my friends at UC Davis, I did gain a passion and talent for learning that I could put to use. I read everything I could find on brewing, and I asked many questions to those around me. I already knew that yeast was probably the key to making perfect beer, and by learning how to better work with yeast, my beer improved.

I became obsessed with making the best beer possible and entered many competitions to get objective feedback on beer quality. I would alter recipes, techniques, and yeast variables one at a time, until I understood what effect my actions had on the results. As my knowledge grew, I felt I should behave like those who helped me by sharing that knowledge. This is what led me to hosting shows on the Brewing Network and writing about brewing. My friend John Palmer got me started down the book path with our collaboration on *Brewing Classic Styles*, and when presented with a chance to work on a book about yeast with Chris White, I felt like it was an opportunity I could not pass up. Writing an authoritative book of this scope was challenging, but I think we succeeded in capturing a lot of the information that I used to take my beers from insipid to award winning. My hope is that this book inspires readers to have a passion for yeast as much as they do for beer. As my daughter Karina so eloquently put it, I hope the yeast will be strong within you, and you will use that passion to make advances in your own beer quality as well.

1
The Importance of Yeast and Fermentation

A Brief History of Yeast

Some historians believe that civilization developed from a desire to drink beer. They speculate that the transition from hunter-gatherer to farmer, and the beginning of civilization, was to grow crops to make beer. Of course, those early brewers could not have made beer without yeast. No yeast, no beer. No beer, no civilization. Therefore, we really have yeast to thank for all our modern-day conveniences and tasty beer.

Thousands of years ago in Mesopotamia, nobody understood that the naturally occurring yeast on soil and plants was critical to creating fermentation. Ancient brewers and winemakers relied on these natural yeast sources to inoculate their fermentations. For most of history, fermentation was a divine mystery. An offering set before a shrine and prayed over for several days would transform into an intoxicating beverage. Brewing implements became family heirlooms. They began to call the froth that would magically appear on the surface of the beer “godisgood,” and they reverently transferred it to another vessel to begin another fermentation. Researchers believe that brewers started reusing yeast from batch to batch in the twelfth century, beginning the process of yeast domestication. Brewers and drinkers wanted beer that tasted better and had a longer shelf life. Brewers reused the yeast from successful batches and discarded the yeast from bad batches, unknowingly putting selective pressure on the yeast.

Before microscopes allowed us to see yeast, no one knew exactly what happened during fermentation. When the Bavarians created the Reinheitsgebot beer purity law in 1516, making it illegal to brew beer containing anything other than water, barley malt, and hops, they left yeast off the list of ingredients because they did not know it existed.

In 1680, more than a century after the purity law went into effect, Anton van Leeuwenhoek was first to observe, through a microscope, that yeast was composed of small, interconnected elements. Interestingly, he did not realize that it was alive. At that time, the most commonly accepted theory of fermentation was that it was a spontaneous process—a chemical reaction promoted by contact with the air—and the yeast was a chemical by-product.

Another century later, in 1789, Antoine-Laurent Lavoisier described the chemical nature of fermentation as parts of sugar turning into carbon dioxide and alcohol. Yet scientists still did not make the connection between yeast and this conversion of sugar into ethanol. It was not until the mid-1800s that Louis Pasteur established that yeast was a living microorganism. This opened the gates for precisely controlling the conversion of sugar into alcohol. It also led to the creation of a separate field of study called biochemistry. The advances made, as direct or indirect results of beer research, led to our understanding of how cells work and laid the groundwork for many other breakthroughs in scientific research.

It is not exaggerating to suggest Pasteur made the greatest advances of anyone in the history of beer, and that these breakthroughs and others led to some important advances for the whole of civilization. His studies into beer and wine fermentation paved the way for his later work on anthrax, rabies, cholera, and other afflictions, which led to the development of the first vaccines.

When Pasteur started working with beer fermentation in the 1860s, most people believed yeast was not the causative agent of fermentation. Beer is a complex soup of material, containing protein, nucleic acids, bacteria, yeast, and much more. Scientists knew yeast was part of the mix, but they regarded it as a by-product of the fermentation. They believed spontaneous generation catalyzed by air caused fermentation. The spontaneous generation theory held that yeast and bacteria were created spontaneously in fermentation. At the time, the theory that living cells could carry out fermentation was too "biological." Scientists had still not perfected their sterilization techniques, and this was one reason the spontaneous generation theory persisted. After all, if a scientist believed he sterilized a medium, yet it still contained cells that would later multiply, it would appear that spontaneous generation was the answer.

Pasteur did not believe this. Pasteur drew on his study of wine and did not believe there was enough air present to explain the growth of the yeast population during fermentation. He designed a simple experiment that would put an end to the theory of spontaneous generation.

Today we know Pasteur's experiment as the "swan neck" fermentation. He filled a swan neck flask with a sterilized mineral medium. Pasteur was fortunate to have used a medium with a pH that was acidic enough to stay sterile in his experiment. In fact, some of the flasks he prepared still remain sterile to this day.

Air can enter, but the swan neck traps any dust, which carries yeast and bacteria. Since the dust cannot reach the medium, there is no fermentation. If air was all that was required for fermentation, fermentation would still proceed, but it does not. Only when the flask is tipped can liquid enter the neck, taking up bacteria and yeast, and fermentation can start.

This was a controversial idea, and Pasteur would spend the next fifteen years conducting experiments to prove certain aspects. He also worked with different sugars, including those from fruits. By 1879 his theory was firmly in place and he wrote, "… we need no longer say, 'we think,' but instead, 'we affirm,' that it is correct," concerning alcoholic fermentation and yeast.

This was important for many reasons beyond academic value. Once you know the cause of something, you can better control the process that causes it. Beermaking went from something that was magical, with the brewer having little control, to something that the brewer could control simply by understanding yeast.

Pasteur understood right away. He not only proved what yeast was doing, he theorized that the bacteria and other yeast present were the cause of off-flavors. After all, the goal of his original work was to discover how to prevent the "disease of beer."

Some breweries adopted his ideas and began cleaning their yeast cultures and breweries. One such brewery was Carlsberg in Denmark. Carlsberg Laboratories,

under the direction of Emil Christian Hansen, isolated the first lager yeast strain and brought it into the brewing world on November 12, 1883. Its scientific name was *Saccharomyces carlsbergensis* or *Saccharomyces uvarum* (now *S. pastorianus*), but most brewers call it “lager yeast.” Hansen was also the first to develop pure culture techniques, techniques that we still use today in microbiology laboratories. It was these techniques that allowed Carlsberg Laboratories to isolate the pure lager yeast culture. Not only was Hansen able to grow this new lager yeast in pure form, he was also able to store it for long periods on a combination of wort and agar. This combination of isolating pure cultures and long-term storage allowed brewers to transport lager yeast all over the world, and soon after, lager brewing overtook ale brewing worldwide.

Why did lager beer become so popular? At the time that Hansen isolated lager yeast, most ale fermentations still contained some wild yeast and bacteria. The resulting beer, even if it was acceptable at first, had a short shelf life before it went bad. For many people, unless they worked in a brewery, the first clean-tasting beer they had was probably a lager beer. Lager beer was also fermented cool, which suppressed the growth of wild yeast and bacteria. Therefore, lager beer had a longer shelf life, which meant a larger distribution area and increased sales. It is possible that many breweries switched to lager brewing because they saw it as an opportunity to increase their sales. Today, with modern pure culture techniques and good hygiene practices, ale is just as contamination free, but mass-market lager beer continues to thrive. Is it marketing or is the flavor more appealing for today’s beer drinker?

Figure 1.1: Busts of Louis Pasteur (left) and Emil Christian Hansen (right) decorating the old Carlsberg brewery in Copenhagen. Photos courtesy of Troels Prahl.

Why Fermentation Is So Important