Home Brewing & Chemical Analysis

An Honors Thesis (HONRS 499)

by

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Abstract:

Although there are countless types of beer, all of them can be broken down into either lagers or ales. This has to do with whether active fermentation occurs on the top or the bottom of the fermentation chamber. For the purposes of home brewing, lagering is slightly more impractical. For this reason, I have created three different home brewed ales. These different types of beer range in a variety of color, brewing process, and alcohol content. There are two majorly accepted types of home brewing: extract and all grain. Extract brewing is where the “mash” or slurry of grains has been condensed into a thick syrup. This type of brewing requires less equipment and less time investment on the brewing day itself. All grain brewing is where the brewer starts from scratch. I have created one extract batch and two all grain batches. Furthermore, a written analysis of my brewing and researching experience is given.

After the brewing process was complete, I chemically analyzed a few of their characteristics. I will collect light spectroscopy data, pH, and hydrometer data. With the art of brewing, there are a few different standard characteristics that are important to the consumer: color, alcohol content and bitterness. By utilizing light spectroscopy, the darkness of the beer can be made quantitative. This is a useful tool when it comes to comparison of similar industrial brews. Alcohol content is another important characteristic that was analyzed. A hydrometer was used to obtain data in order to make a rough estimate of percent alcohol. Lastly, I will analyze the bitterness of each beer through the pH.

Once the lab analysis is complete, I plan to hold a beer-tasting event at an off-campus venue. Here I will discuss the brewing process, chemical analysis, and personal experience.
Because this project is not a full scale “research” project, I have created a compilation of my work. There are multiple sections in this compilation including: scientific review of the fermentation process, data section, step-by-step personal brewing experience, and photo documentation of my work.

The reason that I chose this process is that it intertwines both science and art. The brewing process and chemical analysis are rooted in my major (biochemistry). Furthermore, the art of brewing is something that I have wanted to pursue. After I graduate with a biochemistry degree, I plan to go on to a graduate program for brewing. This project will be a great stepping stone and resume builder for my career.

This being said, my target audience is the scientific community of ages 21 or older. Through this project, I hope to show Ball State University’s future chemistry students that chemistry can be creative and fun. Furthermore, I feel as though people from other majors can appreciate the work put into this project. I feel that this project has the potential to attract undecided students to the chemistry department. To many, brewing seems like an intangible process. I believe this to be a misconception. By providing a written breakdown of the brewing process, I hope to change preconceived notions of intangibility into something very real and comprehensible. It is important to know exactly what you are putting into your body. I hope to educate others on not only what they are consuming, but where it came from.
Acknowledgements:

I would like to thank Nicole Christofield for being my thesis advisor and trying to keep me on track. Also, I would like to thank my brother in law, Ryan Kalcich, for his help and equipment during the brewing process. Lastly, I would like to thank all of my friends who have been supportive and helped out with various brewing tasks.
Home Brewing & Chemical Analysis:

Home Brewing is the process by which different beers can be brewed outside the realm of commercial brewing. This being said, there are multiple types of home brews that can be made. All grain brewing and extract brewing kits are the two means by which beer can be brewed at home. Due to the abundant supply of extract kits produced by breweries, home brewing can be relatively cheap and easy. However, this is comparable to using dehydrated milk and adding water. This is not to say that an extract kit will not yield an extraordinary brew, it is merely removing a step from the brewing process. On the other hand, all grain brewing is brewing from scratch. This is how breweries make their beer. This being said, I created three home brews. The first of these home brews was an Extra Special Bitter extract kit produced by Northern Brewer. The other two all grain batches were done with equipment and help provided by my brother in law. These two beers were a Nukey Brown Ale and a Saison Wheat. A picture of this all grain brewing setup is included below.
Although the previous beers seem like a random assortment, they all have one thing in common. This is the fact that they are all ales. In the beer industry, there are two main types of beer: ales and lagers. Ales are fermented at sixty to seventy degrees Fahrenheit, while lagers are fermented in much colder temperatures (11). When the yeast is most active, the fermentation reaction is strongest. Thus, stronger fermentation yields more alcohol. The type of yeast used for ales, Saccharomyces Cerevisiae, is most active between temperatures of sixty to seventy degrees Fahrenheit (3). Another characteristic of this yeast is that it ferments on the top of the fermentation chamber. To achieve this desired temperature range for optimum fermentation, there is a constant temperature of about sixty five degrees Fahrenheit below the frost line. Because of this convenient fact, it is easy to brew ales in a basement or underground cellar year round. For this reason, I chose to brew three wildly varying ales.

Although more difficult to produce, it is still important to understand how a lager is made. A typical lager undergoes primary fermentation from 48 to 58 degrees Fahrenheit. Once primary fermentation has complete, the temperature is dropped to around forty degrees Fahrenheit for secondary fermentation (8). These low temperatures make refrigeration necessary for extended periods of time. Although there are dark lagers, many lagers tend to be relatively “light” in color. The yeast used to make lagers, Saccharomyces Carlsbergensis, is most active during primary fermentation, but can survive colder temperatures in secondary fermentation for a “smoother” taste. This type of yeast ferments on the bottom of the fermentation chamber (3).
Now that the differences between ales and lagers have been discussed, light beer brewing can be examined. When breweries make a “light” beer, their calories have to go somewhere. Alcohol has a unit enthalpy of seven calories per gram, while carbohydrates have four calories per gram. In order to produce more alcohol, less carbohydrates, and less calories, alternate ingredients and fermentation techniques are used. These ingredients include substituting rice and corn for malt (11). These commodities are cheap sugars that can be converted at an efficient rate into alcohol. Once these goals are achieved, the beer will have a high alcohol content and a low carbohydrate content. However, these circumstances create a high calorie content beverage. For this reason, they water down their “light” beers (9).

Now that beer classification has been discussed, a general knowledge of the brewing process is necessary. Basically, brewing is the process by which alcohol is made from grains through yeast fermentation. There are seven steps in the brewing process; these include: milling, mashing, lautering, boiling, cooling, fermenting, and carbonating. Although understanding the many different steps may seem overwhelming, each step will be examined with detail.

Although many know that beer is made with grain and water, they do not know that it is a “special” type of grain used. This grain is called malt and has been “cracked.” Essentially, malt is grain that has undergone the processes of steeping, germination, and kilning (3). These combined processes and cracking grain together are called milling, otherwise known as the first step in brewing (6). During this step the grain is allowed to germinate. Germination is when a seed begins to sprout after being exposed to moisture and usually under “dark” conditions. This
step is majorly important because of the essential enzymes being made readily available for the reaction mixture (4). Once this germination has commenced, the grain can be roasted and cracked. Roasting or “kilning” plays a large part in determining the darkness of the beer. Once all of these processes have been complete, the “special” grain has been created.

The second step in the brewing process is called mashing. This is the primary step where the grains and water are heated and stirred in the mash tun (4). This step begins the extraction of enzymes and sugars from the cracked malt. In extract brewing kits, the mash is then filtered and boiled down. This creates a condensed syrup that can be stored and used at a later date (8). The use of this dehydrated mash cuts a few hours off of the brewing process. Extract brewing aside, the mashing step is rather similar to steeping tea or brewing coffee. Through the addition of heat and agitation, the sugars and enzymes are extracted from the grains into the reaction mixture (13). Due to the different solubilities of enzymes, mash stepping is a way to target specific enzymes and compounds for specific tastes. This resulting liquid is called the mash (12). There is a picture of the mash included below.
The first mashing temperature is 104 degrees Fahrenheit. This mash step activates beta-glucanase, an enzyme that facilitates the hydrolysis of beta glucans for a more fluid mash. The second step occurs from 120 to 130 degrees Fahrenheit. Many different proteinases are activated in this step. Although this can add clarity to the flavor, if the extraction of proteinases is too efficient it will negatively affect the beer’s ability to maintain head. Beyond head retention, the mash must accomplish the extraction of amylases to break starch into glucose. This occurs between the temperatures of 149 to 160 degrees Fahrenheit. Lastly, the mash out culminates the series of mashing steps. Once the desired enzyme extractions and mashing steps have finished, the reaction mixture is raised above 170 degrees Fahrenheit to halt enzymatic activity (4).

The resulting mash is a hot mixture of spent grains and wort. The next step in the brewing process is called lautering. The mash is filtered through the screen and into the lauter tun to prepare for boiling. In the home brewing process the mash tun has a stainless steel screen that is used to filter the spent grains from the wort (12). Furthermore, it is important that the grains are not ground up too much. The husk provides for a natural grain bed filter, keeping un-fermentable grit out of the wort (6). The spent grains can then be discarded or used as cattle feed or compost. Essentially, lautering is merely a filtration step where the filtrate is the desired product (3). A picture of the grain bed is included below.
The filtered wort can then be boiled. Just as in the mash out, the boiling step completely halts any enzymatic activity. This is important so that the enzymes do not continue to break down proteins and starches during subsequent steps. To ensure this, the boil is usually maintained at above 200 degrees Fahrenheit. Sterility is another important characteristic that is being achieved by this method. Once the brew leaves the boiling pot, it must remain sterile for the remaining steps (6). The reason for this is that although yeast activity is desired, activity of other micro-organisms can be detrimental to the flavor of the resulting beer. Beyond sterility, boiling also tends to precipitate unstable proteins (13). Proteins and undesired sulfur compounds can yield unwanted flavors. Fortunately, the sulfur compounds usually boil off along with excess water. This gives the beer a smoother, more concentrated flavor. Besides these various purifications, the boiling step can contribute to darkness and bitterness (6). Bitterness is introduced by the addition of hops. Most hops are sold in a “pelleted” form as seen below.
Just as there is a mash schedule, there is a hop schedule. For the first fifteen minutes of boiling, the wort must boil unaccompanied by hops. At the beginning of this step, the wort is thick with protein. By boiling the reaction mixture, many proteins have the opportunity to precipitate off. If hops were to be added too early, the tannin within the hops would bind to the not yet precipitated proteins. This creates an odd suspension of protein-tannin complexes, giving the beer a murky appearance (7). Hops are added at different times during the boil for different purposes. These purposes include: bittering, adding aroma, and preserving. Hops were first embraced by the English during their long sea voyages to India. They dry-hopped, or added hops to the fermentation barrel, in order to preserve the beer for months. The resulting beer was an India Pale Ale. Besides preservation, there are hops for bittering and aroma. Bittering hops are added at the beginning of the boil, and must be boiled for an hour. On the other hand, aroma hops are added in the last fifteen minutes of the boil and largely contribute to the crisp smell observed in India Pale Ales (7).
Hops are either aroma or bittering type based solely on the time that they were added to the boiling pot. Hops are small buds that grow on a vine and contain essential oils and alpha acids. These essential oils are volatile and give the beer its aroma. On the other hand, alpha acids are bittering resins that are not water soluble at room temperature (12). After the reaction boils for an hour, most of the alpha acids undergo an isomerization reaction. The resulting isomer is soluble in water (11). Thus, increasing the pH and bittering the beer. However, after an hour of boiling, almost all of the volatile essential oils have been boiled off. For this reason, aroma hops are added within the last fifteen minutes of boiling. This extracts the essential oils, but does not give them enough time to boil off. This creates the wonderful aroma that beer drinkers have learned to love.

Once the wort has been hopped and boiled long enough, the wort must be quickly cooled. This can be done by a number of different devices including: a heat exchanger, plate cooler, counter-flow wort chiller, or ice bath (1). A picture of the counter-flow wort chiller is featured below.
These means are used to cool the wort to active fermentation temperature. This is a decrease of approximately 150 degrees Fahrenheit. The reason that it needs to be cooled so quickly is to eliminate chance for contamination during transfer and precipitate out “cold break” proteins. These are proteins that will only precipitate under an extremely fast temperature decrease. If not sufficiently completed, the beer runs the risk of having “chill haze” or visibility of precipitated suspended proteins when chilled (11).

At this point it is important to remember to use sterile technique. This includes the need to sterilize siphons, fermentation chambers, hoses, yeast packages, bungs, and anything else that will come in contact with the beer. The cooled beer is then transferred into a fermentation chamber. The yeast is then added, and the chamber is sealed with a bung (4). For the next few days, the yeast will be extra active. This can be observed by watching the carbon dioxide bubble out through the bung device. Once the evolution of carbon dioxide can no longer be seen, primary fermentation is over. This is when most of the alcohol is produced.

Once again, sterile technique becomes a necessity. The beer is transferred from the primary to the secondary fermentation chamber. During transfer, the solids at the bottom of the primary fermentation chamber will be discarded, while the liquid is decanted into the secondary fermentation chamber. Then, the secondary fermentation chamber is aerated and sealed with a bung. This batch will sit for the next two weeks or longer during the fermentation. After secondary fermentation has completed, the beer must condition. This is basically a period of time that allows some of the harsher compounds and yeast to settle on the bottom (4).
Once fermentation and conditioning have been completed, the beer can then be bottled or kegged. If the beer is going to be kegged, it is often force carbonated. This is when the noncarbonated beer is sealed in a keg and pressurized with carbon dioxide. If the beer is to be bottled, the beer must be mixed with priming sugar. When the yeast comes in contact with the added sucrose under aerobic conditions, it produces carbon dioxide and water, naturally carbonating the sealed bottle.

In order to fully understand the brewing process, the process of fermentation must be understood. Fermentation is the process by which yeast converts sugars into alcohol. In the beginning of the brewing process, maltose is broken down into glucose by amylase and diastase (10). From here, glucose can be converted to pyruvate via glycolysis. This is a sequence of ten reactions that yield pyruvate and various other byproducts. Pyruvate decarboxylase will then convert pyruvate into acetaldehyde by evolving carbon dioxide and cleaving the C-C bond (1). Lastly, acetaldehyde is reduced to ethanol through the enzyme alcohol dehydrogenase (5). Once the yeast has stopped producing alcohol, anaerobic fermentation is complete.

The brewing process is not extremely complicated. However, the chemistry behind the brewing is intricate. For this reason, chemical analysis is limited to alcohol concentration, pH, and darkness. Alcohol concentration can be determined through a couple different means. The home brewing standard is to utilize a hydrometer. This device is designed to measure viscosity before and after fermentation, through the buoyancy of a hydrometer. The difference in viscosity can be used to calculate percent alcohol change. This can be calculated because water and alcohol have different densities. Another industry standard is the use of an ion specific
electrode. The initial investment is expensive, but this tool is much more accurate than a hydrometer. Bitterness is another quality measured by the industry. This is done through pH. High pH indicates a more bitter beer. The pH can be determined through a number of means including: pH meter and pH paper. Lastly, the darkness of the beer can be assessed using a spectrometer. This machine allows quantitative analysis of transmittance values. These values can be used for a measure of darkness. These values have been tabulated below for the reader’s convenience.

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Saison</th>
<th>Brown Ale</th>
<th>Extra Special Bitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>540</td>
<td>71%</td>
<td>62%</td>
<td>64%</td>
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<tr>
<td>580</td>
<td>75%</td>
<td>64%</td>
<td>66%</td>
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<tr>
<td>600</td>
<td>76%</td>
<td>64%</td>
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</tr>
<tr>
<td>640</td>
<td>77%</td>
<td>66%</td>
<td>68%</td>
</tr>
<tr>
<td>AVG</td>
<td>75%</td>
<td>64%</td>
<td>66%</td>
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<td>3.5</td>
<td>4</td>
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<table>
<thead>
<tr>
<th>Alcohol (percent by volume)</th>
<th>Saison</th>
<th>Brown Ale</th>
<th>Extra Special Bitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.20%</td>
<td>4.90%</td>
<td>5.20%</td>
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**Home Brew Specifics:**

The Extra Special Bitter is the lightest of the three beers with an average transmittance value of 66% from wavelengths of 540-640nm. Being that this was a lighter beer, I would have expected to see the Extra Special Bitter have the highest transmittance values. However, the
decreased transmittance value could have been influenced by beer particulate in suspension. Being that this is an extract kit, it is also possible that the brewers had protein rich wort. If this was true, the expedient addition hops during boiling could form protein-tannin complexes. Furthermore, this beer was brewed with a lot of hops. From the name of the beer, “bitter” can be used as a clue to what its pH should be. Extra Special Bitters are heavily hopped, swaying the pH and preserving the beer. This beer had a pH of 4.0. Lastly, we have percent alcohol. Our hydrometer data indicated that this beer had an alcohol content of approximately 5.2 percent by volume. This value is obtained from the use of two readings; an initial reading before fermentation and a final reading after fermentation. The change in density directly correlates with the yeast’s alcohol production. Lastly, this beer had a good level of carbonation, but its head retention was lacking. This means that this beer was cooked for too long at 120 – 130 degrees Fahrenheit. Essentially, this means that too many proteinases were extracted during the mash. This being said, the Extra Special Bitter was a smoother beer with strong character from the aroma hopping. The tabulated ingredients for this brew are listed below.

**Extra Special Bitter**

- Simpsons Medium Crystal – 1 lb
- Gold Malt Syrup – 6.30 lbs
- Willamette Hops – 2 oz
- Kent Goldings Hops – 2 oz
- Wyeast 1968 London ESB Yeast Packet (Dry)
The Nukey Brown Ale is the darkest of the three beers with a transmittance value of 64\% from the wavelengths of 540 – 640nm. This was the lowest of the transmittance values, meaning that the least amount of light passes through this beer. This beer contains a lot of malt and should taste similar to a Newcastle Brown Ale. This beer’s pH was around 3.5. Despite its darkness, this Brown Ale has a relatively low alcohol percentage at 4.9 percent. Although this beer was slightly over carbonated, it had brilliant head retention. This means that the proteins are still intact. Also, this means that slightly too much priming sugar was used to carbonate the beer. Over all, this was my favorite of the three. This beer has a lot of character, yet the subtle sweetness of the malt makes it easy to drink. The tabulated ingredients for this brew are listed below.

**Nukey Brown Ale**

- English Maris Otter Pale Malt – 9 lbs
- Simpsons Dark Crystal - .25 lbs
- Simpsons Chocolate Malt - .25 lbs
- Weyermann CaraRed - .25 lbs
- Fuggle Hops – 1 oz
- Wyeast #1098 British Ale Yeast (Liquid)

Lastly, the Saison wheat is a Belgium Style beer with transmittance value of 75\% from 540 – 640nm. Although the color of this beer is of a medium darkness, the transmittance value indicates that this is the lightest beer. More than likely, this is an accurate value for this beer. Furthermore, this beer did not have any visible suspension of particulate. For this reason, the
Saison transmits more light than the Extra Special Bitter. This wheat beer is heavily hopped to give a slightly bitter taste. This beer’s pH was measured to be approximately 3.5. The Saison is typically a low alcohol beer with as low as 3% alcohol. This brew ended up being 4.2% alcohol after examination of hydrometer readings. This beer was drastically over carbonated. On multiple occasions, bottles exploded in the room due to excess carbonation and pressure. This was due to the addition of too much priming sugar. Furthermore, this raises the point of utilizing force carbonation. With force carbonation, carbon dioxide is pumped into the keg at a specific desired pressure. This eliminates any variation caused by yeast inactivity. The tabulated ingredients for this brew are listed below.

**Saison Wheat**

- Belgian Pale Malt – 10 lbs
- Briess Caramel 20 - .75 lbs
- Strisselpalt Hops – 3 oz
- Wyeast #3522 Belgian Ardennes Yeast Packet (Liquid)

To sum it all up, this compilation has covered the basics of home brewing and the chemistry behind it. This work was created to reflect my personal home brewing experience, while showing others that home brewing is a very tangible thing. By breaking down the science behind brewing, I hope to bridge the gap between the consumption and production of beer.
References


