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What makes beers different from each other?

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One might imagine that since beer has been around for thousands of years, all of its secrets and intricacies would have been unlocked by now and that there is little research left to be done. In fact, very much the opposite is true. One major overarching theme in much of this article is what causes us to perceive different varieties of beer as distinct and why we might enjoy some but not others. Before diving into the cutting edge research on one of man's oldest beverages, let us take a moment to review how beer is actually made.

Beer is more or less made from a solution of water, hops, and grain extract that has been boiled and allowed to ferment with yeast that converts the sugars from grain extract into alcohol and carbon dioxide. The hop plant is a distant relative of modern conifers and has been used in the brewing process since the middle ages. The oils (also known as hop acids) present in its cones are extracted in the boiling process and lend flavoring and a desirable level of bitterness. The grains favored by brewers are malted barley or wheat for their high content of maltose (a type of sugar). Maltose is broken down to glucose by the enzyme amylase during the boiling process. Brewer's yeast is added in after the boiled solution of sugar and hops, known as wort, is cooled, and is then allowed to work its magic, turning glucose and other sugars into alcohol and carbon dioxide, which carbonates the beer.

Over the course of thousands of years, a countless number of varieties based on this simple recipe have been created by making incremental tweaks. Different beers vary because their recipes are different, but from the consumer end all that matters is the perception of one beer versus another; thus, much research has been devoted to this end. Everything from fermentation temperature, byproducts of fermentation, and addition of hops, to container type and conditions of storage, temperature of tasting, and interactions of chemical compounds that modulate taste, are parameters that brewers and researchers alike consider when trying to understand and improve this already amazing beverage.

> "About 8,000 years, probably. I like to say it's the basis of civilization, and when people first realized they could make beer, they stopped wandering"

Beer has a fairly high caloric content (mainly due to alcohol and carbohydrates) so one target researchers have is to and reduce the number of calories (Wang, et al., 2010). When carbohydrates are converted into alcohol, some of the complex sugars cannot be easily broken down by yeast (notably maltotriose) and remain in the beer, adding to the caloric content and leading to potentially unwanted flavors (Wang, et al., 2010). Other compounds such as acetaldehydes, diacetyls, and pentanedione can contribute undesirable flavors at high enough concentrations (Wang, et al., 2010). As a result, researchers in China have worked to genetically engineer a strain of yeast to help lower both the caloric content and some of these undesirable compounds. The yeast strain used in this study was endowed with the gene for the enzyme amylase, which helps break down some of these more complex sugars, thereby lowering the sugar content (Wang, et al., 2010). The production of acetaldehyde, which lends an unpleasant flavor, was decreased by about half by disabling one copy of the gene that codes for alcohol dehyrogenase (Wang, et al., 2010). This disrupts the metabolic pathway that results in acetaldehyde. Similar results were seen when other

Figure 1. Beer is one of the oldest beverages created by man.

genes related to undesirable compounds were disabled (Wang, et al., 2010). By adding two genes into the yeast's repertoire that aid in breaking down complex sugars, the final sugar content was lower after fermentation with the transformed yeast than after fermentation with the wild type industrial brewer's yeast. When put to a taste test, the beer brewed with the new strain of yeast was proclaimed to taste better than beer from wild type yeast due to the lower acetaldehyde content of the beer (Wang, et al., 2010).

In addition to the yeast, there are many other subtle chemical factors that alter the taste of beer. For example, dissolved solutes in the water that are used to brew beer (notably ions such as calcium and sodium) can affect the pH and taste of the beer (Bamforth, "Searching For Science In A Glass of Beer", 2010). More serious beer connoisseurs will have probably noted that many beers have vanilla-like or other spicy or exotic flavors. Similar flavors in other foods can be attributed to monophenols (Sterckx, Missiaen, Saison, & Delvaux, 2010). These monophenols have been known to be present in beer but (until recently) in an undefined capacity. Many of these compounds are present around the flavor threshold, which is the concentration above which humans can perceive a taste as different from others (Sterckx, Missiaen, Saison, & Delvaux, 2010). Accordingly, individual levels of sensitivity to certain compounds will cause some flavors to be perceived more strongly for some people rather than others, resulting in various flavor combinations that taste different to each individual. Researchers found that different combinations of monophenols result in diverse flavors due to synergistic, antagonistic, and additive interactions between flavor compounds (Sterckx, Missiaen, Saison, & Delvaux, 2010). Additionally, they argue that monophenols with similar structures tend to have stronger additive effects than ones that have different structures, likely due to additional interactions (Sterckx, Missiaen, Saison, & Delvaux, 2010). Ultimately, researchers concluded that the flavor threshold measurement is only a guideline as far as beer is concerned, as there is a wide range of taste sensitivities as well as interactions between compounds which seem to magnify taste greatly (Sterckx, Missiaen, Saison, & Delvaux, 2010). They also characterized monophenols as being the actual source of smoky, spicy, vanilla, flavors in beer (Sterckx, Missiaen, Saison, & Delvaux, 2010).

"Different beers vary because their recipes are different, but from the consumer end all that matters is the perception of one beer versus another"

Figure 2. Hops are added for both their bitter and floral taste qualities.

When thinking about taking a swig of beer, what is the first thing that hits you after the taste? It is all those tiny bubbles of carbon dioxide that we crave so much in soft drinks and alcoholic beverages alike. The bubbles from CO2 activate mechanoreceptors in the mouth while the conversion of CO2 to carbonic acid elicits a tingly response via nociceptors (Clark, Hewson, Bealin-Kelly, & Hort, 2011). The activation of these receptors in our mouths brings us pleasure and leaves us wanting more. It is reasonable to expect this since studies have shown that carbonation increases drinkability and thirst quenching ability in both beer and soda (Clark, Hewson, Bealin-Kelly, & Hort, 2011). At the same time, though, CO2 does not act in a vacuum; rather, there are many complex interactions between the many chemical components of beer. A group from the UK found that hop acids interact with CO2 to increase the tingly sensation caused by CO2 even at low CO2 concentrations (Clark, Hewson, Bealin-Kelly, & Hort, 2011). This is a rather interesting finding, considering hop acids are the main contributors to astringency but do not directly interact with the same mechanical receptors as CO2 (Clark, Hewson, Bealin-Kelly, & Hort, 2011). One of the other sensations associated with drinking any alcoholic beverage is the warming sensation caused by the ethanol content. When combined with hop acids and CO2, though, the warming sensation is attenuated (Clark, Hewson, Bealin-Kelly, & Hort, 2011). Additionally, they found that depending on the concentration, ethanol elicits either a sweet or bitter taste that can have an additive affect when combined with other compounds present in beer (Clark, Hewson, Bealin-Kelly, & Hort, 2011). They reasoned that since both have similar taste transduction pathways, a slight tweak in the sensory input can easily change the perceived taste (Clark, Hewson, Bealin-Kelly, & Hort, 2011). Their final conclusion is that ethanol has some modulating effect on all of the other flavor contributors, and that the ethanol itself interacts with many receptors in the mouth (Clark, Hewson, Bealin-Kelly, & Hort, 2011). Ethanol is thus considered to be the source of much of the complexity in beer flavor.

Beyond the chemical compounds and their interactions are physical factors that affect the taste and perception of beer. This undoubtedly leads us to ask a question that Americans and Europeans have been feuding over for ages: should beer be warm or cold? This simple temperature preference that has long polarized drinkers on opposite sides of the Atlantic may now be debunked with new research out of Canada. The group studied the relationship between taste and temperature. Oral sensation varies within the population according to many factors including age, sex, health status, and psychological and physiological factors (Pickering, Bartolini, & Bajec, 2010). The oral perception of beer has a fairly large bearing on the taste and overall experience of drinking beer. One of the variations in taste sensation among the population is called the thermal taster status (TTs) in which people report phantom flavors when parts of the tongue are subjected to different temperatures (Pickering, Bartolini, & Bajec, 2010). Those who do not exhibit this ability are dubbed thermal non-tasters (TnTs). TTs and TnTs also differ in that TTs tend to have a stronger response to oral stimuli in general (Pickering, Bartolini, & Bajec, 2010). A Canadian research group confirmed that the TT response applies in beer and found that TTs do tend to report flavors (sweetness, sourness, bitterness, astringency, and overall flavor) in beer as being stronger than TnTs do (Pickering, Bartolini, & Bajec, 2010). Alcohol did not seem to make a difference because it is present in beer in concentrations too low for TTs and TnTs to perceive a difference (Pickering, Bartolini, & Bajec, 2010). Interestingly, the group discovered that despite the difference in perceived taste intensity, there is no difference between TTs and TnTs in their enjoyment (taste-wise) or their ranking of the beers (Pickering, Bartolini, & Bajec, 2010). Given this, one can argue that the whole dispute over warm versus cold beer is less about the actual taste, regardless if one is a thermal taster or not, but more about long standing traditions rather than any real difference in enjoyment despite differences in perception of the beers.

Speaking of issues that polarize beer drinkers, consider the containers that beer is packaged in.
Walking into your local supermarket, you will see a vast variety of beer, yet only glass or aluminum packaging. No plastic beers bottles are to be found anywhere. Beer connoisseurs tend to believe that glass is the only real way to pack beer, while others enjoy the convenience of cans. While the battle between can versus bottle rages on, no one seems to advocate for the plastic bottle that is so ubiquitous in the realm of soda and bottled water. One would imagine that the benefits of minimal waste and lower production and shipping costs would be enough to send brewers running for plastic (Bamforth, "Plastic: Too Drastic for Beer", 2010). Charlie Bamforth, who is hailed as one of the leading experts in the brewing field, has an answer for us. Beer tends to take on an unpleasant taste after being exposed to light because the flavor compounds lent by the hops are degraded by UV light into sulfurous compounds. Limiting of light exposure is one reason why beer is stored in low light brown bottles or cans. Cans are actually even better than bottles because they keep out all light and air, increasing shelf life. Plastic on the other hand, allows for much more unwanted gas exchange and has a tendency to absorb flavor from beer. PET plastic allows oxygen to seep into the beverage which is fine for soft drinks as they can tolerate oxygen at 20-40 ppm, whereas beer can only tolerate 0.1ppm oxygen. On top of that, carbonation is readily lost through plastic and even 10% loss of CO_2 for beer adversely affects flavor. Plastic also has the possibility of leeching plastic molecules into the beer, which is potentially hazardous, and anyone who has kept water in a plastic bottle for long enough knows that the plastic gives off an undesirable flavor (Bamforth, Plastic: Too Drastic for Beer, 2010). In the end though, it is not all about what makes beer taste better on a molecular level. There is a certain amount of nostalgia that keeps people going back to glass and cans as opposed to plastic.

"The oral perception of beer has a fairly large bearing on the taste and overall experience of drinking beer"

In addition to the actual packaging of beer, transportation can also have an effect on the beer's final condition by the time it makes it to the consumer. The brewer faces many challenges in transporting the beer as we saw with the packaging of beer. Researchers at Cambridge decided to try to quantify a difference in enjoyment a function of shipping distance. They traveled the world sampling Guinness everywhere from Dublin to America. Their ultimate findings pointed to shipping distance as not being as much of a factor, as the environment in which the beer was served (Kotz, Glynn, Mallen, & Cals, 2011). The bartender, other patrons and general vibe of the bar seemed to really make or break the experience as a whole (Kotz, Glynn, Mallen, & Cals, 2011). This might explain why Ireland, known for its strong pub culture, came out on top.

The big point here is that while the chemistry of beer plays a large role in making beers different from each other, ultimately, our perceptions of them are what really matter. Those perceptions, in turn, are caused by the different chemistry and the biological variation that exists between people. Thus, in reality, it is impossible to focus on only the hard science or the varying human perception. For you and me though, all that matters is that the two work together harmoniously while you enjoy a cold one. Cheers!

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Figure 3. Plastic is not fit for bottling beer.

"Cans are actually even better than bottles because they keep out all light and air, increasing shelf life"