BREW BETTER BEER WITH HONEY

The beer industry has changed. Brewers are pushing the boundaries of flavor and taste; consumers are committed to trying anything at least once. It's the perfect situation for craft brewers to thrive.

It's also the perfect situation for brewing with honey. This all-natural ingredient changes the outcome of the final recipe and marketing strategy in many ways, including:

- **Want your beer to have depth and a complex flavor profile?**
  Add a dark varietal during the boil.
- **Want a sweet finishing note on your holiday beer?**
  Add honey at the last stages of the boil.
- **Want to bottle condition your beers?**
  Add honey.
- **Want a unique market position and labeling that stops shoppers in the beer aisle?**
  Use honey iconography on your cans and bottles.

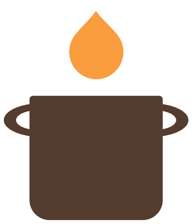
There are plenty of reasons to brew with honey. Flavor, function and marketing are just the start.

Are Honey Beers Sweet?

Let's get this question out of the way. Honey beers can be sweet but not always. Honey's carbohydrates are more than 95% fermentable and adding honey early in the brewing process will yield a product with no residual sweetness.

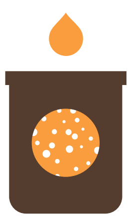
The strength of the honey flavor in honey beer depends upon four major factors: the stage of the brewing process at which the honey is added; the type of beer; the quantity of honey used; and the type of honey used.

Adding honey during...



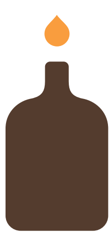
The Boil

Since honey is 95% fermentable, most of the sweetness in honey will be lost unless added at later stages in the boil. If you want a subtle honey flavor, add honey between 10 to 30 minutes left in the boil. To best preserve the aromatics of honey and obtain a stronger honey flavor, pre-process honey at low temperatures and add it at the end of the kettle boil so it is exposed to high temperatures for a minimal amount of time.



Cooling or Primary Fermentation

The benefits of adding honey during these brewing stages include a stronger honey flavor and a boost in gravity. Honey also will help lighten the body of the brew and raise the ABV.



High Krausen

Honey added at this stage will provide a strong honey flavor and help soften any bitter notes in the beer.

Packaging

Honey will provide carbonation after bottling, and also impart a strong honey flavor. If using honey in this manner, it's recommended to boil honey in a water solution, pour the solution into the bottom of the bottling bucket and rack beer on top.

TECHNICAL PROFILE OF HONEY

"Honey is the natural sweet substance produced by honey bees from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honey comb to ripen and mature."

—From **Codex Alimentarius**

The natural process that produces honey has likely existed for 100 million years. But even for the European honey bee (Apis mellifera), the nectar the insect creates is extremely unique and has properties not found in other foods. Honey is classified as a sweetener, but it is so much more than that.

Honey is the substance made when the nectar and sweet deposits from plants are gathered, modified and stored in the honeycomb by honey bees. The definition of honey stipulates a pure product that does not allow for the addition of any other substance. This includes, but is not limited to, water or other sweeteners.

Composition

Honey is comprised primarily of fructose (38.2%), glucose (31%) and water (17.1%). However, the remaining 13.7% of honey provides brewers with some remarkable benefits. Among those components are a variety of other sugars, enzymes, amino acids, antioxidants, vitamins and minerals. It is this unique blend that gives honey its functional advantages.

Honey, on average, has a pH of 3.9. This acidity can work to enhance flavors, and inhibit mold and bacteria growth. The amino acids that give honey its low pH also serve as precursors to honey's antimicrobial capabilities.

	AVERAGE	RANGE
Fructose/Glucose ratio	1.23	0.75 to 1.86
Fructose	38.37%	30.91% to 44.26%
Glucose	30.31%	22.89% to 40.75%
Minerals (ash)	0.169%	0.020% to 1.028%
Moisture	17.2%	12.4% to 22.9%
Reducing sugars	76.75%	61.39% to 83.72%
Sucrose	1.31%	0.25% to 7.57%
Total acidity meq/kg	29.12	8.68 to 59.49
True protein mg/100g	168.6	57.7 to 567

Sweetness

Given the sugars that comprise honey, it is slightly sweeter than sucrose and can be used in smaller quantities than other similar ingredients. The primary carbohydrates that comprise honey include fructose, glucose and maltose, with just a small amount of sucrose. The combination of these sugars produces an ingredient that is naturally sweeter than sucrose. In fact, some honeys contain significantly more fructose than maltose, making them up to 25% sweeter than sucrose.

Honey's Moisture Content

The moisture content of honey varies considerably throughout the year, by region and by floral source. On average, honey's moisture content is about 17%. As long as the moisture content remains below 17%, honey will not spoil. Honey's low pH and antibacterial properties prevents bacterial growth.

Honey Color Designation

The colors of honey form a continuous range from water white to dark amber, and is related to its mineral content and is characteristic of its floral source. Light colored honey typically has a mild flavor, while dark colored honey is usually stronger in flavor. The Pfund color grader measures the color of honey.

COLOR NAME	PFUND SCALE (MM)	OPTICAL DENSITY*
Water White	< 8	0.0945
Extra White	9-17	0.189
White	18-34	0.378
Extra Light Amber	35-50 a	0.595
Light Amber	51-85	1.389
Amber	86-114	3.008
Dark Amber	> 114	-

* Optical density (absorbance = 100/percent transmittance), at 560 nm for 3.15 cm thickness for caramel-glycerin solutions measured versus equal cell containing glycerin.

HONEY STORAGE GUIDELINES

Honey's moisture content (about 17%), low pH and antibacterial properties make it one of the only ingredients that will most likely not go bad. Regardless, it is still very important to store honey properly to maintain its integrity.

Best stored in a sealed container at room temperature, between 64-75°F (18-24°C)

- Cooler temperatures, between 35-60°F, hasten honey's natural crystallization process
- Honey stored at temperatures above 85°F for extended periods of time will darken in color and be subject to subtle flavor changes

300 VARIETALS OF HONEY.

300 Opportunities
To Brew A Unique Beer.

There are more than 300 unique kinds of honey in the United States, originating from such diverse floral sources as Clover, Eucalyptus and Orange Blossoms. This simple yet complex variety of flavors allows brewers to develop unique beers with complex flavor profiles.

Alfalfa

Alfalfa is a legume with blue flowers. It blooms throughout the summer and is ranked as the most important honey plant in Utah, Nevada, Idaho, Oregon and most of the western states. Alfalfa honey is white or extra light amber in color with a fine flavor. The honey also has good body, which makes it a perfect table honey.

Avocado

Avocado honey is gathered from California avocado blossoms. Avocado honey is dark in color, with a rich, buttery taste.

Basswood

This tree is distributed from Southern Canada, to Alabama, to Texas. Basswood honey is often characterized by its distinctive biting flavor. The flowers are cream-colored and they bloom in late June and July. The honey is water-white with a strong flavor.

Blueberry

Taken from the tiny white flowers of the blueberry bush, the nectar makes a honey, which is typically light amber in color and with a full, well-rounded flavor. Blueberry honey is produced in New England and in Michigan.

Buckwheat

Buckwheat plants grow best in cool, moist climates. The buckwheat plant prefers light and well-drained soils, although it can thrive in highly acid, low fertility soils as well. Buckwheat is usually planted in the spring. It blooms quite early and it yields a dark brown honey of strong, distinct flavor.

Clover

Clovers are the most popular honey plants in the United States. White clover, alsike clover, and the white and yellow sweet clover plants are the most important for honey production. Depending on location and source, Clover honey varies in color from water-white to extra light amber and has a mild, delicate flavor.

Eucalyptus

Eucalyptus is one of the larger plant genera with over 500 distinct species and many hybrids. Eucalyptus honey varies greatly in color and flavor, but in general, it tends to be a bold-flavored honey with a slightly medicinal aftertaste.

Fireweed

Fireweed honey is light in color and comes from a perennial herb that affords wonderful bee pasture in the Northern and Pacific states and Canada. Fireweed grows in the open woods, reaching a height of three to five feet and spikes attractive pinkish flowers.

Orange Blossom

Orange Blossom honey is often a combination of citrus floral sources. Orange is a leading honey source in southern Florida, Texas, Arizona and California. Orange trees bloom in March and April and produce a white to extra light amber honey with a distinctive flavor and the aroma of orange blossoms.

Sage

Sage honey can come from different species of the plant. Sage shrubs usually grow along the California coast and in the Sierra Nevada mountains. Sage honey has a mild, delicate flavor. It is generally white or water-white in color.

Sourwood

Sourwood trees can be found in the Appalachian Mountains from Southern Pennsylvania to Northern Georgia. Sourwood honey has a sweet, spicy, anise aroma and flavor with a pleasant, lingering aftertaste.

Tulip Poplar

The tulip poplar is a tall tree with large greenish-yellow flowers. It generally blooms in the month of May. Tulip Poplar honey is produced from southern New England to southern Michigan and south to the Gulf states east of the Mississippi. The honey is dark amber in color, however, its flavor is not as strong as one would expect from a dark honey.

Tupelo

Tupelo honey is produced in the southeastern United States. Tupelo trees have clusters of greenish flowers, which later develop into soft, berrylike fruits. In southern Georgia and northwestern Florida, tupelo is a leading honey plant, producing tons of white or extra light amber honey in April and May. The honey has a mild, pleasant flavor and will not granulate.

Go to www.HoneyLocator.com to find a honey supplier!

BREWING WITH HONEY

The rapid growth of the craft beer industry is only being matched by increased demand from consumers for beers made with honey. Honey is the perfect ingredient for craft brews, providing flavor, functional and marketing benefits. From seasonal offerings to foundational brews, honey is finding its way into stouts, spice beers, ales, light beers and lagers.

This technical research presents an overview of the chemical and microbiology of honey viewed from a brewer's perspective. In terms of honey's composition, the ingredient represents a natural source of extract with a very high degree of fermentability. It represents a rich and diverse source of color and flavor for brewers. And, honey contains an interesting source of enzymes, metals and microorganisms.

The use of honey presents a great opportunity for continued beer innovation. Honey beer is already a recognized category in major competitions such as the Great American Beer Festival. And in 2015, the honey beer category received 52 entries, which is more than other beer styles such as a Vienna Lager and Pilsner.

The following research analyzes the composition of honey as it relates to brewing beer. This is the first step in understanding how to brew better beer with honey.

Carbohydrate Profile

Honey contains about 82.4% carbohydrates, and of these, about 90% to 98% of the carbohydrates in honey are fermentable.

Table 1 illustrates this in more detail, comparing one particular sample of honey to the wort carbohydrate profile of two different beer styles.

TABLE 1: AN EXAMPLE OF HONEY VS BREWER'S WORT CARBOHYDRATE PROFILES

	HONEY	EUROPEAN LAGER WORT	BRITISH PALE ALE WORT
Fructose	46.2%	2.0%	3.5%
Glucose	37.8%	8.9%	10.6%
Sucrose	1.6%	2.2%	5.6%
Maltose	8.8%	51.1%	41.3%
Maltotriose	3.6%	12.5%	12.1%
Maltotetraose	0.2%	2.5%	2.1%
Higher Sugars	1.8%	20.8%	24.7%

Within the fermentable sugars, there is a much higher level of fructose and glucose and lower level of maltose and maltotriose. Importantly, the level of higher molecular weight carbohydrates, which are not fermentable by brewing yeast, is much lower for honey than for these two examples of brewing wort.

The use of honey as part of the recipe for a beer will result in an increased level of fermentability. This higher fermentability can provide for a lighter body and drier finish in the beer. If the brewer wishes to partially compensate for that impact, they can change the mashing schedule, moving some or all of the time spent at 140-150°F to time spent at 158°F.

If you were to make a honey beer starting from an existing wort recipe, and decide to add the honey at the end of kettle boil, the fermentability of the finished wort can be calculated from the fermentability of that wort prior to honey addition and from the fermentability of the honey used. Each number should be weighed by the extract percentage contribution to the finished wort.

For example, if the honey is 94.4% fermentable and the wort (pre-honey) addition is 76.7% fermentable, the finished wort fermentability will increase to approximately 78.5% if honey is added at a rate of 10% of the total extract in the finished wort. This change of a less than 2% fermentability is small, compared to the width of the ranges of fermentability seen in the Brewers Association Beer Style Guidelines for specific beer styles.

Ranges in these guidelines for some styles are close to 20%. Addition of honey at rates of 10% or 20% of the total extract, therefore, would likely not bring fermentability out of these Guidelines' ranges.

There are some possible implications to the high glucose and high fructose concentrations in honey to brewery fermentations. High levels of glucose in wort can trigger catabolite repression on maltose utilization. This means that brewing yeast will show a defined ordered sequence of sugar utilization, such that they will preferentially first use glucose and fructose, followed then by maltose, and lastly, maltotriose. However there is some degree of overlap in this sequential approach.

It should also be noted that sucrose is hydrolyzed by invertase at the cell surface to glucose and fructose, so for practical purposes we can think of sucrose as essentially a source of glucose and fructose (which will be utilized preferentially by the yeast over maltose and maltotriose). Maltose and maltotriose are hydrolyzed within the cell to glucose through maltase, but this begins to happen after most of the glucose and fructose have been consumed.

Interestingly, brewing yeasts tend to show a higher affinity for glucose than fructose. Prior growth on glucose or fructose does not produce a significant repression effect on the uptake of either of these two sugars, and it has been reported that they share the same membrane transport components. The reason focus is given to the topic of the sequential utilization of different sugars by brewing yeast is that the timing of the addition of honey (e.g. at the start vs mid-fermentation) can impact the dynamics of the fermentation.

The sweetness of honey is driven not only by its high percentage of sugars, but also by its high percentage of fructose. While fructose and glucose are both monosaccharides, fructose has been found to be sweeter, reaching a higher peak of sweet taste. Of course, this does not become a factor in beer taste if honey is fully fermented out by the yeast. But, residual amounts of honey in the finished beer can increase the perceived sweetness. Honey's typical solids concentration is high, and with about 17% moisture, it is stable. In other words, spontaneous fermentation on honey will not occur.

Polyphenols

Polyphenol levels vary for different types of honey. This is illustrated in Table 2, where we see that light-color honeys can have a polyphenol level of about half of that of dark-color honeys.

Polyphenols are important for beer, as they are flavor-active, have antioxidant properties, and can influence flavor stability. They also are involved in physical (haze) stability. There are, however, two major sources of polyphenols in beer: malted barley and hops. The question arises, then, how much of a polyphenol contribution would honey provide?

Beer polyphenol levels are in the range of 200 to 400 mg/L. If one were to add honey at a rate of 10% of the total extract, the polyphenols level in the finished beer would increase by only a modest 5% to 8% in the finished beer. Therefore, the impact of honey addition to the level of polyphenols in beer is small.

TABLE 2: POLYPHENOL LEVELS IN HONEY

COLOR TYPE	COLOR (MM PFUND)	POLYPHENOLS (MG/KG)
White	31	250
Extra Light Amber	35	269
Extra Light Amber	39	292
Extra Light Amber	42	274
Light Amber	56	303
Light Amber	71	305
Dark Amber	151	548
Dark Amber	156	444
Dark Amber	160	535
Dark Amber	167	509

Nitrogen Compounds

Nitrogen compounds are of interest to brewers for a number of reasons. For instance, they have an impact in yeast metabolism, and they also have a role in beer turbidity or haze, as well as in foam stability. The use of adjuncts in brewing often, although not always, results in a decrease in nitrogen compounds in wort and finished beer.

In the case of honey, the levels of nitrogen compounds are relatively low compared to malted barley. In honey the levels are about 0.04% to 0.2%, while in malted barley the levels are typically in the range of 1.5% to 2.5% (on a dry basis).

Many of the amino acids found in honey are similar to those in malted barley: Proline, Lysine, Histidine, Arginine, Aspartic acid, Threonine, Serine, Glutamic acid, Glycine, Alanine, Cysteine, Valine, Methionine, Isoleucine, Luecine, Tyrosine, Phenylalanine, Tyrptophan.

Overall, the use of honey as a partial replacement of malted barley will result in a decrease in the wort and final beer's nitrogen content. However, at low to moderate honey usage rates, this decrease would not represent a yeast nutrition issue. For instance, large volumes of beer are successfully produced with adjunct levels of 30% or even 40%

Enzymes

The four major enzymes in honey are: invertase, amylase, glucose oxidase and catalase.

Invertase

Invertase splits sucrose into simple sugars (fructose and glucose), and also is generated by the yeast. Its optimum activity temperature appears to be near 122°F. Beyond that point, its activity decreases exponentially and of course it would not survive wort boiling, and likely would not survive pasteurization. In fact, the level of invertase has been suggested as a way to determine if a beer sample has been pasteurized or not.

Diastase

Diastase or amylase is another enzyme present in honey. This enzyme breaks starches into sugars and dextrins. Similar to invertase, it is heat labile and would not survive wort boil. Its level was used by the honey industry as a marker to assess the heat exposure that honey has been subjected to. The reported levels of amylase in honey appear to be approximately in the same range of malted barley: 9 to 37 Dextrinizing Units (D.U.) for honey vs 24 D.U. for malted barley. This enzyme level could materially further increase beer fermentability, depending on the level and mode of use of honey (e.g. if honey was exposed to heat or not during the brewing process).

Glucose Oxidase

This enzyme converts dextrose to gluconolactone, which in turn forms gluconic acid, which is the principal acid in honey. It also forms hydrogen peroxide, which is a good antibacterial that helps preserve honey from microbial breakdown. Enzyme activity studies in honey indicate that glucose oxidase is not impacted up to 131°F, but begins to decrease in activity at 158°F. Although those enzymes would not survive wort boil, some of them could survive pasteurization. Some implications of glucose oxidase include binding oxygen, reducing iron and partially inhibiting Maillard reactions, with presumably a positive impact on flavor stability.

Catalase

Catalase is an enzyme that decomposes hydrogen peroxide into water and oxygen. Its activity rapidly decreases at temperatures of 149°F and above.

Metals

Metal content varies significantly between honeys, and there are a number of metals that have an impact in the brewing process and in the flavor of the beer. The difference in metal content in honey is partly responsible for its color differences. Darker honeys have been found to have higher levels of potassium, sodium, magnesium, iron, copper and manganese.

Table 3 provides a summary of the levels of several metals found in honey, as well as in malt, hops, brewing wort and finished beer. The summary focuses on potassium, calcium, manganese, copper, iron and zinc.

Potassium is by far highest in concentration in honey, relative to other metal ions in honey, and also relative to the levels found in beer. So, a brewery can expect to see a higher level of potassium in honey beers.

Calcium levels in malt and honey are equivalent. Iron levels are about ten-fold those found in hops, and this can a potential concern for flavor stability. However, the actual impact will greatly depend on the point of addition of the honey in the brewing process. For instance, if added to wort, some of the metal content may be partially removed in trub, and likewise removed by yeast.

Zinc levels in honey are higher than those in malt or hops. Zinc levels in wort are important for yeast performance during fermentation.

TABLE 3: METAL CONTENT IN HONEY

	IN HONEY (MG/KG)	IN MALT (MG/ KG, DM)	IN WORT (MG/L)	IN BEER (MG/L)	IN HOPS (MG/L)
K	1100 - 21600	-	-	200 - 300	-
Ca	152 - 362	200 - 230	40 - 100	40 - 100	-
Mn	1 - 5	8 - 15	0.07 - 0.14	0.08 - 0.2	60 - 70
Fe	136 - 407	10 - 60	0.1 - 0.5	0.02 - 0.3	15 - 25
Cu	13 - 35	2 - 7	0.02 - 0.4	0.02 - 0.1	-
Zn	31 - 106	10 - 15	0.1 - 0.3	0.00 - 0.02	35 -45

Color

The color of honey is classified by the U.S. Department of Agriculture into seven color categories shown on Table 4. The range of colors in a way is reminiscent of the range of colors one finds in malted barley. The challenge, however, is that the measurement methodologies are different.

In the case of beer color, the Standard Reference Method or SRM measures the attenuation of light at a wavelength of 430 nm when passing through 1 cm of beer. To the absorbance reading, a factor of 12.7 is applied for SRM or a factor of 25 for EBC. EBC readings are, therefore, about twice as the SRM reading.

In the case of honey, color is measured with either a Pfund color grader which operates on the basis of comparing the honey sample to an amber colored wedge. The sample cup used is about 1/8th of an inch in depth. Another measurement methodology for honey is to read the absorbance of the sample at 560 nm.

TABLE 4: THE COLOR OF HONEY

HONEY COLOR	PFUND SCALE (MM)	ABSORBANCE @ 560 NM
Water White	< 8	0.0945
Extra White	9 - 17	0.189
White	18 - 34	0.378
Extra Light Amber	35-50	0.595
Light Amber	51 - 85	1.389
Amber	86 - 114	3.008
Dark Amber	> 114	> 3.1

Hydroxymethyl Furfural (HMF)

One parameter that often is specified in honey is the level of hydroxymethyl furfural (HMF). HMF is formed in a Maillard reaction of hexoses and during caramelization. And, HMF is an important indicator of beer aging or staling. For instance, HMF increases as packaged beer ages, as well as with increased heat exposure (pasteurization, hot warehousing). HMF also is used as an indicator of heat damage during wort boiling, to evaluate different kettle boil technologies.

Specifications for honey often have an upper HMF level of 40 mg/ kg. How the honey has been processed, shipped and stored (prior to and upon receipt at the brewery) will have an impact on the HMF level.

Microbial Profile

The microbial profile of honey is very diverse. Bacillus, Micrococcus and Saccharomyces species have been isolated from honeycombs and adult bees. Bacillus species are most prevalent. Beyond bees, secondary sources that contribute to the level of microorganisms in honey are human contact, processing equipment, the containers used, and air or wind exposure. Due to honey's low pH, pathogen growth is not a concern. And, because of honey's high solids concentration, microorganisms will not grow in honey (while the honey has that high concentration). Organisms will grow, however, once honey is diluted.

This presents a potential challenge and a potential opportunity. If honey is used in the cold side of the brewing process, and if honey is not previously pasteurized, it presents the risk of introducing bacteria and wild yeast. For sour beer production, this represents an opportunity. For most of the other beer styles it is a risk.

BREW BETTER BEER WITH HONEY

PART II:

BREWERY TESTING RESULTS

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SECTION 1

Executive Summary

The first part of this study comprised an overview of the chemical and microbiology composition of honey viewed from a brewer's perspective. This section of the study illustrates how honey can be used at a variety of points in the brewing process, with different results. The beer style targeted for this study was a honey blonde ale.

Two series of brews were conducted. In the first series, an adjustment to the mashing schedule is shown an as option to partially compensate for the higher fermentability of honey. In the second set of brews, the mashing schedule was unchanged, such that the only difference between beers was in the amount and mode of use of honey. Key findings include:

- The fermentable sugar profile of the worts showed a higher percentage of glucose and particularly fructose for the recipes involving honey. Fermentation rates showed some slight differences during most of the fermentation, but all fermentations were completed in approximately the same amount of time. In other words, the impact in the length of the fermentation process was negligible for practical purposes.
- In terms of beer chemistry, the use of honey resulted in slightly lower color, lower pH, higher alcohol and higher degree of fermentation. The difference in alcohol and degree of fermentation were partially compensated (reduced to about half) by the change in mashing schedule.
- In terms of sensory analysis, descriptive data shows statistically significant differences in the beers produced. Attributes impacted included sulfury, estery, body, maltiness, sweetness and overall palate intensities.

This work illustrates how a modest amount of honey used in brewing a honey blonde ale can have a different chemistry and sensory impact on the beer produced depending on where it is added in the brewing process.

Please note that all tables and figures referenced in the report can be found in Appendix A.

Test Brew Series I

Testing was conducted at the Canadian Malting Barley Technical Centre (CMBTC) on its 250 liter (2.1 bbl) brewing system.

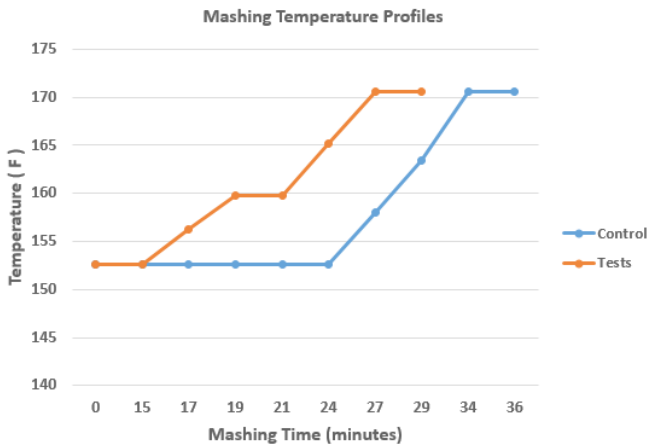
2.1 EXPERIMENTAL DESIGN

The following describes the experimental design used in the first test brew series. A total of four different tests were conducted, as follows:

I. Control Brew
No honey addition and 100% malt. Based on prior experience at CMBTC for brews with a similar fermentability target, mash-in temperature was at 153°F. The mash was held at this temperature for 24 minutes. From there, the mash temperature was raised to 171°F.

II. Test 1
Honey added 5 minutes prior to the end of wort kettle boil. The amount of extract provided by honey is 10% of the total extract. Similar to the Control, mash-in temperature was at 153°F. The mash was held at this temperature for 15 minutes and then ramped to 160°F and held at that temperature until conversion (which took place at 18 minutes). From there, the mash temperature was raised to 171°F. The difference in mashing schedules is illustrated in Figure 1.

FIGURE 1: COMPARING MASHING SCHEDULES: CONTROL VERSUS TEST IN SERIES I



III. Test 2
Brew with honey added at start of fermentation. The amount of extract provided by honey is 10% of the total extract. Mashing schedule was similar to Test 1.

IV. Test 3
Brew with honey added at approximately 48 hours after the start of fermentation. The amount of extract provided by honey is 10% of the total extract. Mashing schedule was similar to Test 1.

2.2 FORMULATION FOR TEST SERIES I

The same type of malt, honey, hops and yeast were used across all four brews. The brew formulation was as follows:

- **Original gravity:** 11.5 - 12.5°Plato (target 12.0°Plato)
- **Final gravity:** 2.3 - 3.0°Plato (target 2.6°Plato)
- **BU:** 15 - 25 (target 20)
- **Color:** 4 to 5°SRM (target 4.5°)
- **ABV:** 4.2 to 5.0% (target 4.6%)
- **Carbonation:** 2.55 to 2.65 V/V (target 2.60 V/V)
- **Malts:**
  A. 2-row pale malt (approximately 80%)
  B. Malted wheat (10%)
  C. Crystal 15 malt (5 to 10% to hit color target)
- **Hops:**
  D. Approximately 60% of the BU to come from Magnum, added at the start of boil.
  E. The other 40% of the BU to come from Willamette. Of the 40%, half (20% of the total) was added 30 minutes prior to kettle knockout and the other half (20% of the total) was added 5 minutes prior to kettle knockout.
- **Honey:** The honey used in this study was Amber Honey. A description of its specification is summarized in Table 1, and its carbohydrate profile is described in Table 2 (for a 12°Plato honey solution).
  F. For Test 1, honey was added directly to the kettle. For Tests 2 and 3, honey was added as a 12°Plato honey solution.
  G. For Tests 2 and 3, the honey solution was prepared as follows:
  A 12°Plato honey solution is made, and then the solution is warmed up to 185°F to 194°F. The solution was held within that range for 5 to 10 minutes and then chilled to the temperature in the fermenter (approximately 63°F).
- **Wort:** The wort was chilled to 63°F, and oxygenated to 8 to 10 ppm.

TABLE 1: HONEY USED IN THE TEST BREWS - CANADA AMBER HONEY SPECIFICATION

Color (mm)	71 to 85
Moisture (%)	< 18.5
pH	pH 3.6 to 3.9
Average density (lbs/gal)	14
HMF (ppm)	< 40
Distase activity	> 3

TABLE 2: ANALYSIS OF A 12°PLATO AMBER HONEY SOLUTION

Fructose (gr/L)	57.98
Glucose (gr/L)	60.94
Maltose	1.10
Maltotriose (gr/L)	7.17
Maltotetraose (gr/L)	0.04

TABLE 3: WORT PH AND COLOR FOR TEST SERIES I

	Wort pH			Wort Color		
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
Control	5.24	5.28	5.26	6.58	5.82	6.66
Test 1 (Honey 5' before KO)	4.96	5.23	5.18	5.62	5.42	6.97
Difference (Test 1 - Control)	-0.28	-0.05	-0.08	-0.96	-0.4	0.31

- **Yeast:** The ale yeast used was WLP001 at a rate of approximately 15 M cells/ml, which was held constant across all four brews.
- **Fermentation:** The fermentation temperature was allowed to rise from the starting 63°F to 66°F. After a hold for diacetyl reduction, the beer was chilled in transfer to maturation. Residence time in maturation was 7 to 10 days. Beer was subsequently filtered.

2.3 TEST RESULTS FROM SERIES I

The tests were conducted in triplicate up to maturation. The following charts highlight the results.

As shown in Table 4, the fermentability of the wort increased, resulting in a lower Apparent Extract (AE) by approximately 0.1 to 0.3°Plato when comparing the Control wort to the Test 1 wort (honey added at the end of boil). In terms of fermentation rate, Table 5 shows that, although the control wort fermented faster in the first five days of the fermentation, the AE was very similar by the sixth day.

TABLE 4: WORT FERMENTABILITY IN FORCED (RAPID) FERMENTATIONS – TEST SERIES (UNITS IN °PLATO)

	Replicate 1	Replicate 2	Replicate 3
Control	2.32	2.35	2.26
Test 1 (Honey added 5' before end of boil)	2.06	2.08	2.14
Difference (Test 1 - Control)	-0.26	-0.27	-0.12

TABLE 5: FERMENTATION PERFORMANCE OF CONTROL VERSUS TEST 1 – TEST SERIES I (UNITS IN °PLATO)

	Replicate Run #1		Replicate Run #2		Replicate Run #3	
Hours	**Control (No Honey Added)**	**Honey Added at End of Kettle Boil**	**Control (No Honey Added)**	**Honey Added at End of Kettle Boil**	**Control (No Honey Added)**	**Honey Added at End of Kettle Boil**
0	11.44	11.35	11.74	11.72	11.34	11.58
24	11.02	11.11	11.23	11.02	10.78	11.16
48	7.65	6.39	7.27	7.49	7.08	7.87
72	4.19	4.92	4.9	5.61	4.48	5.24
96	4.39	4.2	3.55	4.37	2.85	3.81
120	2.53	2.91	2.78	3.51	2.64	3.6
144	2.52	2.59	2.6	2.94	2.64	2.58

Table 6 summarizes the fermentation performance of the three test brews for two replicate runs. The later honey addition resulted in higher AE during the second half of the fermentation. But, the differences at the end of fermentation (day 7) were minimal.

TABLE 6: FERMENTATION PERFORMANCE OF CONTROL VERSUS TEST 1 – TEST SERIES I (UNITS IN °PLATO)

	Replicate Run #1		Replicate Run #2		Replicate Run #3	
Hours	**At End of Boil**	**At Fermentation Start**	**At 48 Hours of Fermentation**	**At End of Boil**	**At Fermentation Start**	**At 48 hours of Fermentation**
0	11.58	11.35	11.69	11.35	11.54	11.83
24	11.16	11.02	11.5	11.11	11.25	10.46
48	7.87	7.27	7.85	6.39	6.71	7.92
72	5.24	4.91	4.95	4.92	5.19	5.68
96	3.81	3.07	3.55	4.2	3.52	4.19
120	3.6	2.61	2.56	2.91	2.66	3.31
144	2.58	2.28	2.27	2.59	2.36	2.84
168		2.21	2.18		2.27	2.61

Table 7 summarizes the beer chemistry at the end of fermentation. Even with the mashing schedule adjustments, the apparent degree of fermentation (ADF) was higher for the test beers by approximately 0.3 to 1.1%, with the corresponding higher ethanol levels (by approximately 0.1 to 0.2% w/w). Color across tests and control was higher than targeted (7 versus 4.5°SRM). The color was lower for the tests using honey (by 0.3 to 0.6°SRM) while color was slightly higher for the test with honey added at the end of boil (by 0.4°SRM), suggesting color formation from the honey added during the end of the kettle boil and the whirlpool. The pH of the beers were lower by about 0.2 units, partly driven by the lower pH of the honey, and partly by the lower amount of buffering substances from the decreased malt bill.

TABLE 7: END OF FERMENTATION BEER ANALYSIS – TEST SERIES I

	Replicate Run #1		Replicate Run #2	
	Control (No Honey Addition)	Honey Added at End of Boil	At Fermentation Start	At 48 Hours of Fermentation
Apparent Extract (°P)	2.4	2.4	2.2	2.4
Ethanol (% v/v)	4.8	4.9	5.0	4.9
ADF (%)	78.8	79.1	80.9	79.4
Calculated OE (°P)	11.4	11.6	11.6	11.7
Real Extract (°P)	4.2	4.2	4.0	4.2
Ethanol (% w/w)	3.7	3.8	3.9	3.9
Color (SRM)	7.7	8.1	7.3	7.1
pH	4.4	4.2	4.2	4.2

SECTION 3

Test Brew Series II

3.1 EXPERIMENTAL DESIGN FOR TEST SERIES II

The experimental design was identical to Series I for the Control and Tests 1, 2 and 3, with one exception: the mashing time-temperature schedule was held constant across all four brews. All beers were filtered, carbonated, packaged and pasteurized.

For Test Brew Series II, a fourth test was added. Test 4 consisted of using some of the unfiltered Control beer after maturation, and then bottle conditioning that beer (in lieu of forced carbonation). The fermentable extract used for bottle conditioning was honey.

The same target for final carbonation was used for Test 4 as for the other test beers. To calculate the amount of honey to add, the following formula was used:

H = V * (Δ CO)/0.25

V represents the liters of beer to be carbonated
Δ CO represents the amount of carbonation to add (in volumes of CO per volume of beer)
H represents the amount of honey to add in grams

For instance, if V = 18.9 liters (for a 5 gallon Cornelius keg) and Δ CO = 0.9 v/v then H = 68 grams of honey.

To pasteurize the honey prior to adding it to the beer to be conditioned, the honey was first prediluted in a small amount of brewing water, warmed up to 185°F, held at that temperature for 5 minutes, and quickly chilled to about 41°F. The honey solution was then added to a Cornelius keg and hand bottled. The filled bottles were not pasteurized.

3.2 FORMULATION FOR SERIES II

The formulation targets were the same for Test Series II, relative to Series I.

3.3 TEST RESULTS FROM SERIES II

Table 8 provides a comparison of the fermentable sugars in wort without honey added in the brewhouse versus wort made with honey addition at the end of boil (Test 1). Finished (cold) wort samples were analyzed by High Performance Liquid Chromatography (HPLC), and the table shows the percentage of each sugar relative to the total fermentable sugars (i.e. the total of maltotriose, maltose, glucose and fructose). As it would be expected from the honey sugar profile previously described in Table 2 (Page 5), fructose and glucose represent a higher percentage of the total fermentable sugars for the wort containing honey. While the difference is modest (i.e. maltose continues to be over half of the total fermentable sugars), this difference would grow if a higher percentage of the total extract comes from honey.

TABLE 8: WORT FERMENTABLE SUGAR PROFILE – PERCENTAGE OF FERMENTABLE SUGARS

	Test Series I			Test Series II		
	No Honey Addition	Honey at Kettle Knockout	Difference (Honey - No Honey)	No Honey Addition	Honey at Kettle Knockout	Difference (Honey - No Honey)
Maltotriose	15.4%	18.4%	3.0%	14.4%	20.3%	5.9%
Maltose	56.6%	64.1%	7.5%	59.7%	71.5%	11.8%
Glucose	18.5%	16.2%	-2.3%	14.4%	8.1%	-6.4%
Fructose	9.4%	1.2%	-8.2%	11.5%	0.1%	-11.3%

Figure 2 summarizes the fermentation performance of the Control brew compared to Test 1 (honey added in the kettle). Fermentation rates are very similar, with a slight faster performance for the Control in the first three days of fermentation (similar to what was observed in Series I), and a slightly lower apparent extract reached for Test 1 at the end of fermentation.

FIGURE 2: FERMENTATION ATTENUATION CURVES FOR TEST IN SERIES II (CONTROL VERSUS HONEY ADDITION IN THE KETTLE)

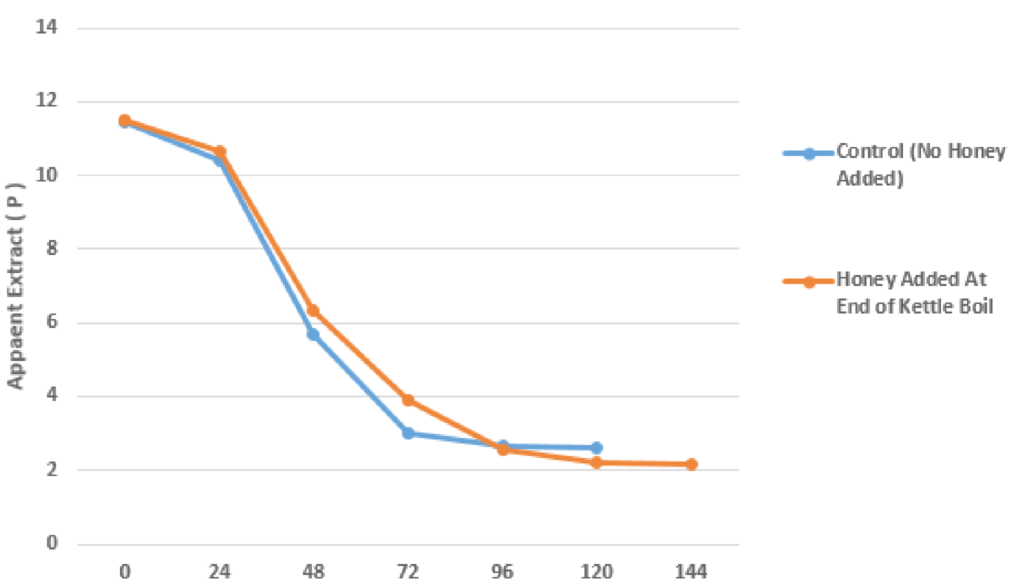


Figure 3 compares Test 2 versus Test 3. In this test, the fermentation rates are also similar, with Test 3 (i.e. honey added 48 hours into the fermentation) having the faster performance during most of the fermentation, but the difference in apparent extract at the end of fermentation was minimal.

FIGURE 3: FERMENTATION ATTENUATION CURVES FOR TEST IN SERIES II (HONEY ADDITIONS IN THE FERMENTER)

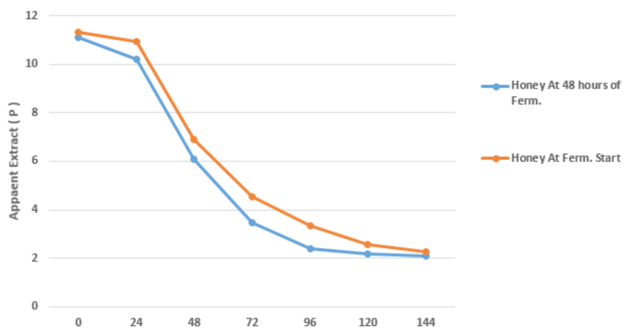


Table 9 compares the beer chemistry of all beers produced in Series II. As anticipated, we see an increase in ADF, increase in ethanol and a corresponding decrease in AE. The magnitude of the differences in the tests and the control in AE and ADF is about double of what was observed in Series I. This is to be expected, as Series I attempted to compensate for the honey's higher fermentability by changing mashing conditions, while Series II did not. Color and pH differences between the tests and the Control were of a similar magnitude to those seen in Series I.

TABLE 9: FINISHED BEER ANALYSIS – TEST SERIES II

	Control (No Honey Addition)	Honey Added at End of Boil	At Fermentation Start	At 48 hours of Fermentation	For Bottle Conditioning
Apparent Extract (°P)	2.56	2.16	2.09	2.06	2.64
Ethanol (% v/v)	4.68	4.91	4.89	4.82	4.58
ADF (%)	77.48	81.10	81.54	81.55	76.59
Calculated OE (°P)	11.38	11.42	11.34	11.17	11.27
Real Extract (°P)	4.26	3.94	3.87	3.82	4.30
Color (SRM)	4.99	4.66	4.77	4.53	6.00
BU	23.9	23.1	22.5	21.8	25.9
Turbidity (FTU)	25.2	20.8	27.7	21.8	7076.0
pH	4.19	4.01	4.13	4.04	4.18

Figure 4 provides an overview of the sensory results for Tests 1, 2 and 3. These are beers that essentially received the same amount of honey in the recipe, but the honey was added in different ways prior to or during fermentation. Test 2 generated a higher sulfur intensity, higher body and lower palate and sweetness. Test 3, on the other hand, resulted in the highest flavor, estery and palate intensity. Test 1 resulted in the lowest estery and highest maltiness. These differences were statistically significant, suggesting that the timing of addition of honey in this part of the process can make a considerable flavor difference.

FIGURE 4: DESCRIPTIVE SENSORY PANEL RESULTS FOR SERIES II – TESTS 1, 2 AND 3

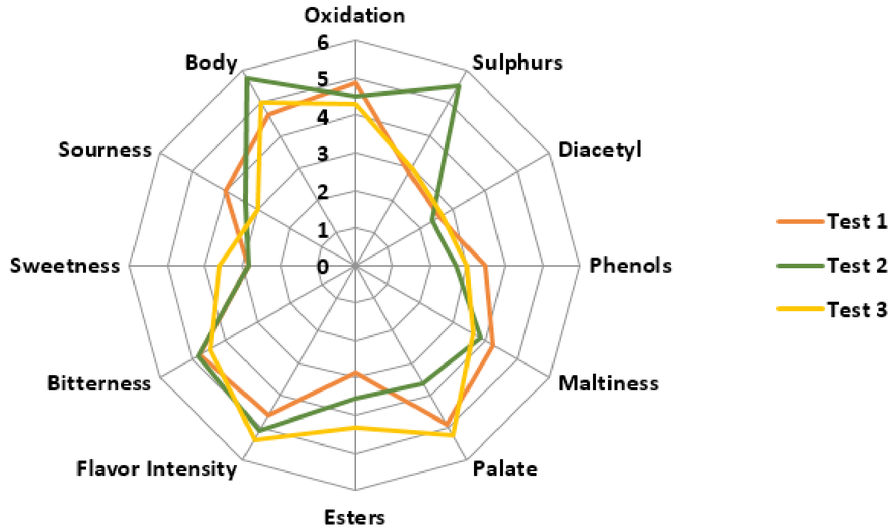
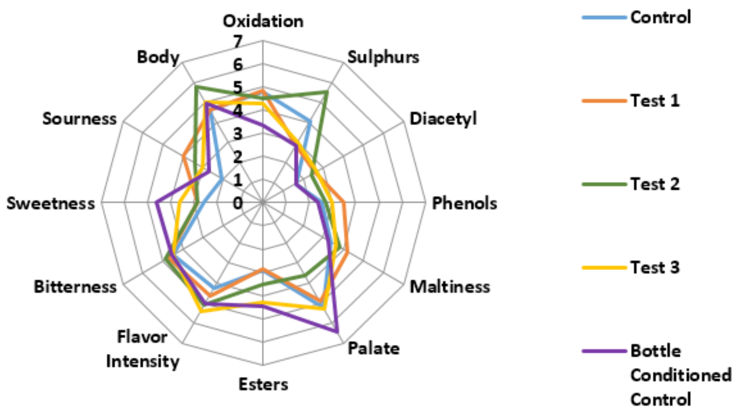


Figure 5 summarizes the descriptive flavor profile results for all four test beers and the Control. We see significant differences, where the Control had the lower overall flavor intensity, and Test 3 had the highest overall flavor and estery perception. The bottle conditioned beer had the highest palate and sweetness perception. It is likely that the sensory results will evolve for the bottle conditioned product as the sensory panel evaluated the beers approximately 10 days after packaging

FIGURE 5: DESCRIPTIVE SENSORY PANEL RESULTS FOR ALL BEERS IN SERIES II



SECTION 4

Conclusion

Honey plays a significant role in brewing when added to a recipe. At just 10%, honey will have an impact on fermentability, color and pH in the finished beers. When it comes to taste, the impact is even greater, and depends on what stage of the brewing process the honey is added.

Added in the boil, and 95% of the honey will ferment out. However, the remaining 5% provides a depth of flavor to the beer. Added after the boil, and brewers can expect to maintain the exceptional aromatics and flavor honey imparts.

This versatility makes honey an excellent ingredient for multiple reasons, not just creating sweet beers.

APPENDIX A

Tables & Figures

TABLE 1: HONEY USED IN THE TEST BREWS - CANADA AMBER HONEY SPECIFICATION

Color (mm)	71 to 85
Moisture (%)	< 18.5
pH	pH 3.6 to 3.9
Average density (lbs/gal)	14
HMF (ppm)	< 40
Diastase activity	> 3

TABLE 2: ANALYSIS OF A 12°PLATO AMBER HONEY SOLUTION

Fructose (g/L)	57.98
Glucose (g/L)	60.94
Maltose	1.10
Maltotriose (g/L)	7.17
Maltotetraose (g/L)	0.04

TABLE 3: WORT PH AND COLOR FOR TEST SERIES I

	Wort pH			Wort Color		
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
Control	5.24	5.28	5.26	6.58	5.82	6.66
Test 1 (Honey 5' before KO)	4.96	5.23	5.18	5.62	5.42	6.97
Difference (Test 1 - Control)	-0.28	-0.05	-0.08	-0.96	-0.4	0.31

TABLE 4: WORT FERMENTABILITY IN FORCED (RAPID) FERMENTATIONS – TEST SERIES (UNITS IN °PLATO)

	Replicate 1	Replicate 2	Replicate 3
Control	2.32	2.35	2.26
Test 1 (Honey 5' before End of Boil)	2.06	2.08	2.14
Difference (Test 1 - Control)	-0.26	-0.27	-0.12

TABLE 5: FERMENTATION PERFORMANCE OF CONTROL VERSUS TEST 1 – TEST SERIES I (UNITS IN °PLATO)

	Replicate Run #1		Replicate Run #2		Replicate Run #3	
Hours	Control (No Honey Added)	Honey Added at End of Kettle Boil	Control (No Honey Added)	Honey Added at End of Kettle Boil	Control (No Honey Added)	Honey Added at End of Kettle Boil
0	11.44	11.35	11.74	11.72	11.34	11.58
24	11.02	11.11	11.23	11.02	10.78	11.16
48	7.65	6.39	7.27	7.49	7.08	7.87
72	4.19	4.92	4.9	5.61	4.48	5.24
96	4.39	4.2	3.55	4.37	2.85	3.81
120	2.53	2.91	2.78	3.51	2.64	3.6
144	2.52	2.59	2.6	2.94	2.64	2.58

TABLE 6: FERMENTATION PERFORMANCE OF CONTROL VERSUS TEST 1 – TEST SERIES I (UNITS IN °PLATO)

	Replicate Run #1		Replicate Run #2		Replicate Run #3	
Hours	At End of Boil	At Fermentation Start	At 48 Hours of Fermentation	At End of Boil	At Fermentation Start	At 48 Hours of Fermentation
0	11.58	11.35	11.69	11.35	11.54	11.83
24	11.16	11.02	11.5	11.11	11.25	10.46
48	7.87	7.27	7.85	6.39	6.71	7.92
72	5.24	4.91	4.95	4.92	5.19	5.68
96	3.81	3.07	3.55	4.2	3.52	4.19
120	3.6	2.61	2.56	2.91	2.66	3.31
144	2.58	2.28	2.27	2.59	2.36	2.84
168		2.21	2.18		2.27	2.61

TABLE 7: END OF FERMENTATION BEER ANALYSIS – TEST SERIES I

	Replicate Run #1		Replicate Run #2	
	Control (No Honey Addition)	Honey Added at End of Boil	At Fermentation Start	At 48 Hours of Fermentation
Apparent Extract (°P)	2.4	2.4	2.2	2.4
Ethanol (% v/v)	4.8	4.9	5.0	4.9
ADF (%)	78.8	79.1	80.9	79.4
Calculated OE (°P)	11.4	11.6	11.6	11.7
Real Extract (°P)	4.2	4.2	4.0	4.2
Ethanol (% w/w)	3.7	3.8	3.9	3.9
Color (SRM)	7.7	8.1	7.3	7.1
pH	4.4	4.2	4.2	4.2

TABLE 8: WORT FERMENTABLE SUGAR PROFILE – PERCENTAGE OF FERMENTABLE SUGARS

	Test Series I			Test Series II		
	No Honey Addition	Honey at Kettle Knockout	Difference (Honey - No Honey)	No Honey Addition	Honey at Kettle Knockout	Difference (Honey - No Honey)
Maltotriose (%)	15.4%	18.4%	3.0%	14.4%	20.3%	5.9%
Maltose (%)	56.6%	64.1%	7.5%	59.7%	71.5%	11.8%
Glucose (%)	18.5%	16.2%	-2.3%	14.4%	8.1%	-6.4%
Fructose (%)	9.4%	1.2%	-8.2%	11.5%	0.1%	-11.3%

TABLE 9: FINISHED BEER ANALYSIS – TEST SERIES II

	Control (No Honey Addition)	Honey Added at End of Boil	At Fermentation Start	At 48 Hours of Fermentation	For Bottle Conditioning
Apparent Extract (°P)	2.56	2.16	2.09	2.06	2.64
Ethanol (% v/v)	4.68	4.91	4.89	4.82	4.58
ADF (%)	77.48	81.10	81.54	81.55	76.59
Calculated OE (°P)	11.38	11.42	11.34	11.17	11.27
Real Extract (°P)	4.26	3.94	3.87	3.82	4.30
Color (SRM)	4.99	4.66	4.77	4.53	6.00
BU	23.9	23.1	22.5	21.8	25.9
Turbidity (FTU)	25.2	20.8	27.7	21.8	7076.0
pH	4.19	4.01	4.13	4.04	4.18

FIGURE 1: COMPARING MASHING SCHEDULES: CONTROL VERSUS TEST IN SERIES I

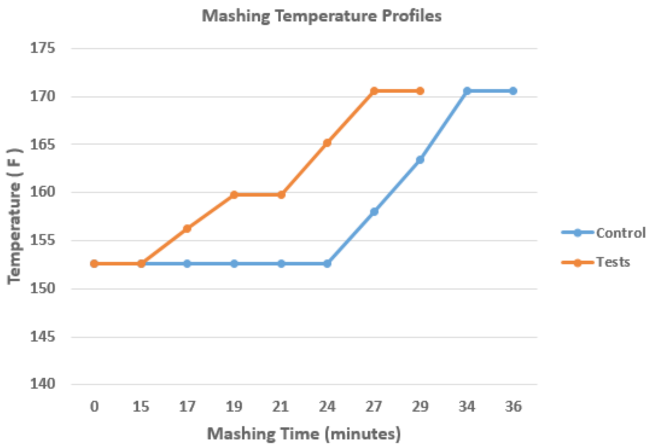


FIGURE 2: FERMENTATION ATTENUATION CURVES FOR TEST IN SERIES II (CONTROL VERSUS HONEY ADDITION IN THE KETTLE)

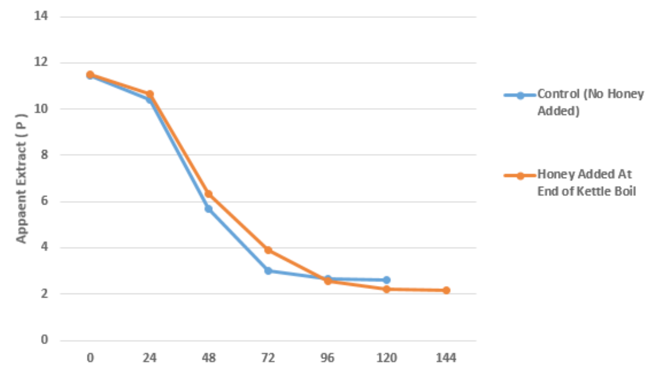


FIGURE 3: FERMENTATION ATTENUATION CURVES FOR TEST IN SERIES II (HONEY ADDITIONS IN THE FERMENTER)

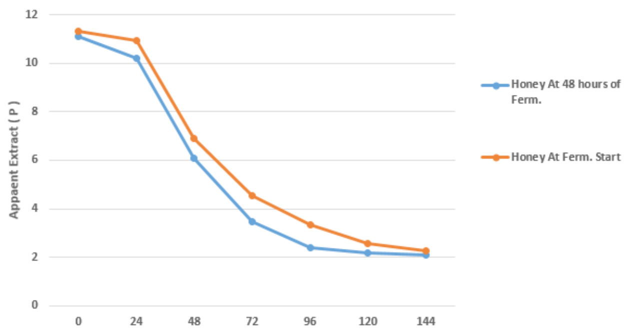


FIGURE 4: DESCRIPTIVE SENSORY PANEL RESULTS FOR SERIES II – TESTS 1, 2 AND 3

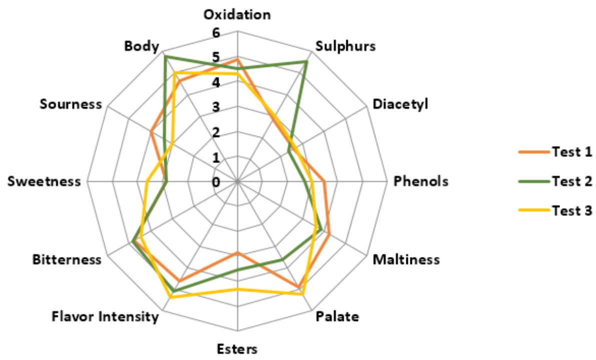


FIGURE 5: DESCRIPTIVE SENSORY PANEL RESULTS FOR ALL BEERS IN SERIES II