The evolution of sugars and of wort density during beer fermentation

Simone Bellassai Chemist – Enologist and expert in food and beverage analysis at CDR – **Lisa Mearelli** researcher at the CDR Chemical Lab "Francesco Bonicolini"

One of the crucial problems in the control of the brewing process is the correct identification of the end of fermentation. Another phase of the brewing process, which can cause troublesome problems, is the priming phase.

Researchers from the CDR Chemical Lab "Francesco Bonicolini" conducted a study on brewing with the aim of:

- • understanding which is the best method to determine the end of the fermentation process;
- • determining the residual sugar concentration in order to avoid problems in the priming phase.

For this purpose they studied the evolution of fermentable sugars as well as the variation of wort density during fermentation.

Sugars in beer wort

Four types of sugars may be present in beer wort:

- **Glucose and fructose**: simple sugars, which are completely fermentable by the yeasts used in brewing;
- **Maltose**: complex sugar, formed by two molecules of glucose, which is completely fermentable by yeasts;
- **Maltotriose**: complex sugar, formed by three molecules of glucose, which is completely fermentable only by certain yeasts used in brewing, while for others it is partially fermentable or even non-fermentable at all;
- **Sucrose**: complex sugar, formed by a molecule of glucose and one of fructose, which is easily fermentable by yeasts.

Glucose, fructose, maltose and maltotriose are sugars naturally present in beer wort because they derive from the barley starch used in mashing, while sucrose can be added by the brewer if it is required by the given beer recipe.

Materials and methods

In order to perform this study two different beer worts were produced in the laboratory with the following recipes:

BEER RECIPE 1

INGREDIENTS	TYPE	QUANTITY
Malt extract	*Extra light liquid malt extract*	489 gr
Dry malt extract	*Extra light dry malt extract*	250 gr
Hops	*Hops in Cascade pellet*	22 gr
Orange peels	*Dried sweet orange peels*	23 gr
Sucrose	*Kitchen sugar*	50 gr
Water	**	5 L
Yeast	*White labs WLP002 (attenuation: 63-70%)*	8,7 mL

BEER RECIPE 2

INGREDIENTS	TYPE	QUANTITY
Malt extract	*Extra light liquid malt extract*	489 gr
Dry malt extract	*Extra light dry malt extract*	250 gr
Hops	*Hops in Cascade pellet*	22 gr
Orange peels	*Dried sweet orange peels*	23 gr
Sucrose	*Kitchen sugar*	50 gr
Water	**	5 L
Yeast	*White labs WLP099 (attenuation: 80-100%)*	7,6 mL

** The water used presented the following characteristics:

- Calcium: 115 mg/L
- Alkalinity: 98 ppm
- Sulphates: 256 mg/L
- Chlorides: 56 mg/L

The yeasts used

Both beers were produced following a recipe for IPA beers, except for the yeast type. In fact, a low attenuation yeast was added to the wort in one beer, while a high attenuation yeast was used in the other. The characteristics of the yeasts used are as described below:

- *White Labs WLP002:* it is a yeast with a low attenuation (63-70%), which therefore is not able to transform all the sugars into alcohol. The optimal temperature range for fermentation is 18-20 °C, it has a very high flocculation and presents an average alcohol tolerance (5-10% v/v).
  A slight production of diacetyl is common. Due to the high flocculation of this strain, the finished beer is clear and the yeast can easily be collected by the fermenter for future use. It is common for this yeast to appear coagulated.
- *White Labs WLP099:* it is a yeast with a high attenuation (80-100%), which therefore can transform almost all sugars into alcohol. The optimal temperature range for fermentation is 18-20.5 °C, it has a medium degree of flocculation and has a very high alcohol tolerance (> 15% v/v). This type of yeast has been genetically modified to increase the attenuation rate.

Data on the concentration of the fermentable sugars and on the density of the wort were collected, for each wort, from the moment of inoculation of the two yeasts.

Measurement tools and analysis

CDR BeerLab® was used to determine the change in concentration of **fermentable sugars**, while a portable digital density meter was used to measure the variation in density of the wort. Data was collected thanks to these two tools from the yeast inoculation until the time in which fermentation was said to be ended. For each session of analysis, about 10 mL of fermenting wort was taken from each container and filtered with paper filters. About 3 mL of sample was needed for the density measurement, while about 1 mL of sample was sufficient to complete all the analyzes with CDR BeerLab®.

BEERLab®

The results

The data collected, divided for each beer wort, are reported in the following tables.

Table 1. Data related to beer wort no. 1 (*i.l.m.= data below the minimum limit detectable by the tool*).

Measurement tool	CDR BeerLab®						Density Meter
Date and time of analysis	Glucose + Fructose+ Maltose (g/L)	Glucose + Fructose + Maltose + Sucrose (g/L)	Glucose (g/L)	Fructose (g/L)	Maltose (g/L)	Sucrose (g/L)	Density (g/cm³)
04/01/2019 16:30	85	92,2	12,7	2,6	69,7	7,2	1,055
07/01/2019 09:30	66	73,5	6,9	6,7	52,4	7,5	1,048
07/01/2019 15:00	70	70,7	6,7	5,6	57,7	0,7	1,044
08/01/2019 09:00	35	37,1	0,1	2	32,9	2,1	1,029
08/01/2019 14:30	31	31,1	i.l.m.	1,1	29,9	0,1	1,025
09/01/2019 08:30	20	20	i.l.m.	i.l.m.	20	i.l.m.	1,020
09/01/2019 14:30	18	< 18	i.l.m.	i.l.m.	18	i.l.m.	1,011
09/01/2019 16:30	19,5	< 18	i.l.m.	i.l.m.	19,5	i.l.m.	1,019
10/01/2019 09:00	16,2	< 18	i.l.m.	i.l.m.	16,2	i.l.m.	1,017
10/01/2019 14:30	16,3	< 18	i.l.m.	i.l.m.	16,3	i.l.m.	1,017
11/01/2019 09:30	15	< 18	i.l.m.	i.l.m.	15	i.l.m.	1,015
11/01/2019 14:30	13,6	< 18	i.l.m.	i.l.m.	13,6	i.l.m.	1,015
14/01/2019 08:30	12,7	< 18	i.l.m.	i.l.m.	12,7	i.l.m.	1,014
15/01/2019 08:30	12,7	< 18	i.l.m.	i.l.m.	12,7	i.l.m.	1,015

Table 2. Data related to beer wort no. 2 (*i.l.m.= data below the minimum limit detectable by the tool*).

Measurement tool	CDR BeerLab®						Density Meter
Date and time of analysis	Glucose + Fructose + Maltose (g/L)	Glucose + Fructose + Maltose + Sucrose (g/L)	Glucose (g/L)	Fructose (g/L)	Maltose (g/L)	Sucrose (g/L)	Density (g/cm³)
04/01/2019 16:30	87	96,3	12,8	2,7	71,5	9,3	1,054
07/01/2019 09:30	59	59,9	0,5	1,4	57,1	0,9	1,037
07/01/2019 15:00	55	56,6	0,4	0,8	53,8	1,6	1,034
08/01/2019 09:00	37	37,2	0,3	0,1	36,6	0,2	1,025
08/01/2019 14:30	35	34,6	0,3	0,1	34,6	*i.l.m.*	1,023
09/01/2019 08:30	16,5	< 18	*i.l.m.*	*i.l.m.*	16,5	*i.l.m.*	1,016
09/01/2019 14:30	14,4	< 18	*i.l.m.*	*i.l.m.*	14,4	*i.l.m.*	1,014
09/01/2019 16:30	12,2	< 18	*i.l.m.*	*i.l.m.*	12,2	*i.l.m.*	1,013
10/01/2019 09:00	6,4	< 18	*i.l.m.*	*i.l.m.*	6,4	*i.l.m.*	1,009
10/01/2019 14:30	4,7	< 18	*i.l.m.*	*i.l.m.*	4,7	*i.l.m.*	1,008
11/01/2019 09:30	1,7	< 18	*i.l.m.*	*i.l.m.*	1,7	*i.l.m.*	1,006
11/01/2019 14:30	1,2	< 18	*i.l.m.*	*i.l.m.*	1,2	*i.l.m.*	1,005
14/01/2019 08:30	1	< 18	*i.l.m.*	*i.l.m.*	1	*i.l.m.*	1,005
15/01/2019 08:30	1	< 18	*i.l.m.*	*i.l.m.*	1	*i.l.m.*	1,006

The CDR BeerLab® tool allows two types of analysis: the determination of the sum of glucose, fructose and maltose and the determination of the sum of glucose, fructose, maltose and sucrose. For this research, however, the various sugars were measured individually for a more detailed analysis.

From the data reported in the previous tables it is possible to evaluate the trend in concentration of fermentable sugars present in the beer wort. The first sugars to be fermented by the yeasts are glucose, fructose and sucrose. In fact, for both worts, these three sugars are almost absent after four days. Also maltose and maltotriose (determined together with maltose) are fermented but at a later stage. Fermentation can be considered completed after 6 days, when the concentration of sugars remains constant in 2 measurements performed at a distance of 24 hours.

As can be seen from the tables, considering the column *Glucose + Fructose + Maltose (g/L)*, the yeasts acted differently at the end of the fermentation process. In fact, by the end of the action of the White Labs WLP002 (low attenuation) yeast, 12.7 g/L of unfermented sugar (maltotriose) remained in the wort, while the White Labs WLP099 (high attenuation) yeast allowed the fermentation of almost all of the sugars, leaving only 1 g/L of unfermented sugar (maltotriose) within the wort. This difference in final concentration of sugars, due to the characteristics of the different yeasts used, is to be kept in mind when assessing the end of fermentation, since, as demonstrated by these measurements, fermentation does not always end when the residual concentration of sugars is close to zero.

It is also important to know the residual concentration of sugars at the end of fermentation in order to correctly evaluate the amount of sugar to be added to the beer in the priming phase in order to avoid over-gassing.

Priming is the process by which carbon dioxide is added to the beer. The most common priming method used by craft breweries is the natural method; carbonation is obtained by adding fermentable sugars to the beer before bottling. As a rule, a concentration varying from 4 to 7 g/L of sugar is added for priming, as each beer may require a different level of gassing.

Comparison between the results obtained with the density meter and with CDR BeerLab®

In order to determine the end of fermentation and measure the residual sugar concentration it is necessary to focus on the last four days of this process.

Both for beer no. 1 than for no. 2 we note how the density of the wort detected by the portable densimeter in the last four days varies by 0.001. Since the resolution of the tool is 0.001, the density meter provides a potentially insignificant result as it does not reflect the change in concentration of sugars.

Instead, when analyzing the results of the analyzes obtained with CDR BeerLab® in the last 4 days of fermentation, we note that the concentration of the fermentable sugars detected varies by 2.3 g/L in the case of beer no. 1 and by 0.7 g/L in the case of beer no. 2.

From the results of the analysis performed, we note that the portable digital density meter is quite accurate in assessing the density of the wort, thus it can be used to control the progress of the fermentation process. Instead, the use of CDR BeerLab® is to be favored to establish the effective end of fermentation, since it is more precise and capable of detecting even the slightest changes in sugar concentration that the portable density meter is not capable of highlighting as effectively.

Having the safety of having completed the fermentation is essential for the priming phase.

To avoid over-gassing, which could give rise to gushing, it is essential to be sure that the fermentation is complete. The analysis of fermentable sugars is therefore of primary importance for the calculation of the amount of sugar to be added in the priming phase, thus obtaining the volumes of CO_2 required from the recipe adopted.

Beer style	Volumes of CO_2
British ales	1,5 - 2,0
Porter, Stout	1,7 - 2,3
Belgian ales	1,9 - 2,4
Lager	2,2 - 2,7
Wheat beer	3,3 - 4,5

More specifically, based on the beers produced, if we had evaluated the end of fermentation by using the densimeter, we would have considered a point of early fermentation that would have left sugar residues corresponding to 2.3 g/L of sugar and 0.7 g/L of sugar in the case of beer no. 1 and beer no. 2, respectively. These quantities of residual fermentable sugars would have given rise to 0.57 and 0.17 volumes of CO_2, respectively, which could have caused an excessive gassing of the beer.

Conclusions

We can state that fermentation is concluded when the concentration of sugars remains constant for 24 consecutive hours. Therefore, to determine the end of the fermentation process, it is much more effective to control the variation in concentration of sugars in the wort rather than the density.

CDR BeerLab® is considered the most suitable tool to determine the end of fermentation, being able to detect even the slightest variations in concentration of sugars that otherwise, i.e. by measuring the density, would not be able to be appreciated.

With CDR BeerLab® it is possible to measure the exact concentration of residual sugars at the end of fermentation in order to avoid errors in the priming phase.

Useful links

Densimeter or Density Meter
Determination of fermentable sugars
CDR BeerLab® analysis system