Introduction

From a carbohydrate point of view, the efficiency of barley-to-beer conversion can be assessed as the potential to convert fermentable carbohydrates into alcohol and is mainly determined by the efficacy of enzymes during malting, mashing, and fermentation. In former times, this extract yield was evaluated based on density measurements. However, vital information on fermentable sugars is often overlooked.

The aim of this study is to establish a new approach that allows the comparison of different brewing techniques or installations on the production of fermentable sugars.

Here, we use the combination of GC and HPAEC-PAD carbohydrate analyses to calculate the fermentable extract yield. Analytical challenges that were addressed include the potential interference of high enzyme activities or high sugar contents that are known to affect conventional measurements.

Materials & Methods

**Mashing**
- Triplicate mashing procedure was performed with 50 g barley malt and 200 mL deionized water
- Mash was modified with 75 mg CaCl₂ and 0.3 mL of a 0.5 M H₂SO₄ solution¹
- Figure 1 gives a schematic overview of the process
- Resting times were at 45°C, 62°C, 72°C for 30 min and 78°C for 10 min

**Analysis of total monosaccharide composition after hydrolysis (Englyst method - GC)**
- Dry samples and 1:100 diluted wort samples were hydrolyzed with trifluoroacetic acid (2N)
- Reduction with NaBH₄ and acetylation with acetic anhydride was performed²
- The alditol acetates were separated with GC as described by Courtn et al. (2000).
- The total monomeric glucose content is the highest yieldable fermentable glucose, maltose, and maltritolose and is here referred to as the glucose potential.

**Enzyme inactivation in malt prior to fermentable sugar analysis**
- Milled malt was boiled for 2 h in a 80% (v/v) aqueous ethanol solution under constant reflux.
- The solvent was removed by a rotary evaporator and the sample dried overnight at 50°C³.

**Analysis of fermentable sugars after mashing (HPAEC-PAD)**
- Dry samples and 1:5 diluted wort samples were diluted to 5 µg/mL after addition of internal standard.
- Glucose, fructose, sucrose, maltose, and maltritolose are quantified.
- For maltose, additional calibration samples with concentrations up to 40 µg/mL were used.
- Samples were separated with HPAEC-PAD,⁴,⁵
- Fermentable sugars were converted to monomer equivalents using the hydrolysis factors (Table 1).

Results & Discussion

This lab-scale mashing process can be evaluated based on two critical values, being the fermentable extract yield based on the glucose potential (FEY-GP) and the fermentable extract yield based on the malt mass (FEY-M).

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FEY - GP = \frac{\text{Fermentable sugars in wort (HPAEC - PAD)}}{ \text{Glucose potential in malt (GC)}} = 93.0\%
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FEY - M = \frac{\text{Fermentable sugars in wort (HPAEC - PAD)}}{ \text{malt mass (dm)}} = 79.3\%
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This lab-scale mashing unit has a FEY-GP of 93.0%, which means that 7.0% of the carbohydrates that could be converted to fermentable sugars is not fermentable. This value is independent of the starch content of malt and only reviews the mashing process. Both values can be compared with values of other systems with different external factors, e.g. with the addition of exogenous enzymes.

This leads to the conclusion that the comparison of mashing processes by means of the FEY-GP allows a better understanding of the conversion to fermentable sugars and is therefore inevitable for brewhouse optimization.

References: