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New Ideas for Quantifying the Gushing Potential of Malt

In this work it was first shown how to quantify the gushing potential of malt with a modification of a common gushing test. Today there exist two acknowledged gushing tests for the brewing industry (Modified Carlsberg Test and Weihenstephaner Test). Both analytical methods use the overfoaming amount of a test-specific produced carbonated wort to determine the gushing potential of malt. Unfortunately the overfoaming amount can vary statistically in a way that this parameter can "only" be used for qualitative information if the malt has a potential for gushing or not and if one malt has a higher or lower gushing potential than another one; but a precise quantitative comparison for example between two malts which both have a gushing potential is difficult. This was the focus of this investigation. With two gushing-positive samples (malt A and B) it could be shown that with an increase of the concentration of malt solutes a certain point is reached where gushing appears the first time determined by the overfoaming amount applied the Modified Carlsberg Test. For malt A a frequently higher gushing potential ($f \geq 5$) than for malt B was identified. These results were verified by determining the amount of a gushing suppressing hop product that led gushing to zero by having a constant concentration of malt solutes. The results demonstrated enhanced gushing analyses to quantify the gushing potential reproducibly, not by the overfoaming amount but by the "zero point" where gushing begins (concentration of malt solutes) or is neutralized (amount of hop product). The introduced methods enable the chance for the first time to quantify the gushing potential of malt more precisely.

Descriptors: gushing analysis, Modified Carlsberg Test, Weihenstephaner Test, quantification, gushing potential

1 Introduction

The brewing industry is furthermore faced with the problem of gushing which is characterized by the eruptive overfoaming of carbonated beverages directly after opening the bottle. As gushing is a complex phenomenon with a high diversity of causing factors, it is not yet completely under control despite of intensive investigations for a long time [1–7]. Therefore, risk analyzing for early gushing detection of the malt before the beer production gets more important as the brewers have the chance to react appropriately e.g. with technological measures. Malt is analyzed by two common used gushing tests according to MEBAK [8], the Weihenstephaner Test [8–10] and the Modified Carlsberg Test [8,11]. These tests determine the gushing potential of malt. The gushing potential is detected by the overfoaming amount of carbonated wort after shaking the bottles. The wort is produced according to test-specific mashing and boiling procedures. Experiments have shown that the overfoaming amount can fluctuate whilst efforts are made to improve the reproducibility [9,11].

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Figures see Appendix

In this work the question is posed and answered if the overfoaming amount is really convenient for estimating the gushing potential. With present knowledge about the development and suppression of gushing it was possible to enhance an established gushing test (Modified Carlsberg Test) to characterize the gushing potentials of two malts more precisely. Hop is known for its gushing reducing characteristic [12–15]. A gushing suppressing hop product was applied purposefully to verify the first results.

2 Materials and methods

2.1 Raw materials and chemicals

For the experiments two barley malt samples (malt A and B) from German malt houses were applied. Malt A had been investigated for gushing in a previous study [16].

The gushing suppressing hop product (CO_2 hop extract) has been provided by Joh. Barth & Sohn GmbH & Co. KG. Information of the CO_2 hop extract is given in the following [17]: The extract have been prepared from natural hops or hop pellets and contain α-acids, β-acids and essential oils. The content of α-acids for aroma hops is approx. 35 % and for high alpha hops (depending on variety) above 50 %.

The extract was stored at 4 °C and was homogenized by stirring shortly before starting the experiments. The hop extract was dissolved in ethanol (99 %).

2.2 Experiments with both gushing tests

For determining the gushing potentials of the used malt samples A and B the worts were produced according to MEBAK instructions of the gushing tests [8] and were subsequently examined for gushing (Fig. 1). Wort A was produced from malt A according to the Weihenstephaner Test and wort B from malt B as to the Modified Carlsberg Test. The worts were added to Bonaqa®-water (carbonated table water) in definite amounts either in original form or with the mentioned CO_2 hop extract. After corking the bottles were turned manually once by 180 degrees. All bottles were shaken and opened according to the Modified Carlsberg Test.

2.3 Statistical evaluation

For examining the reproducibility wort A and B were produced several times under the same experimental conditions. Both worts showed gushing in further process of the Modified Carlsberg Test (Fig. 2 and 3). The experiments were performed four times ($n = 4$). The results are illustrated as arithmetic means including confidence intervals with a probability of $P = 0.95$ applying Student`s t-test [18].

2.4 Preparation and addition of the hop extract-ethanol-solution

The gushing suppressing CO_2 hop extract dissolved in ethanol was added to both worts (A and B) in increasing amounts. The hop extract-ethanol-solution (HES) has a concentration of $c = 6$ mg/ml (360 mg of the homogenized hop extract dissolved in 60 ml ethanol). The solution was kept homogenous by permanent stirring. The necessary volume of the solution (V_{HES}) is calculated of the intended amount of extract ($m_{Extract}$). For example, for the addition of 6 mg extract 1 ml of the solution is needed ($c = m_{Extract}/V_{HES}$, $V_{HES} = m_{Extract}/c$, $V_{HES} = m_{Extract}/6$ mg/ml). For all experiments the volume of the solution (V_{HES}) was increased by further addition of ethanol to a constant volume of 2.5 ml. In this way a constant volume of 2.5 ml ethanol with varied amount of hop extract $m_{Extract}$ was mixed with the respective wort sample. The completed hop extract-ethanol-wort-solution comprised 52.5 ml. This solution (52.5 ml) was substituted with 55 ml Bonaqa®-water. The obtained results (Fig. 4, 5 and 7) are illustrated as overfoaming amounts (in g) in relation to the amounts of the hop extract (in mg).

2.5 Processing the wort according to the Modified Carlsberg Test

After addition of the wort to Bonaqa®-water, the bottles were shaken and opened according to the Modified Carlsberg Test (Fig. 1). The bottles were shaken horizontally applying the instrument VKS-75 Control from Edmund Bühler GmbH (frequency: 1.25 Hz, stroke length: 0.05 m). Afterwards, they were left standing for 10 min, then three times turned manually (180 degrees) within 10 s, and after 30 s standing opened.

3 Results and Discussion

3.1 Indirect Quantification of the gushing potential by increasing wort volume in Bonaqa®-water

In a previous study [16] it has already been shown that gushing develops with increasing volume of wort A in Bonaqa®-water. The observation that gushing begins only if sufficient volumes of wort are present can be explained by the hypotheses that gushing inducing substances have to reach a minimum concentration to cause gushing. The existence of a minimum concentration for observing gushing has already been shown by a former work with hydrophobins [19] and in a recent one with an aliphatic surfactant [20] that demonstrates a further gushing mechanism induced by micelles. This implies that wort samples with high concentrations of gushing inducing substances need lower volumes in Bonaqa®-water for producing gushing than a sample with a lower concentration.

The figures 2 and 3 show comprehensive concentration series with wort A and B ($n = 4$). For this the same volume of Bonaqa®-water was substituted with the same volume of wort in the range from 5 ml to 50 ml (wort volume below 5 ml were added to Bonaqa® without substitution). In these experiments the CO_2 content decreases with increasing substituted volume. For establishing this analysis a constant CO_2 content should be aspired by applying a constant substituted volume (X ml wort and Y ml gushing-neutral medium: X + Y = const.).

The figures 2 and 3 show that gushing induced by wort A begins at ca. 5 ml (V_A); for wort B initial gushing was observed at approx. 25 ml (V_B). Wort B generates only initial gushing if the volume is five times larger than that of wort A ($f_1 = V_B/V_A$, $f_1 \approx$ 25ml/5ml, $f_1 \approx 5$). Consequently malt A have a five times higher gushing potential than malt B. In this way the gushing potential can be quantified indirectly by the volume of wort (concentration of malt solutes) essential for inducing initial gushing. The following experiments aim to verify the quantified gushing potentials of malt A and B.

3.2 Verifying the quantified gushing potentials by a gushing suppressing hop product

By addition of a gushing suppressing product gushing can be reduced down to complete suppression (neutralization). At the neutral point the effect of gushing inducing substances is totally compensated. The amount of the gushing suppressing product for neutralization of gushing may facilitate to quantify the gushing potential. These considerations are tested in the following experiments with CO_2 hop extract in wort A and B. The aim is to verify the already quantified gushing potentials obtained by the wort volume for initial gushing.

The results of the concentration series with CO_2 hop extract in wort A and B ($n = 4$) are presented in figures 4 and 5. All samples contain 2.5 ml ethanol, inclusive the blank test (50 ml wort) with 0 mg CO_2 hop extract. The overfoaming amounts of wort A and B decrease with increasing amounts of hop extract down to absolute inhibition. The first neutral point is significant if it remains with further increasing amounts of hop extract.

Gushing in wort A was neutralized with 9 mg hop extract (m_A) (Fig. 4). The neutral point for wort B can be determined at approx. 1 mg (m_B) (Fig. 5). The results demonstrate that the neutralization points for wort A and B with CO_2 hop extract are reproducible as the confidence interval tends to zero. The “zero points” of wort

A and B differ considerably. Consequently malt A possesses a frequently higher gushing potential than malt B. In this case the gushing potential of malt A is by the comparative factor $f_2 \approx 9$ ($f_2 = m_A/m_B$, $f_2 \approx 9$ mg/1 mg) higher than of malt B.

By "titrating" of the hop extract into the wort up to the neutral point it has been confirmed that malt A has a frequently higher gushing potential than malt B. So both methods are qualified to quantify the gushing potential.

The gushing reducing effect of the hop product (2nd method) should be tested in the beer production process to minimize the risk of gushing in the industry. If the gushing reducing effect is verified, the analytically determined amount of this hop product to neutralize gushing could be possibly used as reference value. If there is a correlation, the brewer will know how much hop should be added to the beer production process to minimize gushing.

3.3 Examining the correlation between the overfoaming amount (MEBAK) and the new quantified gushing potential

According to the Weihenstephaner Test and Modified Carlsberg Test (MEBAK) the gushing potential of malt is determined by the overfoaming amount of the carbonated wort. High overfoaming indicates a high gushing potential, whereas only low overfoaming signifies a lower one.

In the following it is examined in what way the overfoaming amount represents the actual gushing potential measured by the enhanced methods. The question should be answered if a correlation between the overfoaming amount and the present gushing potential exists. Wort A and B (50 ml wort in 280 ml Bonaqa®-water according to MEBAK) produce distinct gushing (Fig. 2 and 3). Gushing was observed for wort A at ca. 200 g and for wort B around 120 g. In this case wort A exhibits a douple overfoaming amount than wort B. According to these results malt A may have twice as much gushing potential than malt B. But this is not compatible with the determined comparative factors ($f_{1,2} \geq 5$) of both enhanced gushing analyses. The disadvantage of the overfoaming amount (MEBAK) in case of very high gushing potentials is that the overfoaming amount is limited by the nominal filling quantity (330 ml). In this case it is not possible to identify actual differences in the gushing potentials. For wort A the "end value" of approx. 200 g has been already reached from 20 ml wort upward (Fig. 2): the overfoaming amounts remain constant, although there is a further increase of wort A and gushing inducing substances respectively. If there is a direct proportionality of the overfoaming amount and the volume of wort starting from 200 g at 20 ml, 300 g is expected at 30 ml, 400 g at 40 ml and 500 g at 50 ml. If these non-detectable values of gushing are true, the comparative factor for 50 ml is $f_{50ml} \approx 4$ ($f_{50ml} \approx 500$ g/120 g). That is in a good agreement with the result of the enhanced gushing analyses that wort A has a frequently higher gushing capacity than wort B. In this particular case the overfoaming amount according to MEBAK is not really helpful to quantify the gushing potential precisely, "only" a qualitative comparison is possible (lower or higher gushing). The described problem of limited detection of gushing would not exist for the enhanced gushing analyses.

3.4 Further evaluation of both methods by mixing wort A and B

In a further experiment the evaluation of both methods was continued by using another sample whose capability to induce gushing should be already known. Such a sample was created by mixing wort A and B in a chosen ratio of 1:1. With this ratio an intermediate gushing result is expected in both methods. In the 1st method it has been shown that wort A leads to initial gushing with a volume of ca. 5 ml (Fig. 2) and wort B with ca. 25 ml (Fig. 3). In the following the volume for initial gushing of the mixed wort with 50 % wort A and 50 % wort B is estimated. For this the critical volume for initial gushing is defined as 100 %. That means that overfoaming cannot occur for volumes below 100 % whereas gushing increases for higher volumes above 100 %. To determine the volume X of the mixed wort for initial gushing (100 %) following "calculations" are suggested.

By definition 5 ml of wort A are equal to 100 % and 25 ml of wort B as well:

5 ml wort A = 100 %

25 ml wort B = 100 %.

This means that 1 ml of wort A is 20 % and 1 ml of wort B is 4 %:

1 ml wort A = 20 %

1 ml wort B = 4 %.

The mixed wort is the result of the combination of wort A and B in an equal ratio:

1 ml wort A + 1 ml wort B = 24 %. [1]

The question is posed which volume of the mixed wort is 100 %:

X ml = 100 %. [2]

To determine X "equation" 2 is divided by 1:

X ml/(1 ml wort A + 1 ml wort B) = 100 % / 24 %.

That implies that:

X ml = 100/24 · (1 ml wort A + 1 ml wort B)

X ≈ 4.17 ml wort A + 4.17 ml wort B

X ≈ 8.34 ml.

So initial gushing induced by the mixed wort is expected at a volume of approx. 8.3 ml. The results of the experiments are shown in figure 6.

Initial gushing of the mixed wort was detected near the calculated value at a volume of 10 ml. The expected value of 8.3 ml for initial gushing has not been identified as such in the experiments, but the volume for initial gushing can be set between 9 ml (no overfoaming) and 10 ml (first overfoaming). This interval (from 9 ml to 10 ml) can be considered to be in an acceptable agreement with the calculated value. The confidence intervals from 10 ml upward (Fig. 6) show once more the problem of fluctuating overfoaming amounts. It is worth mentioning again that fluctuations of the overfoaming amount are irrelevant in the new enhanced methods, but the change is decisive from "no overfoaming" to overfoaming (1^{st} method) and reverse (2^{nd} method).

In the 2^{nd} method ca. 9 mg (m_A) of the hop product for wort A (50 ml) and ca. 1 mg (m_B) for wort B (50 ml) were necessary to suppress gushing completely for the first time (Fig. 4 and 5). Consequently the mixed wort of 25 ml wort A and 25 ml wort B is expected to be neutralized by half of m_A and m_B, namely $m_{A+B} \approx 5$ mg ($m_{A+B} = m_A/2 + m_B/2$, $m_{A+B} \approx 9$ mg/2 + 1 mg/2). The results are illustrated in figure 7.

Gushing can be still observed at an amount of the hop extract of 3 mg, but decreases at 4 mg and disappears completely at 5 mg. The neutralizing effect remains for a further higher amount of the hop product. The determined neutralization point at 5 mg corresponds to the expected value $m_{A+B} \approx 5$ mg.

These obtained results demonstrate once more that the methods` principles provide acceptable results to quantify the gushing potential.

4 Conclusion

Known preconditions for development and suppression of gushing enable to enhance an established gushing test (Modified Carlsberg Test). The new analyzing methods enable the chance for the first time to quantify the gushing potential of malt more precisely. Applying two different worts (A and B) it was shown that the wort volume in Bonaqa®-water (concentration series), which is sufficient for initial gushing, is a reference value for the quantitative magnitude of the present gushing potential. This method has been verified by determining the amount of the hop product to neutralize gushing. Both analyses confirm the frequently higher gushing potential of malt A in comparison with malt B ($f_{1,2} \geq 5$). In further experiments the quantifying principles of both methods were evaluated by applying another sample. This sample was created by mixing wort A and B in a defined ratio of 1:1 to get a wort sample with a predictable capability to induce gushing. The expected values have been confirmed by both methods.

Furthermore, it was demonstrated that the overfoaming amount (according to MEBAK) proves to be inappropriate to quantify the gushing potential of malt A and B, "only" a qualitative comparison is possible (lower or higher gushing).

Both suggested analyzing methods are appropriate to quantify the gushing potential of malt. They are equal in determining the "zero point" where overfoaming either begins (wort volume) or is suppressed completely (amount of hop product). They differ only from the direction of reading the overfoaming amounts that is reverse.

The introduced methods for quantifying the gushing potential provide for the first time the opportunity to work out influencing factors more precisely so minor changes in the gushing potential can be detected. For example, the maltster can examine the influence of malting parameters on the gushing potential in the produced malt. A prerequisite for this is that identical produced malt extracts are applied. Equally by applying the same malt samples possible influencing variables in the further process steps such as mashing and boiling can be proved.

The gushing reducing effect of the hop product (2^{nd} method) should be tested in the beer production process to minimize the risk of gushing in the industry. If the hop product has a gushing reducing effect, the method could possibly serve as a tool for the brewers to know how much hop product should be added to minimize gushing. The method could provide a reference value that has been determined by the amount of hop product to neutralize gushing. In this context it is worth mentioning that a natural hop product as gushing suppressing product in analysis and in beer production corresponds to the principles of the German purity law.

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Appendix

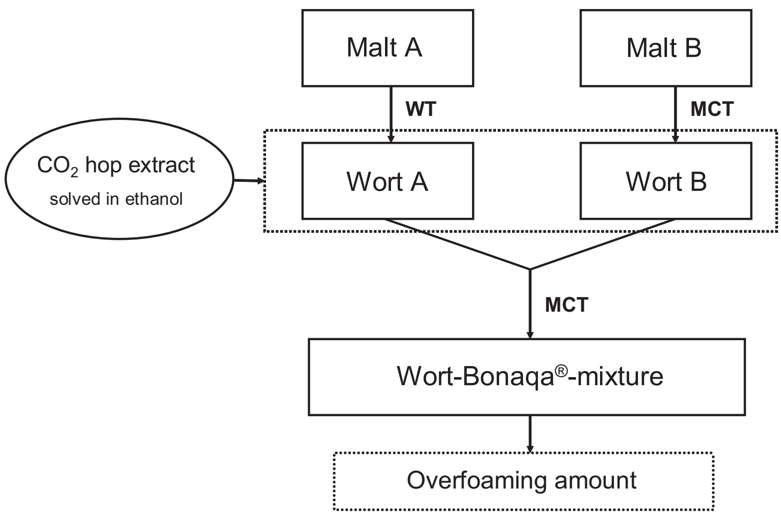

Fig. 1 Flow diagram showing the production of wort A and B, their possible treatment with CO_2 hop extract and processing for investigating the gushing behavior. Wort A were produced from malt A as to the Weihenstephaner Test (WT), while wort B originated from malt B according to the Modified Carlsberg Test (MCT). Both worts either in natural form or mixed with hop extract were processed in certain amounts as to MCT (filling the bottles, shaking and opening).

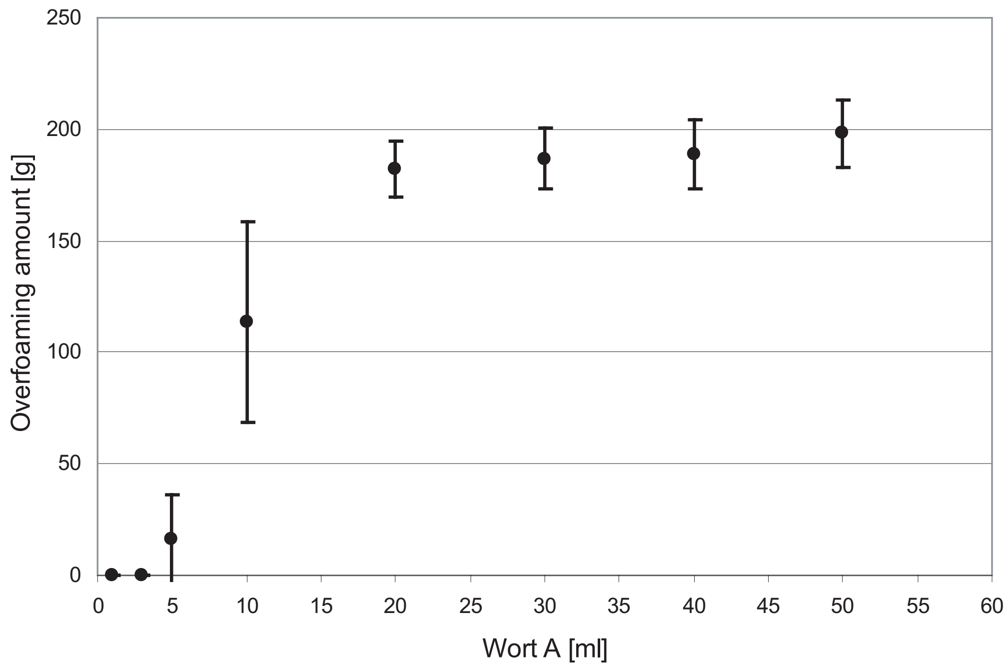

Fig. 2 Overfoaming amount of wort A with increasing volume in Bonaqa®-water (Modified Carlsberg Test, *n* = 4)

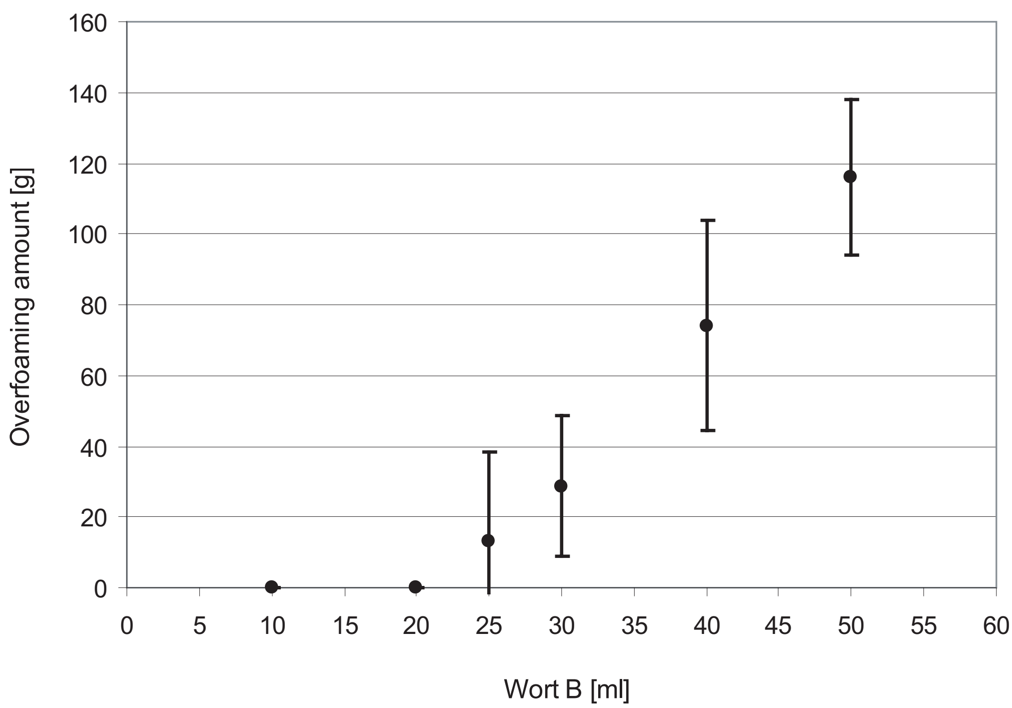

Fig. 3 Overfoaming amount of wort B with increasing volume in Bonaqa®-water (Modified Carlsberg Test, *n* = 4)

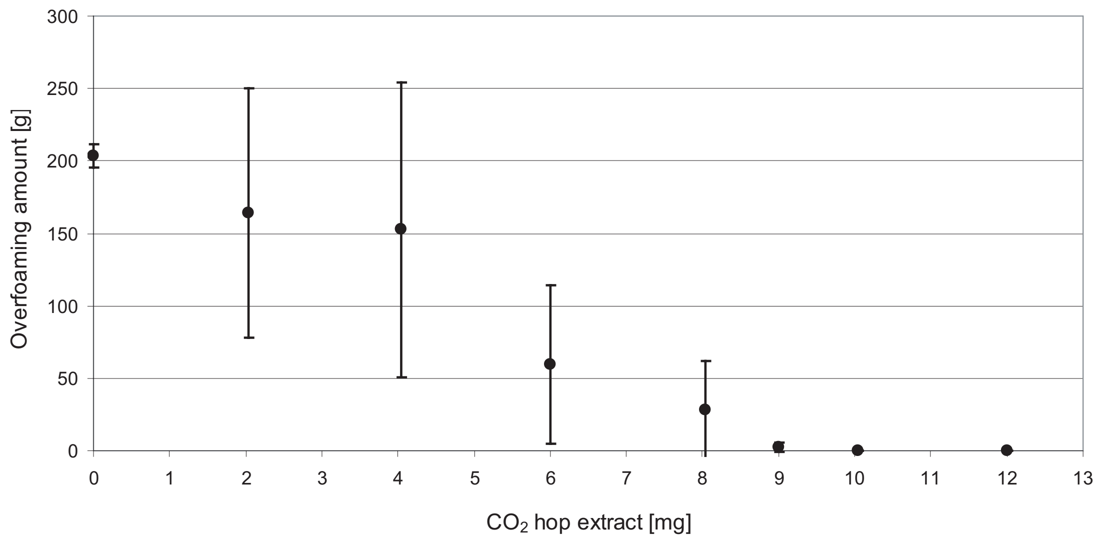

Fig. 4 **Overfoaming amount of wort A (constant volume of 50 ml) with increasing amount of CO_2 hop extract dissolved in ethanol (Modified Carlsberg Test, *n* = 4)**

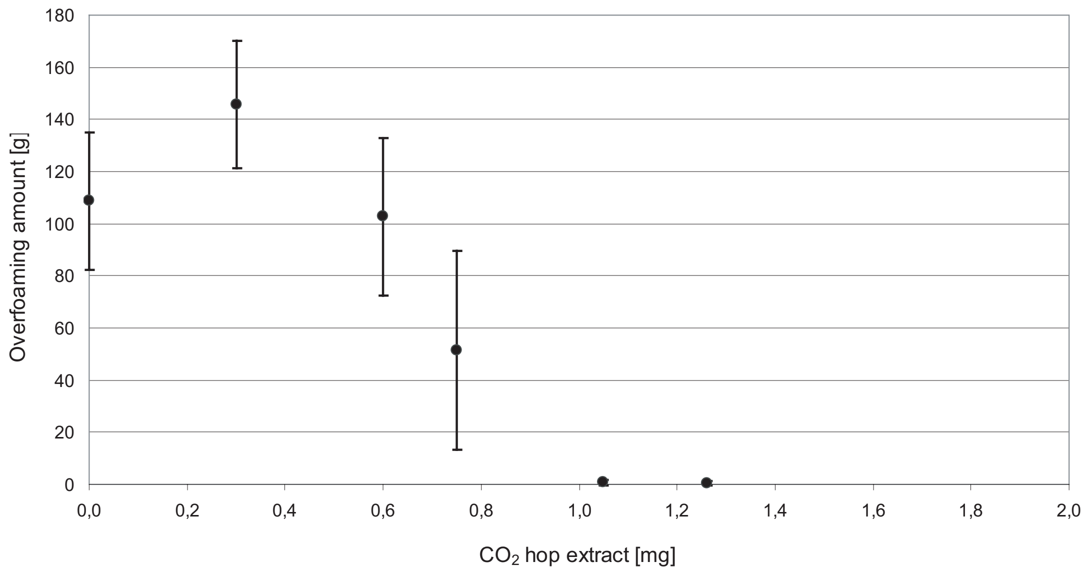

Fig. 5 **Overfoaming amount of wort B (constant volume of 50 ml) with increasing amount of CO_2 hop extract dissolved in ethanol (Modified Carlsberg Test, *n* = 4)**

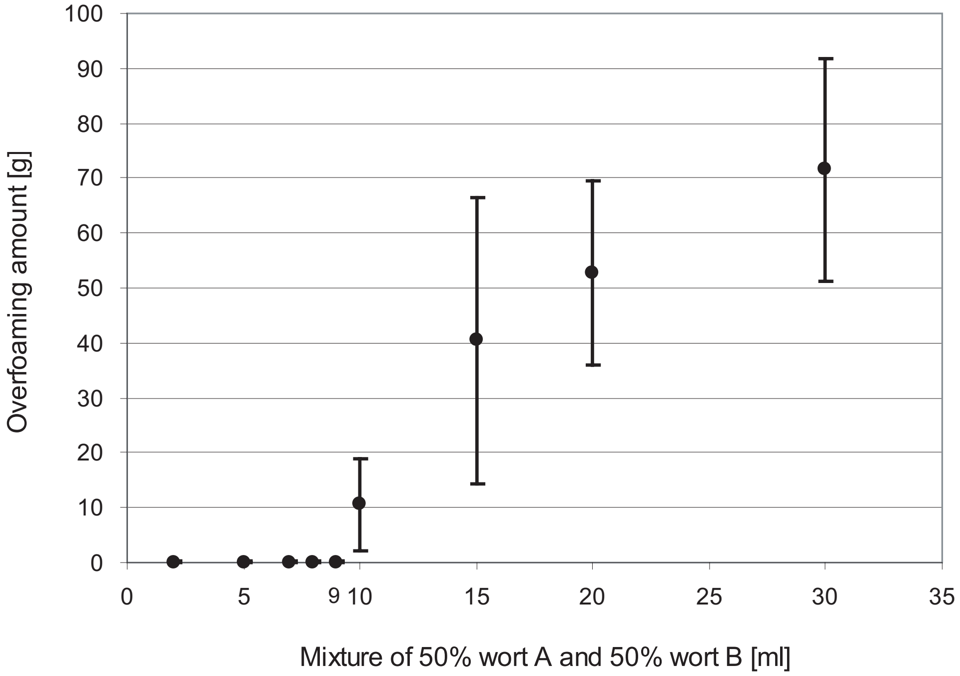

Fig. 6 Overfoaming amount of the mixed wort (50% wort A and 50 % wort B) with increasing volume in Bonaqa®-water (Modified Carlsberg Test, *n* = 4)

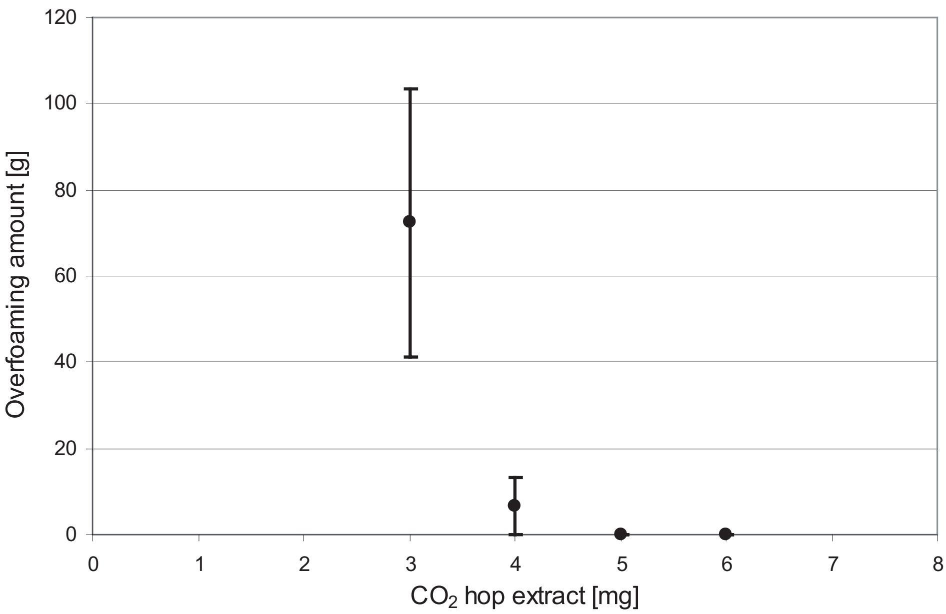

Fig. 7 Overfoaming amount of the mixed wort (constant volume of 25 ml wort A and 25 ml wort B) with increasing amount of CO_2 hop extract dissolved in ethanol (Modified Carlsberg Test, *n* = 4)