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Variation of the Steeping Regime for Optimising the Cytolytic Modification using an Accelerated Malting Procedure

Producing high-modified malt within short malting procedures due to higher temperatures can be a major advantage for the malting industry. At this, the malt kernel's cytolytic and proteolytic modifications are the most important quality parameters. In literature, steeping and germination regimes with low temperatures between 12 and 17 °C during long process times up to 8 days including kilning are recommended. The majority of these recommendations were given decades ago. Economical reasons have led to studies for shortening the process time to save energy whereby the malt quality should be kept as high as possible. Aim of this study was to optimise an accelerated malting procedure by varying the duration of the wet steeps in respect of short process times and acceptable malt qualities, particularly with regards to the cytolytic modification. Laboratory steeping trials as well as a pilot plant malting were carried out with focus on the intensity of water uptake and germination performance. The first wet steep was varied between 2 and 8 hours and the second between 20 minutes and 2.5 hours. The chosen temperature during the first wet steep was set to 22 °C, followed by an 18 h air-rest at 21 °C. Equal steeping degrees of 45 % in all trials were adjusted by spraying with water. The germination was carried out at temperatures between 17 and 22 °C for 3 days in all trials and also kilning was kept constantly. An optimal steeping regime was found to be a 5–6 hour first wet steep, followed by a reduced second wet steep of 20 to 60 minutes. Those regimes led to the highest cytolytic modification and malt homogeneities. In general, the proteolytic modification was too low, which has to be changed in prospective trials for optimising the germination parameters.

Descriptors: steeping, temperature, water uptake, germination performance

1 Introduction

Steeping, as the first major step of malt production, has a huge impact on the resulting malt quality. During the last decades, the steeping procedure has been perceived as more and more important and critical production step [1, 7]. In industry, the steeping and germination procedure are mostly separated, whereby in nature, both form a biological unit [8]. Therefore, it seems worthwhile to regard both production steps together. Furthermore, the steeping and germination procedure should be adjusted for each cereal and variety [26].

The aims of steeping procedures are a fast and homogenous water absorption and germination initiation of the grain whereby an insufficient steeping performance cannot be compensated later [1]. The water uptake depends on barley variety, steeping temperature and the steeping regime [31].

The duration of germination usually lies between 5 and 7 days in dependence of temperature and steeping degree [4, 5, 8, 14, 15, 21, 29]. Thus, the production of malt is a time and energy consuming process and higher steeping temperatures consequently lead to a faster water uptake and a sooner initialisation of the germination, which in turn results in a possible advantageous reduction of the germination time [5, 9, 21, 23]. Hence, many authors investigated the use of higher steeping temperatures during the last decades whereby the influences on malt quality are discussed controversially. Several authors suggested relatively low temperatures of 12–17 °Cduring steeping [8, 13, 14, 19] and germination [15, 18, 25, 29] to produce malt with a high quality, such as high extract yields, low malting losses and a good proteolytic and cytolytic modification. Depending on the barley variety, higher steeping temperatures lead to faster initially growth and higher respiration, resulting in lower extract contents and lower protein modification [13].

Baxter et al. [3, 4] and *Reeves et al.* [21] carried out trials comparing the even higher steeping temperature of 20, 25 and 30 °C with 16 °C and reduced the germination time by one day. Here, considerably reduced enzyme activities in the warm steeped malt samples but a faster cytolytic modification were found. Also, the filterability (filtrate volume after 30 min by folded filter tests) of mashes produced from warm steeped malt samples was markedly lower.

Recent studies from *Müller et al.* [11] found that applying steeping temperatures between 20 up to 30 °C leads to an improved homogeneity, enhanced cytolytic modification and improved lautering performance without negatively affecting the malt quality as

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compared to lower steeping temperature of 15 °C. An optimum in germination performance and homogeneity lay between 20 and 25 °C, resulting in a quicker start of the germination promoting an earlier onset of the cytolytic modification of the barley. The malting losses only increased slightly applying higher steeping temperatures and a time reduction of the germination process appears to be possible while similar or better malt qualities can be achieved. Müller [12] also varied the germination temperature between 16 and 28 °C to obtain the influence of the temperature on the germination and thus the resulting malt quality and malting losses. Applying a germination temperature of up to 24 °C compared to 16 °C led to a faster start of germination, to an improved malt quality, and in particular to an enhanced cytolytic modification. Furthermore, a similar to improved homogeneity was achieved in a shorter germination time without markedly increasing the malting losses. The optimal germination temperature was detected between 20 and 24 °C.

Lubert et al. [9] investigated the influence on the water sensitivity of even higher steeping temperatures from 20 up to 50 °C during the first of three wet steeps, varied from 15 min to 12 hours. The water sensitivity of a more heat sensitive barley did not increase by 10 % with wet steeps up to 8 hours at 25 °C, 6 hours at 30 °C, 3.5 hours at 35 °C, 2 hours at 40 °C and 1 hour at 45 °C. When applying different temperatures, the malt quality parameters extract and extract difference were impaired remarkably above these maximal initial steeping periods. The other barley cultivar could be steeped about twice as long at the different temperatures without exceedingly worsening the malt quality. It was recommended that short wet steeps at high temperatures below 30 °C lead to an optimal initially growth, but the best malt extract contents are achieved at 20 °C steeps. *Ward* and *Briggs* [28] agreed to this, whereby 25 °C and steeps over 8 hours should not be exceeded; otherwise the procedure could be harmful to the grain.

Regarding the water supply there are two main procedures applied, pneumatic wet steeps and spraying steeps. Traditionally, a steeping procedure includes two or three wet steeps to achieve a high steeping degree. A spray steeping can replace parts of the wet phases. *Narziß et al.* [17] assumed that spray steeping is not as efficient as wet steeping. According to *Voborsky* [27], spraying results in a faster initial germination, which is strongly supported through a higher temperature of the spraying water.

An important parameter to regulate the germination is the steeping degree defined by the water content of the steeped barley [26]. Between 32 and 38 % the germination processes in the barley grains start [9]. *Dietrich* and *Siegfried* [5] described a direct correlation between embryonic activity and moisture content. To achieve a fast initial growth, water contents of 38–40 % seem to be necessary. In consequence, raised water contents intensify the growth leading to amplified enzymatic activities and modification, but also greater losses [22].

Furthermore, the homogeneity of a malting batch is of interest. Heterogeneities during steeping cannot be corrected during the later germination or kilning processes [1]. For this reason, *Home et al.* [6] suggested the counting of chitted grains during steeping and at the start of germination to evaluate the homogeneity of the germination initiation and progress.

The aim of this study was to find an optimal steeping regime using elevated steeping and germination temperatures according to previous trials of Müller et al. [11, 12] which recommended steeping as well as germination temperatures from 20 to 25 or 24 °C, respectively. For this reason, different steeping regimes were implemented in laboratory steeping and small scale malting trials using two common barley cultivars. The procedure consisted of two wet steeps, whereby the first was varied between 2 and 8 hours and the second between 0 (spraying) and 2.5 hours. Dry rests between the wet steeps, the adjusted steeping degree, germination and kilning programs were kept constant for all trials. This was necessary to investigate the influence of different wet steep' durations on the water uptake, speed of germination as well as the final malt homogeneity and the malt quality, exclusively. During steeping and germination the growth performance was recorded.

2 Materials and methods

2.1 Used barley varieties

Two two-row spring barley varieties Propino and Scarlett were used for laboratory steeping and pilot plant malting trials. The characteristics of the cultivars are summarised in table 1.

2.2 Lab-scale trials

Two pre-trials were done in laboratory scale. The first trial was done with the common summer barley variety Propino. Steeping was carried out with 200 g batches in perforated plastic cups in duplicate. A basin with tempered and agitated water functioned as steep where the false-bottomed cups were placed. The duration of the first wet steeps was 2, 3, 4 and 5 h at 22 °C, followed by an air-rest of 18 h at 21 °C. After the air-rest was over, which was performed in an insulated chamber with slowly air circulation, a second steep was held with a duration of 1.5, 2 and 2.5 h at a temperature of 20 °C. The different temperatures of the steeping steps were applied for all trials. Only the wet steep durations were varied.

In the second laboratory trial, the steeping regimes of the first trials were extended. Six different steeping regimes were implemented with a first steep of 5, 6, 7 and 8 h at 22 °C, followed by an air-rest of 18 h. The second wet steep was kept at 2.5 h. Additionally, two

Table 1 Data of used two-row summer barley cultivars Propino and Scarlett

	Origin	Crop year	Water [%]	Protein [%]	Germination energy [%]	Water sensitivity [%]
Propino	Germany	2012	12.6	10.3	98	23.5
Scarlett	Argentina	2011	12.7	10.5	99	7.0

special trials with an first wet steep of 6 h were conducted; one with a second wet steep of 20 min in order to simulate a direct steeping out after filling the steeping vessel and one without a second wet steep. The barley was only sprayed with 15 mL of water for simulating a steeping regime without second wet steep and a first spraying after steeping out dry.

The germination was aborted after the first day of germination. For evaluation of the steeping regimes, the reached steeping degree and the percentage of germinated kernels was determined before the second wet steeps and on the first germination day. To get a first information about the cytolytical progress, the green malt was kilned after one germination day and the mealiness was analysed.

2.3 Pilot plant trial

For further investigation of the optimal wet steeping phases, both barley cultivars (Propino and Scarlett) were steeped in a small scale malting plant (system model A1-2008, no. 176/1, Schmidt-Seeger, Beilngries, Germany) for 3 h/2 h, 4 h/1 h, 5 h/1 h and 6 h/0.33 h at 22 °C/20 °C for the first / second wet steep, respectively. Afterwards the germination (3 days: 20–21.5 h at 20 °C, 23 h at 22 °C, 13 h at 21 °C and 17 h at 17 °C) and kilning (1 day: 6,5 h at 37,5 °C, 4,5 h at 40 °C, 2,5 h at 45 °C, 2 h at 50 °C, 2 h at 55 °C 1,5 h at 60 °C, 4 h at 80 °C, 1 h at 82 °C) procedures were kept constant to investigate the influence of the steeping regime, exclusively. All trials were done in duplicate.

The automated malting plant consists of a combined steeping-/germination unit with a maximum load of 16 baskets á 400 g each and an accordingly adjusted kilning unit. The steeping-/germination unit is equipped with a box containing the 16 baskets and housed in an insulated floodable chamber. The box can be ventilated with tempered and humidified air and can be periodically rotated (every 6 h) to avoid the formation of clusters. During germination, the water content of the samples was checked daily by weighing the germination baskets and calculating the steeping degree with reference to the dry matter. Afterwards, the amount of water for adjusting the steeping degree to 45 % was calculated by the actual steeping degree and initial barley weight. It was sprayed onto the baskets on the first (twice) and second germination day (only little corrections necessary).

After air rest and on the first germination day, the percentage of chitted and forked grains were counted to monitor the germination performance and homogeneity influenced by the different steeping regimes.

The rootlets of the kilned malt were removed with an automated sample cleaner (model SLN, Pfeuffer, Kitzingen, Germany) and the removed rootlets were weighed for determining the losses.

2.4 Malt analyses

The malt analyses mealiness, extract fine grist, Kolbach-Index, β-glucan content, modification and homogeneity (Carlsberg method), homogeneity of acrospire length were performed according to MEBAK [10]. To verify the results, all the analyses were done in duplicate.

3 Results and Discussion

In the first laboratory trial, the first wet steep was varied between 2 and 5 hours and the second between 1.5 and 2.5 hours (see Fig. 1). Longer first steeps at 22 °C result in significant higher moisture contents after the air rest compared to short ones which also was found in several investigations [3, 4, 7]. The variation of the second wet steep did not result in significant higher steeping degrees. Differences in water content after first steep could not be caught up with the second steep. Hence, the duration of the first wet steep seemed to be markedly more important for the final steeping degree after steeping.

The counting the percentage of chitted kernels after the air rest and on germination day 1 (germinative energy after one day) showed that the duration of the first wet steep significantly influences the start of germination. On germination day 1, no difference could be found which may be traced back to the relatively high steeping and germination temperatures and the resulting accelerated growth. As Dietrich [5] and *Sims* [22] stated, a higher initial steeping degree yields a faster germination performance.

Based on the highest water uptake and germination performance of the samples steeped for 5 hours, a second laboratory trial was done extending the first wet steeps up to 8 hours. Two additional trials with a first wet steep of 6 h were conducted; one with a second wet steep of 20 minutes in order to simulate a direct steeping out after filling the steeping vessel and one without a second wet steep. This sample was sprayed with 15 mL water for simulating a steeping regime without a second wet steep and a first spraying after steeping out dry.

The laboratory trials (see Fig. 2) show a strong correlation between the duration of the first steep and the moisture content after air rest ($R^2 = 0.96$). A first wet steep higher than 6 hours seemed to be useless due to no significant increase of the steeping degree on germination day 1. After a first wet steep of 6 hours, a spraying instead of a second wet steep was sufficient to increase the steeping degree to the value of a 4 h/2.5 h steeping regime, but compared to the other samples which had a first wet steep of

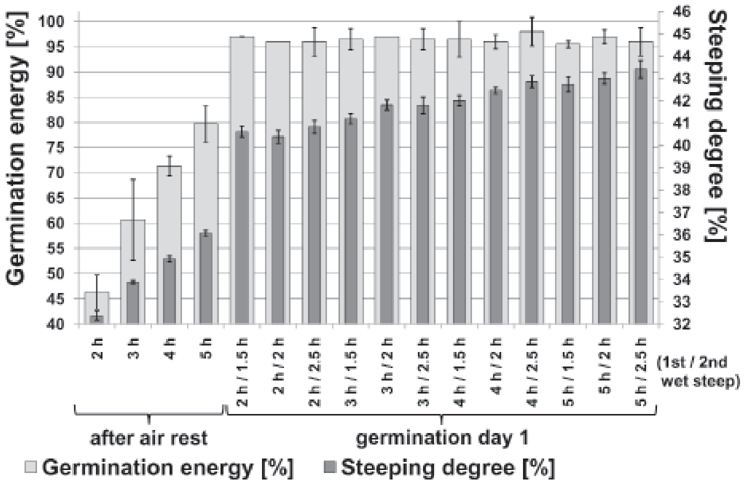

Fig. 1 **Germination energies and steeping degrees after the air rest and on germination day 1 (standard deviation of duplicate determination), lab-scale trial 1**

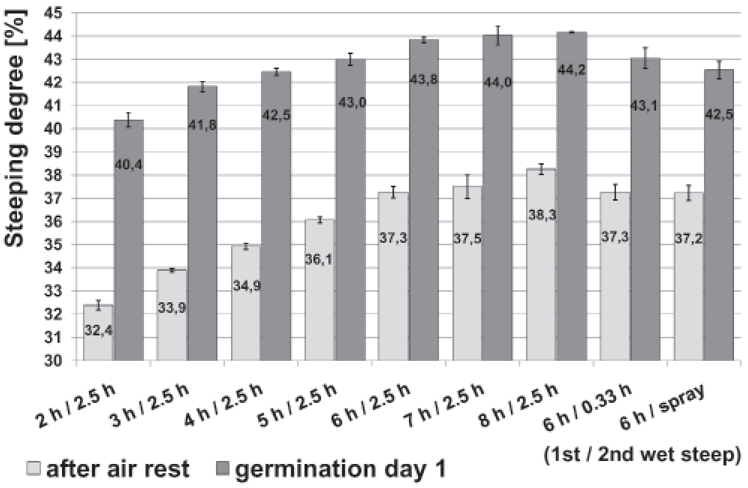

Fig. 2 Steeping degrees after air rest and on germination day 1 (standard deviation of duplicate determination), lab-scale trial 1+2

6 hours, the steeping degree was significantly lower. Narziß et al. [17] already assumed that spray steeping is not as efficient as wet steeping.

Regarding the germinative energy, no significant differences between the wet steep duration of 5 to 8 hours could be detected (see Fig. 3). Nevertheless, the germinative energy of the samples steeped for 8 hours seemed to decrease slightly. According to Lubert et al. [9] and Ward et al. [28], e.g. wet steeps of longer than 8 hours at 25 °C can lead to an increase of the grain's water sensitivity thus decreasing the germinative energy. This could also have been the cause for the slight decrease applying a first wet steep of 8 hours in present investigations. Even though the spraying instead of a second wet steep led to a reduced steeping degree, the germination performance was similar to the other samples steeped longer than 5 hours. This may be explained by the lack of a growth inhibiting second wet phase due to the low solubility of oxygen. This outcome confirms Voborsky's findings [27] in which spraying resulted in a faster initial germination performance.

To get first information about the progress of cytolytic modification, the green malt samples of the second lab-scale trial were kilned after one germination day and the mealiness was analysed (see Fig. 4). Despite of no significant differences, the highest mealiness was found for the 5 h/2.5 h-sample. Surprisingly, no correlation between the mealiness and the germination performance could be found which suggests that kernel growth and kernel modification do not necessarily relate to each other.

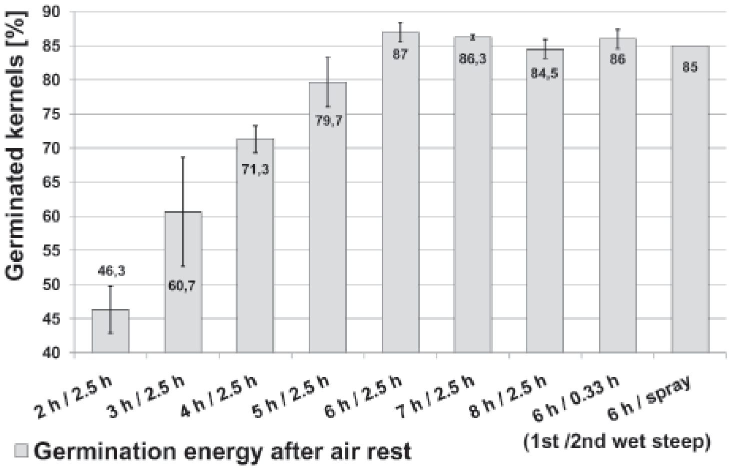

Fig. 3 Germination energies after air rest (standard deviation of duplicate determination), lab-scale trial 1+2

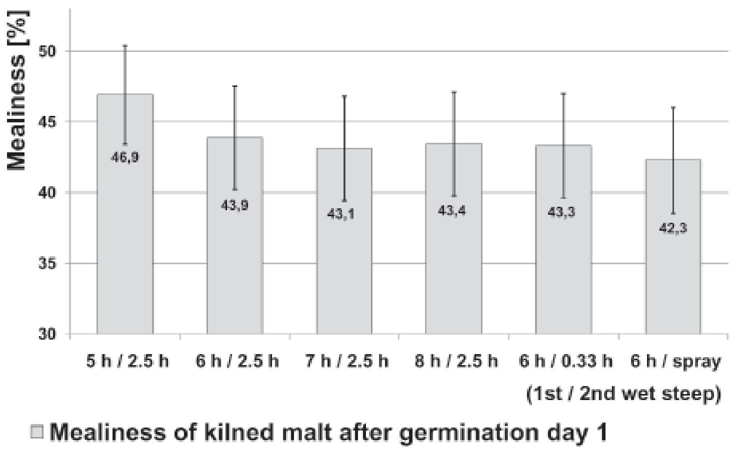

Fig. 4 Mealiness of kilned malt after one germination day (standard viation according to MEBAK), lab-scale trial 2

Based on this, the facts that the germinative energy is not increased with first wet steeps of higher than 5 hours and that the second wet steep was found to be less important for the water uptake, the steeping regimes for the small scale malting trial were chosen. Using the two barley cultivars Propino and Scarlett, extended steeping regimes 4 h/1 h, 5 h/1 h and 6 h/0.33 h (1st/2nd wet steep) were compared with a reference steeping applying a first wet steep of 3 hours and a second wet steep of 2 hours.

Again, a shorter wet steep led to markedly reduced steeping degrees after the air rest. It can be assumed that the first steep is much more effective for water uptake than the second steep. Despite of the smaller kernels of barley cultivar Scarlett, the barley Propino soaked the steeping water a bit faster during the first wet steep and air rest. In addition to the kernel size, the barley variety and year of crop also can influence the water uptake [31]. The samples 5 h/1 h and 6 h/0.33 h were similar, but a higher steeping degree range of 40–41 % was reached compared to the samples which were steeped 5 hours in total.

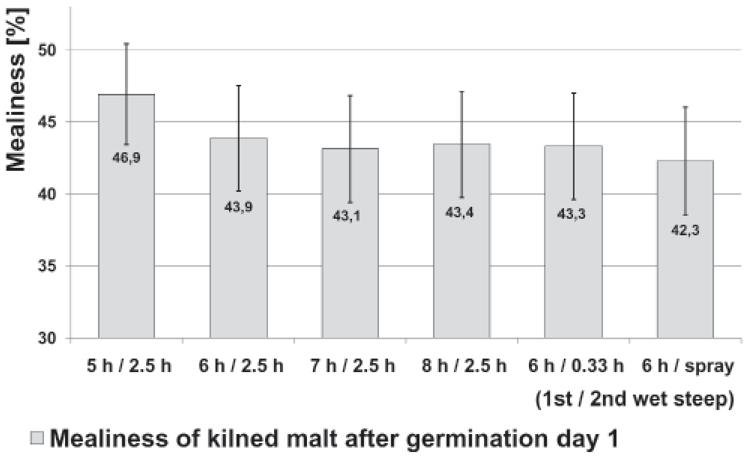

Fig. 5 Steeping degrees after air rest and on germination day 1 (standard deviation of duplicate determination), pilot plant trial

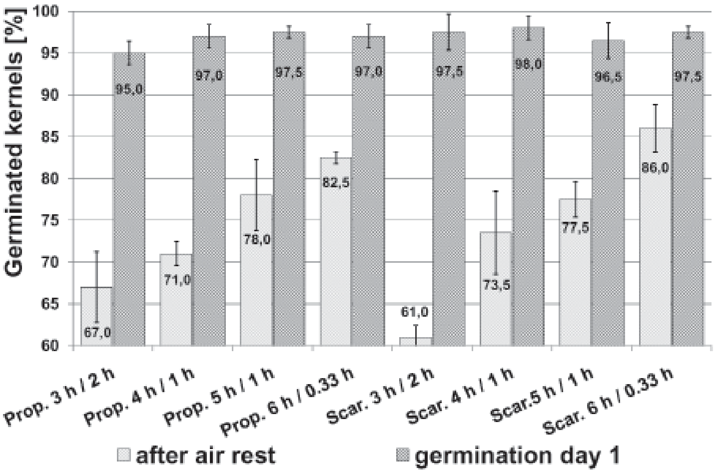

Fig. 6 **Germinative energies after air rest and on germination day 1 (standard deviation of duplicate determination), pilot plant trial**

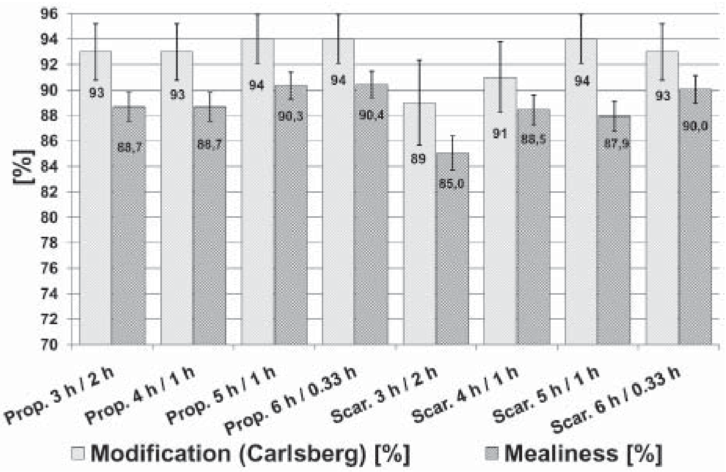

Fig. 8 **Comparison of malt analyses modification and mealiness (standard deviation according to MEBAK), pilot plant trial**

Regarding the germination performance, for both barley varieties, a faster germination start was found when applying longer first wet steeps (see Fig. 6) which confirmed the results of the lab-scale trials. On the first germination day, again, no differences were observable because of the accelerated growth at the applied temperatures. Up to a first steep of 6 hours, no inhibition of growth was detectable.

Typical malt analyses (Fig. 7–10) were carried out to evaluate the different steeping regimes by its malt quality. In general, the results of malt analyses were in the specifications recommended by MEBAK.

Figure 7 compares the extracts and malting losses of the different steeped malt samples, whereby the extracts did not show any differences. In correlation with the higher steeping degrees and faster germination initiation, the malting losses were slightly higher when applying first wet steeps of 5 and 6 hours compared to shorter steeps. The losses may be compensable by reducing the germination time. This seems possible with regards to the enhanced cytolytic modification, as indicated by the β-glucan contents in figure 9, which were significantly lower when applying first wet steeps of 5 and 6 hours for the barley Propino. Additionally, for Scarlett, the β-glucan content also was lower in the 4 h/2 h-sample compared to the reference sample (3 h/2 h). This could be confirmed by the parameters modification according to Carlsberg and the mealiness, both showing higher values. Nevertheless, the results of these parameters were not significant due to the high standard deviation of the methods.

The proteolytic modification, indicated by the Kolbach-Index, was rather low for all malt samples steeped at relatively high temperatures between 20 and 22 °C and germinated between 17 and 22 °C. Several authors [13, 14, 16, 18, 24, 29, 30] exposed the same observation in malting trials at higher temperatures. The Propino malt samples steeped 4 and 5 hours showed significant higher Kolbach-Indices which are nearly acceptable according the MEBAK specifications. This gave a hint that prospective trials might solve the problem of the too low protein degradation by adapting the germination program which is more affecting the proteolysis compared to the steeping regime.

Figure 10 illustrates a comparison of the homogeneities analysed with the Calcofluor method according to Carlsberg and evaluated by the acrospire length. Due to the high standard deviations of both methods, no significant differences could be observed. Ne-

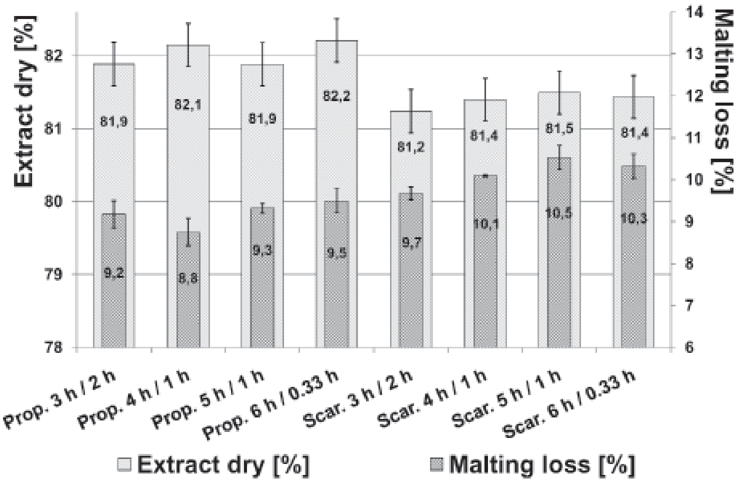

Fig. 7 **Comparison of malt analysis extract and malting losses (extract's standard deviation according to MEBAK; malting loss' standard deviation of duplicate determination), pilot plant trial**

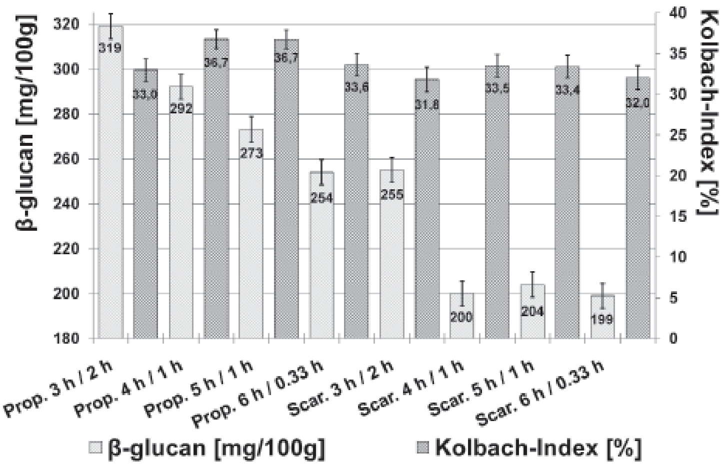

Fig. 9 **Comparison of malt analyses β-glucan content and Kolbach-Index (standard deviation according to MEBAK), pilot plant trial**

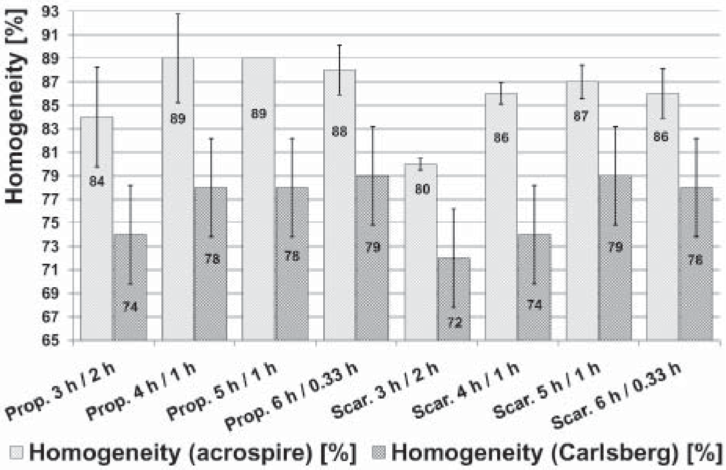

Fig. 10 **Comparison of the homogeneity according to Carlsberg and the homogeneity of the acrospires length (Carlsberg's standard deviation according to MEBAK; acrospires' standard deviation of duplicate determination)**

vertheless, both methods showed higher homogeneities for the extended first wet steeps up to 6 hours compared to the reference steeping regime (3 h/2 h) for both barley cultivars. This confirms the other results which showed that a longer first wet steep was advantageous for the resulting malt quality due to the higher importance and effectiveness of the first wet steep compared to the second wet steep.

Summarising the findings, the steeping procedures 5 h/1 h and 6 h/0.33 h (1st and 2nd wet steep) led to the highest water uptake which in turn resulted in the faster germination start and finally in enhanced cytolytic modification and slightly higher homogeneities.

4 Conclusion

Different steeping regimes with varied durations of the first (2–8 h) and second (20 min to 2.5 h or only spraying) wet steeps were investigated, using the two row barley cultivars Propino and Scarlett. In all trials, the same temperature regime (1st wet steep at 22 °C, air rest 18 h at 21 °C, 2nd wet steep at 20 °C) was used. Furthermore, the steeping degrees were adjusted to 45 % for all small scale malting trials and germination as well as kilning programs were kept constant for an investigation of wet phases' impacts, exclusively.

The duration of the first wet steep correlated with the moisture content after the air rest, which was also described in literature [3, 4, 7]. Supporting Dietrich and Sims [5, 22], a higher initial steeping degree yielded a faster germination start.

Furthermore, the first wet steep turned out to be more important for the water uptake compared to the second wet steep. An inadequate steeping degree after first wet steep could not be compensated by a longer second wet steep. When applying a reasonable long first wet steep, a spraying instead of a second wet steep seemed to be sufficient for acceptable malt quality.

The reached steeping degree had an impact on the germination performance, which increased with higher initial steeping degrees. On the other side, laboratory trials showed an inhibition in initial germination by too long first wet steeps of 8 hours, which was also stated by *Lubert et al.* [9] and *Ward et al.* [28]. It is important, to achieve a growth-adequate moisture content in the grain as fast as possible to gain a good cytolytic modification and malt homogeneity. In consideration of the laboratory and pilot plant malting trials, the optimal steeping procedure seems to contain a first wet steep around 5–6 hours, whereas the second steep should be rather short. This can be explained by a slow metabolism when the grain has not yet started germination. During the second wet steep, when metabolism is already accelerated, an oxygen deficiency by long wet steeps must be avoided because the grain has to recover from an "anaerobic" phase, thus, the longer the second wet steep, the lower the germination performance.

The malting losses increased slightly with a higher germination performance. Due to a better initial modification, this might be compensated with a shorter total germination time [11].

Referring to the malt analyses, it was obvious that the proteolytic modification was too low compared to literature recommended values [10] which should be balanced by varying the germination program in prospective trials.

Compared to the moderate steeping regime (1st wet steep 3 h; 2nd wet steep 2 h), the cytolytic modification, indicated by the β-glucan content, was markedly increased by extending the first wet steeps to 5 or 6 hours, also resulting in slightly higher homogeneities. The positive effect of the first wet steeps points out the importance of the water distribution in the endosperm which was already stated by *Axcell et al.* and *Rath* [2, 20].

Nevertheless, water and temperature sensitivity of the barley, variety and crop year must be taken into consideration and thus the suitability of barley for an accelerated steeping and germination program should be verified.

It has to be taken into consideration that applying warm steeping at 20–22 °C can lead to a fast heating up of the grain bed in dependency on the climatic conditions and the steeping equipment of the malting plant. High steeping temperatures thus may require a heating unit for the water preparation as well as insolated steeping tanks and perhaps a stronger CO_2-extraction to keep the temperature during the dry rests, especially during warm seasons and regions.

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6 References

1. Aalbers, V. J., Drost, B. W. and Pesman, L.: Aerated Steeping Systems, MBAA Techn. Quart. **20** (1983), no. 2, pp. 74-79.
2. Axcell, B., Jankovski, D. and Morrall, P.: The Crucial Factor in Determining Malt Quality, The Brewers Digest **58** (1983), pp. 20-23.

3. Baxter, E. D., Reeves, S. G. and Bamforth, C. W.: The Effects of Increased Steeping Temperatures on Enzyme Development in Malt, J. Inst. Brew. **86** (1980), pp. 182-185.
4. Baxter, E. D. and O'Farrell, D. D.: Effects on Raised Temperatures During Steeping and Germination on Proteolysis During Malting, J. Inst. Brew. **86** (1980) pp. 291-295.
5. Dietrich, B.: Einfluß und Bedeutung der Belüftung während der Weicharbeit, BRAUWELT **106** (1966), no. 1/2, pp. 1-4.
6. Home, S., Stenholm, K. and Olkku, J.: Measuring and Evaluating Malt Homogeneity, Proc. 27th EBC Congr., Fachverlag Hans Carl, Nürnberg, Germany, (1999), pp. 365-375.
7. Huang, X., Han, Y. and Yu, S.: The Effect of Steeping Conditions on Arapiles Malting, BrewingScience – Monatsschrift für Brauwissenschaft **57** (2004), no. 2, pp. 13-15.
8. Kretschmer, K. F.: Über die Güteeigenschaften von Braumalzen, BRAUWELT **107** (1967), no. 48/49, pp. 929-934.
9. Lubert, D. J. and Pool, A. A.: Studies in Barley and Malt XXII. Effect of Elevated Temperatures During Multiple Steeping, J. Inst. Brew. **70** (1964), pp. 145-155.
10. Mitteleuropäische Brautechnische Analysenkommision. Brautechnische Analysemethoden, Band Rohstoffe, Selbstverlag der MEBAK, Freising-Weihenstephan, Germany (2006)
11. Müller, C., Kleinwächter, M., Selmar, D. and Methner, F.-J.: The Influence of Elevated Steeping Temperatures on the Resulting Malt Homogeneity and Malt Quality, BrewingScience – Monatsschrift für Brauwissenschaft **66** (2013), no. 7/8, pp. 114-122.
12. Müller, C., Kleinwächter, M., Selmar, D. and Methner, F.-J.: The Influence of Elevated Germination Temperatures on the Resulting Malt Quality and Malting Losses, BrewingScience – Monatsschrift für Brauwissenschaft **67** (2014), no. 3/4, pp. 18-25.
13. Narziß, L.: Moderne Mälzungsmethoden I. Der Einfluß der Weicharbeit auf Keimung und Malzqualität unter besonderer Berücksichtigung der Weichtemperatur, BRAUWELT **105** (1965), no. 81, pp. 1506-1515.
14. Narziß, L.: Steeping as the Foundation of Modern Malting Technology, MBAA Techn. Quart. **3/4** (1966), pp. 237-243.
15. Narziß, L. and Hellich, P.: Die Keimung mit fallenden Temperaturen, BRAUWELT **106** (1966), no. 48/49, pp. 885-894.
16. Narziß, L. and Hellich, P.: Mälzungsversuche bei verschieden hohen, aber konstanten Keimtemperaturen und unterschiedlichen Feuchtigkeitsniveau, wobei der jeweils maximale Keimgutwassergehalt zu verschiedenen Zeiten hergestellt wird, BRAUWELT **106** (1966), no. 44, pp. 801-811.
17. Narziß, L.: Die Weicharbeit im Lichte neuester Erkenntnisse, BRAUWELT **107** (1967), no. 84/85, pp. 1569-1582.
18. Narziß, L.: Der Stand der Mälzereitechnologie, BRAUWELT **129** (1989), no. 21/22, pp. 939-940, 953 -961.
19. Pollock, J. R. A. and Pool, A. A.: Enzymes of Barley and Malt III – The latent β-amylase of Barley, J. Inst. Brew. **64** (1958), pp. 151-156.
20. Rath, F.: Histologische und physiologische Untersuchungen zur Wasseraufnahme bei der Vermälzung unterschiedlicher Gerstengenotypenverschiedener Herkünfte und Erntejahrgänge mit dem Ziel der Optimierung von Mälzungsarbeit und Malzqualität, dissertation, TU Berlin, (1993), pp. 152-171.
21. Reeves, S. G., O'Farrell, D. D. and Wainwright, T.: The Effect of Increased Steeping Temperature on Malt Properties, J. Inst. Brew. **86** (1980), pp. 226-229.
22. Sims, R. C.: Germination of Barley: Effects of Varying Water Contents upon the initiation and maintenance of growth, J. Inst. Brew. **65** (1958), pp. 46-50.
23. Sommer, G. and Antelmann, H.: Untersuchungen über ein Verfahren zur Minderung des Mälzungsschwands, Brauwissenschaft **19** (1966), no. 12, pp. 337-343.
24. Sommer, G.: Eiweißabbau und Aminosäure-Zusammensetzung, EBC Monograph **II** (1975), pp. 188-197.
25. Sommer, G.: Einige Aspekte moderner Mälzereitechnologie, Brauwissenschaft **29** (1976), no. 1, pp. 21-28.
26. Swanston, J. S. and Taylor, K.: The Effects of Different Steeping Regimes on Water Uptake, J. Inst. Brew. **96** (1990), pp. 3-6.
27. Voborsky, J.: Einfluß der Sprühweiche und der Wassertemperatur auf die Qualität des Malzes, Die Lebensmittelindustr. **18 (10)** (1971), pp. 377-380, 428-431.
28. Ward, P. and Briggs, D. E.: Methods for Accelerating Malting a Small Scale Investigation, J. Sci. Fd Agric. **22** (1971), pp. 581-586.
29. Weith, L.: Studien zu Technologie der Mälzerei VII. Der Einfluss der Faktoren Zeit, Temperatur und Wassergehalt auf die Malzqualität, Proc. 11th EBC Congr., Fachverlag Hans Carl, Nürnberg, Germany, (1967), pp. 251-265.
30. Zastrow, K.: Aufgaben, Ergebnisse und Probleme der Kleinmälzung, Mschr. Brauerei **14** (1961), pp. 36-40.
31. Zila, V. V., Trkan, M. and Skvor, F.: Über Korngröße und Weiche, Woch. Brau. **59**/14 (1942), pp. 63-65.

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