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# The Influence of Elevated Steeping Temperatures on the Resulting Malt Homogeneity and Malt Quality

**Achieving a homogenous malt quality within industrial scale malt batches of up to 300 tons is a major goal for the malt industry. Malt analyses represent only small samples and merely give a rough mean score over thousands of kernels. Cytolytically badly modified or even ungerminated kernels may occur consequently leading to lautering and filtration problems e.g. due to high remaining unhydrolysed β-glucan fractions. Published findings claim that relatively low temperatures during steeping and germination (12–17 °C) are required to produce high quality malts, however, these processes consequently take 5 to 7 days excluding the kilning. Most of these studies were carried out several decades ago and new barley varieties with improved malting properties are available now.**

**In this study, constant steeping temperatures between 15 and 35 °C were used to obtain the influence of the temperature on the germination and thus the resulting malt homogeneity and quality. The use of a steeping temperature of up to 30 °C resulted in faster germination rates, higher germination energies and improved malt qualities as well as increased malt homogeneities in comparison to the reference temperature of 15 °C. Furthermore, the lautering performance of the produced malts, evaluated by a laboratory lautering test, was improved or equal when using a steeping temperature of up to 30 °C. The optimal steeping temperature in the trials was proven to lie 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. The outcome of these trials could help the malting industry to save energy and time.**

Descriptors: steeping temperature, germination energy, homogeneity, malt quality

## 1 Introduction

During steeping, which is the initial and key step in malt production, the grain's water content, the so-called steeping degree, is increased to induce the germination [3]. According to Sims [28], the grain kernels start germinating at water contents above 30 %. The steeping regime in most cases consists of 2–3 immersion phases (wet steeps) and periodic dry rests. After the steeping process, the steeping degree normally ranges between 38 and 41 %. The germination performance is primarily influenced by the steeping regime, the temperatures and the rate of water uptake. Latter, in turn, is dependent on the cultivar, the crop year, the kernel size, the nitrogen content, the kernels' physiological status (dormancy, water sensitivity) [3, 6, 7] and a sufficient oxygen supply [9, 32, 34]. Nevertheless, the steeping temperature is probably the most important influencing factor on the water uptake of the grain. The literature suggests relatively low temperatures of 12–17 °C during steeping [14, 18, 20, 25] and germination [19, 24, 30, 33] to produce malt with a high quality, such as high extract yields and a good proteolytic and cytolytic modification. 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 [29]. Hence, many authors investigated the use of higher steeping temperatures during the last decades.

Despite of suggested steeping temperatures below 13 °C [20] in order to get a good malt quality while achieving low malting losses, *Narziss* and *Friedrich* [22] found higher activities of all analysed amylolytic, proteolytic and particularly cytolytic enzymes in the malts produced with wet steep temperatures of 21 °C compared to 15 °C. The temperature during the dry rests as well as germination was constantly kept at 15 °C for both trials. According to all malt analysis parameters, a germination time reduction of one germination day was possible. Trials of *Sommer* [29] with steeping temperatures of 12, 16 and 20 °C during the complete steeping process provided evidence of similarly satisfying malt qualities. In particular, the cytolytic modification was slightly improved, but the extract yield concomitantly decreased when higher steeping temperatures were

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applied. *Baxter* et al. [4] and *Reeves* et al. [26] carried out trials comparing the even higher steeping temperature of 30 °C with 16 °C and reduced the germination by one day. Here, considerably reduced enzyme activities in the warm steeped malts were found. Also, the filterability (filtrate volume after 30 min by folded filter tests) of mashes produced from warm steeped malts was markedly lower. In further trials [5], the steeping and germination temperatures of 16, 20 and 25 °C at different process time points were compared. The best results were achieved for a malt produced with warm (20 °C) wet phases at the end of steeping. Warm temperatures generally led to a faster cytolytic modification, evaluated by the malt parameter extract difference, but also to reduced filterabilities up to 50 %. *Huang* et al. [11] immersed barley for 31, 24 and 16 hours at steeping temperatures of 15, 20 and 25 °C, respectively, and used the same germination conditions for all trials. Increased free amino nitrogen values, diastatic power but also increased malting losses when applying higher temperatures could be found. The optimum temperature of this trial was suggested to be 20 °C. Investigations of *Voborsky* et al. [31] using different steeping temperatures from 18 to 30 °C and applying a spray-steeping program (spraying with water every 10 min) showed contradictory results with considerably decreasing amylolytic activities (diastatic power, α- and β-amylase) and lowered malting losses when applying higher temperatures. This was achieved by adjusting 2 % lower steeping degrees for the warmer steeped samples and by shortening the germination time by one day when applying elevated temperatures of 24 and 30 °C as compared to the 18 °C-trial. As a consequence, the lack of time and lower steeping degree could have compensated possible advantages applying higher temperatures. Nevertheless, the 30 °C-trial resulted in a significantly worse malt quality, thus a maximum steeping temperature of 24 °C was suggested. *Lubert* et al. [16] investigated the influence of even higher steeping temperatures from 20 up to 50 °C during the first of three wet steeps, varied from 15 min to 12 h, on the water sensitivity. The two barley varieties reacted in a different manner to the treatments. The water sensitivity of the 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. Furthermore, the malt quality parameters extract and extract difference were impaired remarkably above these maximal initial steeping periods when applying the different temperatures. The other barley could be steeped about twice as long at the different temperatures without exceedingly worsening the malt quality.

Nowadays, very large malt batches are processed, which frequently lead to heterogeneities within the grain beds. As a result, β-glucanase activities vary within the batches, thus remaining high concentrations of viscosity increasing non-hydrolyzed β-glucan in parts of the batches. This, in turn, can lead to lautering and filtration problems during the brewing process [2, 8, 23]. The kernels' enzyme activities mainly depend on their physiological status, which can be influenced by the steeping parameters. According to *Aalbers* et al. [1], heterogeneities during steeping cannot be corrected during the later germination or kilning processes. Apart from inhomogeneities in a barley batch originated from the growth on the field, e.g. kernel size or physiological status, *Axcell* et al. [3] proposed that a homogenous water uptake of the kernels in one batch is very important for a simultaneous start of the germination and thus for the homogeneity of the resulting malt. For this reason, *Home* et al. [10] suggested the counting of chitted kernels during steeping and at the start of germination to evaluate the homogeneity of the germination ignition and progress.

The topic of the present study was to elaborate the effect of different steeping temperatures (15, 20, 25, 30, 35 °C) in small scale malting trials on the speed of germination and on the final malt homogeneity and quality. Here, common barley varieties used nowadays were malted using a modern steeping regime with two "short" wet steep phases and "long" dry rests (14–15 h). The germination parameters time, steeping degree and temperature and the kilning program were kept constant for all trials. Hence, the influence of the steeping temperature on the malt quality could exclusively be observed by controlling the germination performance and malt analyses. Additionally, laboratory lautering tests as well as the time of the congress wort separation were carried out with the produced malts to get information about the processability.

## 2 Materials and methods

### 2.1 Malt Analyses

The malt analyses extract, lautering and saccharification time, apparent final attenuation, viscosity, pH value, free amino nitrogen, colour of boiled wort, turbidity, Kolbach index, modification and homogeneity (Carlsberg method), β-glucan, friability and acrospire length were performed according to MEBAK [17]. The activities of α- and β-amylases were determined with commercial assay kits (Megazyme, Bray, Ireland). All analyses were done in duplicate.

### 2.2 Laboratory lautering tests

An in-house-method of a laboratory lautering test was used to determine the lautering properties of the mashes produced from the respective malts. The lautering test was performed in triplicate using the Filtercheck®-apparatus (Stabifix, Gräfelfing, Germany) at 20 °C. For this, 50 g malt are ground with a DLFÜ-mill (Bühler, Uzwil, Switzerland) with a disk gap of 0.8 mm and mashed in with 180 mL bidistilled water of 45° C. For mashing, the congress mashing apparatus (Bender & Holbein, Bruchsal, Germany) and regime [17] are used. After cooling the mash to 20 °C, bi-distilled water is added to the mashes adjusting the beaker contents to 200 g. After filling the Filtercheck®-apparatus followed by a lautering rest of exact 2 minutes, the filtrate is collected on a scale and the filtrate volume is recorded during the test and plotted against the lautering time. Comparing the curves and the filtrate volume after 300 seconds provides information about the malts' lautering properties.

### 2.3 Small-scale malting

For the steeping trials, the two two-row barley varieties Marthe (water 13.9 %, protein 10.5 %, germination energy 98 %, water sensitivity 35 %) and Tipple (water 13.5 %, protein 9.2 %, germination energy 96 %, water sensitivity 26 %) were malted in a "Heyl" small scale malting. The "Heyl" system consists of four steeping/germination wheels each holding 12 cylindrical mesh baskets (950 g barley). The wheels are housed in an insulated chamber which is ventilated with tempered and humidified air. For steeping, the baskets are

dipped periodically into a water tubs, located below the wheels, by the turning wheels (0.25 turns per minute) to ensure a good water and oxygen supply of the malt. During germination, the water tubs are drained and the wheels are turned continuously to aerate the grain and to avoid the formation of clusters.

The first wet steep and the dry rest were carried out in the laboratory. 2 L-flasks were filled with aliquots of 950 g (in duplicate) of the two cleaned two-row summer barley varieties and with tempered tap water (15 °C for 4.25 h; 20 °C for 3.5 h; 25 °C for 2.75 h; 30 °C for 2 h and 35 °C for 1.5 h). For the dry rest (14–15 h), the samples were placed in the baskets of the "Heyl" system and kept in several heating chambers in order to ensure the different temperatures. Afterwards, the baskets were transferred to the "Heyl" plant for the second wet steep which was carried out at 15 °C to ensure the same germination temperature for each sample (germination for 5 days at 15 °C). The duration of the second wet steep was set according to the reached steeping degree after the dry rest (Table 1).

The water content was checked daily by weighing the germination baskets and calculating the steeping degree with reference to the dry matter. The amount of water to adjust the steeping degree to 45 % was calculated by steeping degree and initial barley weight. It was sprayed onto the wheels' baskets on the first and second germination day. After the dry rest and on the first and second germination day, the percentage of chitted and forked kernels were counted to monitor the germination performance and homogeneity influenced by the different steeping temperatures. On the sixth day, the baskets were transferred to a conventional small scale kiln and withered at 50 °C for 18 hours and cured at 80 °C for 5 hours. The rootlets of the kilned malt were removed with an automated sample cleaner model SLN (Pfeuffer, Kitzingen, Germany) whereby the rootlets were weighed for determining the losses. The steeping regime and the resulting steeping degrees of the different samples are depicted in following table.

## 3 Results and Discussion

Higher temperatures during steeping consequently result in higher steeping degrees of the green malt [29]. The factor steeping parameter itself also is quite important for the germination and influences the resulting malt quality [22]. In contrast to the previously reviewed studies, the chosen durations of the first wet steeps, applying different temperatures (Table 1), were therefore conducted according to preliminary trials in which the suitable wet steep durations were ascertained with the goal to achieve similar steeping degrees after the second wet steep. An influence of a higher steeping degree with increasing steeping temperatures should be excluded and unnecessary extended wet periods at higher temperatures should be avoided. The steeping degrees varied only by about 1.5 % for each barley variety. The slightly decreased steeping degrees when applying higher steeping temperatures, probably was caused by a little faster drying of the film-water after the wet steep through the cylindrical mesh baskets. Due to the negative correlation between the temperature and the achieved steeping degree after the dry rest (Table 1), the warmer steeped samples should not have had an advantage by an influence of the steeping degree. Comparing both barley varieties, the barley Tipple showed a faster water uptake resulting in about 3 % higher steeping degrees after steeping.

According to the reached steeping degrees after the dry rests, the cold second wet steeps were varied, resulting in quite similar steeping degrees for each barley variety until the end of germination. This and achieving steeping degrees above 30 % after the first wet steep were basic requirements for determining the effect of the steeping temperature on the resulting malt homogeneity and quality, exclusively.

As a further process control, the germination performance was monitored by counting and determining the percentage of chitted and forked kernels in duplicate. The germination progress was determined 2 hours after the second wet steep and on the first and second germination day, that is 24, 48, 72 hours after steeping in, respectively (Fig. 1).

Optimal germination performance and germination homogeneity, evaluated by the percentage of germinated kernels (germination energy) and by the difference between forked and chitted kernels, could be observed between 20 and 25 °C for both barley varieties. Despite of a 9 % higher water sensitivity, the barley Marthe showed a higher percentage of germinated kernels within the 35 °C-sample after 48 and 72 hours indicating that it is less heat sensitive than Tipple originated either by different variety proper-

**Table 1 Steeping regimes and resulting steeping degrees (mean of two germination boxes)**

| Barley | Temperature of 1. wet steep + dry rest | Duration of 1. wet steep [hh:mm] | Duration of dry rest [h] | Steeping degree after dry rest [%] | Duration of 2. wet steep (15 °C) [hh:mm] | Steeping degree on germination day 1 [%] | Steeping degree on germination day 5 [%] |
|---|---|---|---|---|---|---|---|
| Marthe | 15 °C | 04:15 | 14–15 | 34 | 03:45 | 41.1 | 44.7 |
| | 20 °C | 03:30 | | 32.6 | 03:55 | 41.8 | 45.0 |
| | 25 °C | 02:45 | | 32.3 | 03:55 | 42.0 | 45.1 |
| | 30 °C | 02:00 | | 31.3 | 04:00 | 41.6 | 45.0 |
| | 35 °C | 01:30 | | 31.4 | 04:00 | 41.4 | 44.7 |
| Tipple | 15 °C | 04:15 | | 37.0 | 02:35 | 44.3 | 44.9 |
| | 20 °C | 03:30 | | 35.9 | 03:10 | 45.3 | 45.4 |
| | 25 °C | 02:45 | | 35.5 | 03:25 | 45.2 | 45.4 |
| | 30 °C | 02:00 | | 34.8 | 03:40 | 44.7 | 44.9 |
| | 35 °C | 01:30 | | 34.6 | 03:40 | 44.6 | 44.6 |

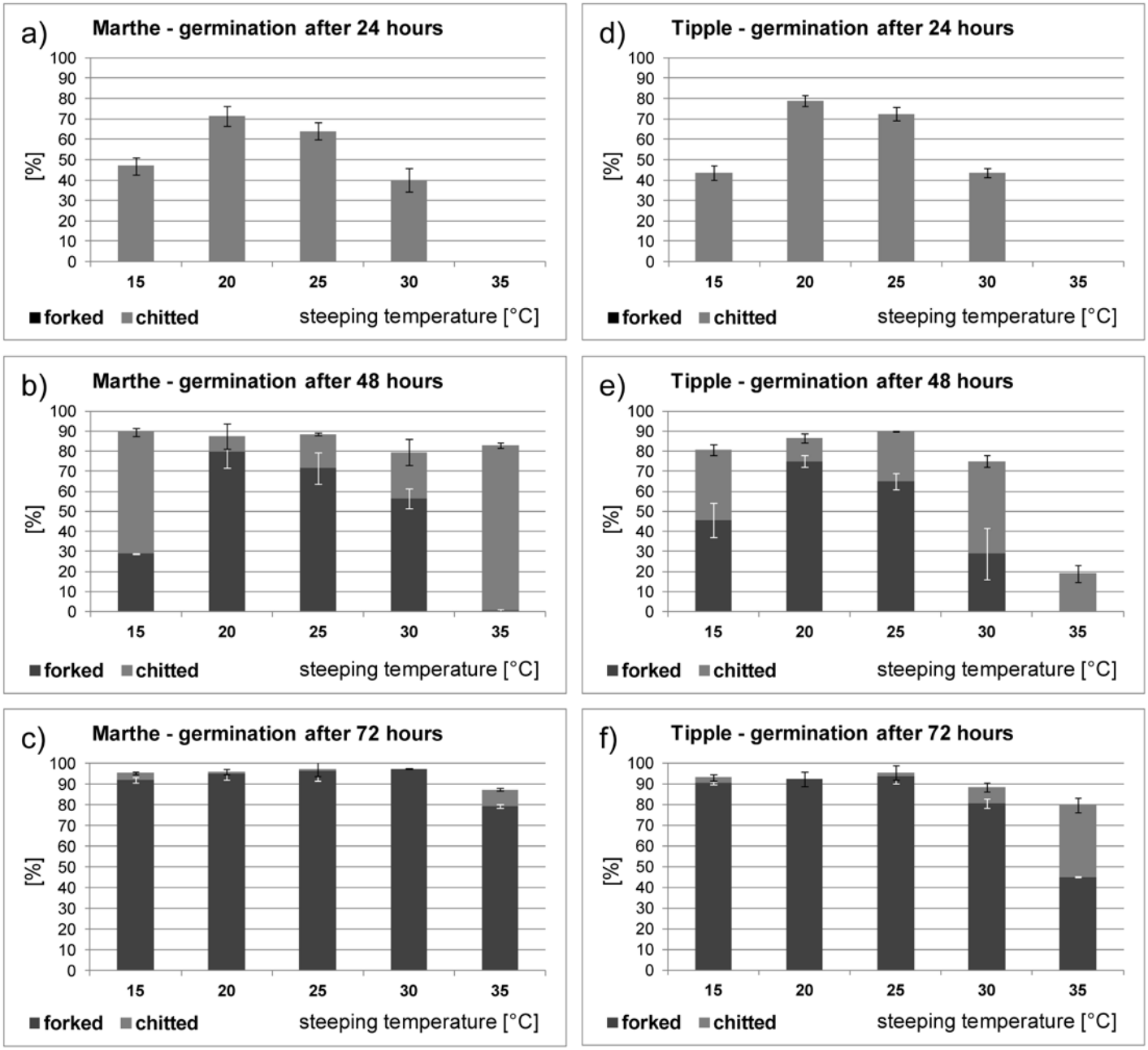


**Fig. 1 Evaluation of the germination performance by counting the percentages of chitted and forked kernels after second wet steep (24 h). on the first (48 h) and second (72 h) germination day; barley Marthe a. b. c; barley Tipple d. e. f. (mean of two germination boxes. duplicate standard deviation of forked and germinateted kernels included)**

ties or by the unknown cultivation conditions. As indicated by the higher germination energy on the second germination day and the smaller difference between forked and chitted kernels after 48 and 72 hours, the germination performance of Marthe was improved up to 30 °C when compared to the reference steeping temperature of 15 °C. The germination performance of the more heat sensitive barley Tipple was inhibited at 30/35 °C as compared to the steeping temperature of 15 °C. Axcell et al. [3] and Home et al. [10] claimed that warm steeping improves the water distribution within the kernels which is important for a simultaneous germination start. This may also explain the improved germination performance from the present study applying higher stepping temperatures than 15 °C. Narziss [24] described decreasing germination energies when cooling the steeped barley fast by more than 10 °C. In the present studies, this temperature shock could not be obtained up to the 30 °C-sample for the barley Marthe and up to the 25 °C-sample for the barley Tipple. In addition to generally too high steeping temperatures, a cause for the decreased germination energies after 72 hours could be a temperature shock due to high temperature differences between the barley samples after the dry rest and the 15 °C of the second wet step. In this case, the germination properties applying higher temperatures possibly could be improved by cooling the barley slowly in the germination box.

The results as observed from the germination control were reflected in the final malt quality. The results of the malt analyses are summarised in tables 2 and 3.

Generally, also the high steeping temperatures up to 35 °C led to acceptable malt qualities which were in the range of the MEBAK

**Table 2 Malt analyses (mean of duplicate) of barley Marthe (+ positively / – negatively evaluated values in comparison to the "normal" steeping temperature of 15 °C). Cursive written parameters are graphically shown in figures 2 and 3**

| Marthe | | | Steeping temperatures | | | | |
|---|---|---|---|---|---|---|---|
| Analyses | Unit | Repeatability r | 15 °C | 20 °C | 25 °C | 30 °C | 35 °C |
| Extract fine grist (d.m.) | % | 0.58 X2 | 81.3 | 81.2 | 81.5 | 81.2 | 81.5 |
| Filtration time | min | 1–8.5 X1 | 43 | 33 **+ | 31 **+ | 28 **+ | 32 **+ |
| Saccharification time | min | – | 10 | 10 | 10 | 10 | 10 |
| Kolbach index | % | 6.7–0.12 m X2 | 44.0 | 43.8 | 44.6 * | 44.7 * | 45.1 * |
| Free amino nitrogen | mg/L | 28–0.105 m X2 | 159 | 150 * | 152 * | 157 | 166 * |
| Turbidity 90° | EBC | 0.04 X2 | 1.2 | 1.3 ** | 1.5 *** | 1.4 ** | 2.1 *** |
| Colour of boiled wort | EBC | 0.052 m X2 | 6.1 | 5.3 * | 5.4 * | 5.3 * | 5.5 * |
| pH value | 1 | 0.08 X2 | 5.93 | 5.94 | 5.94 | 5.92 | 5.86 |
| Viscosity (8.6%) | mPa*s | –0.26+0.2 m X2 | 1.49 | 1.46 *+ | 1.45 *+ | 1.47 *+ | 1.46 *+ |
| *Friability – mealiness* | % | 12–0.11 m X2 | 88.3 | 91.5 **+ | 92.0 **+ | 92.2 **+ | 92.8 **+ |
| Friability – glassiness | % | 0,15+0,35 m X2 | 0.4 | 0.3 | 0.3 | 0.2 * | 0.2 * |
| β-*glucan (d.m.)* | mg/100g | 11 X2 | 170 | 91 ***+ | 69 ***+ | 79 ***+ | 79 ***+ |
| Calcofluor modification | % | 55.3–0.55 m X2 | 93 | 98 **+ | 98 **+ | 95 *+ | 95 *+ |
| *Calcofluor homogeneity* | % | 8.2 X2 | 69 | 92 **+ | 89 **+ | 78 *+ | 70 |
| Acrospire length | % | 1.5–3 X1 | 67 | 71 ** | 72 ** | 71 ** | 62 |
| Homogeneity of acrospire length | % | 0.2–8.5 X1 | 86 | 93 *+ | 94 ***+ | 96 ***+ | 92 **+ |
| α-amylase (d.m.) Megazyme | U/g | 0.05 m X3 | 273 | 266 | 246 * | 264 | 259* |
| β-amylase (d.m.) Megazyme | U/g | 0.05 m X3 | 794 | 862 *+ | 779 | 741 *- | 632 **- |
| App. final attenuation | % | 0.6 X2 | 77.6 | 79.1 **+ | 78..6 **+ | 78.2 * | 77.3 * |
| Malting losses | % | 0.1–0.65 X1 | 7.0 | 6.3 * | 6.6 * | 6.7 * | 7.0 |

(X = repeatability 1: given by each duplicate determination; 2: given by MEBAK ; 3: given by Megazyme – confidence coefficient by t-test: * 95 %, ** 99 %, *** 99.9 %)

specifications [17] with the exception of the Tipple malt steeped at 35 °C. Hence, the results of the germination performance obtained by counting chitted and forked kernels already gave evidence for the resulting quality of the final malts. The parameter glassiness, which indicates quite late germinated or non-germinated kernels, implies a higher heat sensitivity for the barley Tipple due to a significantly increased glassiness applying 35 °C.

The α-amylase activities of the Marthe malts were not markedly influenced by the different steeping temperatures. The enzyme α-amylase is not formed before the second day after steeping in [12, 13, 22], and thus the high steeping temperatures marginally affected the α-amylase formation of the less heat sensitive barley Marthe.

In contrast to this, the α-amylase activities of the Tipple malts were strongly negatively influenced by the high steeping temperatures of 30 and 35 °C. This confirmed published results from Baxter et al. [4], Reeves et al. [26] and Voborski [31], who reported a similar behavior. In contrast to previous investigations of Narziss and Friedrich [22], improved α-amylase activities up to 25 °C could not be observed for both cultivars used. This may be led back to a slightly higher steeping degree when applying wet steeps at 21 °C instead of 15 °C [22].

The enzyme activities of β-amylases were highest at 20 °C and decreased slightly when applying higher temperatures up to 30 °C and strongly when applying 35 °C for both varieties. The enzyme β-amylase is already present in barley and released from the kernel's aleurone layer during germination [12, 13, 25]. In correlation to the significantly lower germination performance (Fig. 1), it was demonstrated that applying a temperature of 35 °C during steeping considerably inhibited the release and formation of β-amylases. A decrease of 10 and 32 % as compared to 30 °C was observed for Marthe and Tipple malts, respectively.

The disadvantage of using elevated temperatures up to 30 °C during steeping was an increased turbidity of the congress wort produced from the Tipple malts. Again, Tipple happened to be more heat sensitive and showed higher turbidities when compared to Marthe malt.

Tipple showed a too extensive proteolytic modification (Kolbach index) with 46–47 % at 20 and 25 °C. In contrast to this, the Kolbach indices of the Marthe malts only varied little. This behaviour proves again the variance in heat sensitivity of the two barley cultivars used, caused either by different variety properties or by the unknown cultivation conditions.

Regarding the malting losses, the results of the barley Marthe did not fall into the line with the other analytical data. Comparing e.g. the acrospire length or the modification, a measuring inaccuracy should be assumed for the 20 and 25 °C-samples. Yet, the barley Tipple showed a suitable trend. Applying a steeping temperature

**Table 3 Malt analyses (mean of duplicate) of barley Tipple (+ positively / – negatively evaluated values in comparison to the "normal" steeping temperature of 15 °C). Cursive written parameters are graphically shown in figures 2 and 3**

| Tipple | | | Steeping temperatures | | | | |
|---|---|---|---|---|---|---|---|
| Analyses | Unit | Repeatability r | 15 °C | 20 °C | 25 °C | 30 °C | 35 °C |
| Extract fine grist (d.m.) | % | 0.58 X2 | 82.7 | 83.0 * | 82.7 | 82.2 * | 82.5 |
| Filtration time | min | 10–37.5 X1 | 112 | 58 ***+ | 72 ***+ | 92 **+ | >120 (*)– |
| Saccharification time | min | – | 10 | 10 | 10 | 10 | 10 |
| Kolbach index | % | 6.7–0.12 m X2 | 44.3 | 46.0 *– | 46.9 **– | 43.5 * | 44.0 |
| Free amino nitrogen | mg/L | 28–0.105 m X2 | 142 | 142 | 160 * | 142 | 141 |
| Turbidity 90° | EBC | 0.04 X2 | 1.8 | 2.6 *** | 3.1*** | 4.7 ***– | 6.7 ***– |
| Colour of boiled wort | EBC | 0.052 m X2 | 6.0 | 5.8 | 6.1 | 5.0 ** | 5.1 ** |
| pH value | 1 | 0.08 X2 | 5.90 | 5.88 | 5.89 | 5.96 | 5.93 |
| Viscosity (8.6%) | mPa*s | –0.26+0.2 m X2 | 1.50 | 1.47 *+ | 1.48 *+ | 1.49 + | 1.52 *– |
| *Friability – mealiness* | % | 12–0.11 m X2 | 88.2 | 93.5 **+ | 95.1 **+ | 92.6 **+ | 82.6** – |
| Friability – glassiness | % | 0,15+0,35 m X2 | 0.7 | 0.3 * | 0.4 | 0.4 | 2.8 ***– |
| β-*glucan (d.m.)* | mg/100g | 11 X2 | 214 | 112 ***+ | 94 ***+ | 113 ***+ | 259 **– |
| Calcofluor modification | % | 55.3–0.548 m X2 | 90 | 99 **+ | 97 **+ | 97 **+ | 81 *– |
| *Calcofluor homogeneity* | % | 8.2 X2 | 71 | 91 **+ | 86 **+ | 78 *+ | 53 **– |
| Acrospire length | % | 0–8.3 X1 | 61 | 63 * | 62 * | 61 | 53 ** |
| *Homogeneity of acrospire length* | % | 0.2–8.5X1 | 82 | 90 ***+ | 90 ***+ | 89 **+ | 63 ***– |
| α-amylase (d.m.) Megazyme | U/g | 0.05 m X3 | 293 | 289 | 276 *– | 248 **– | 222 **– |
| β-amylase (d.m.) Megazyme | U/g | 0.05 m X3 | 781 | 802 + | 780 | 763 | 519 **– |
| App. final attenuation | % | 0.6 X2 | 76.0 | 77.8 **+ | 78.1 **+ | 77.9 **+ | 76.1 |
| Malting losses | % | 0.55–1.05 X1 | 8.5 | 9.0 *– | 8.5 – | 6.8 ** | 6.6 ** |

(X = repeatability 1: given by each duplicate determination; 2: given by MEBAK ; 3: given by Megazyme – confidence coefficient by t-test: * 95 %, ** 99 %, *** 99.9 %)

of 20 °C led to slightly increased malting losses by 0.5 % due to an enhanced growth. In comparison to the reference steeping temperature, the malting losses were equal at 25 °C and strongly reduced by 1.7 and 1.9 % when applying 30 and 35 °C, respectively. Comparing the cytolytic malt parameters (lautering time, viscosity, mealiness, β-glucan content, modification and apparent final attenuation, except turbidity) of the reference sample (15 °C) with those of the malt samples steeped at increased steeping temperatures demonstrates a markedly improved modification up to a steeping temperature of 30 °C for both cultivars used and even up to 35 °C for the Marthe malt. An improved cytolytic modification with higher temperatures up to 25 °C could also be shown in by previously discussed investigations from Baxter and Sommer [5, 29]. The results of the filtration time correlated well with the β-glucan content. Linear correlation coefficients of $R^2 > 0.91$ for the Marthe malts and of $R^2 > 0.78$ for the Tipple malts could be observed, whereas latter would be higher if the filtration of the 35 °C-sample would not had been interrupted after 120 min. In contrast to the findings of Baxter et al. [4] and Reeves et al. [26], all Marthe malts steeped at higher temperatures than 15 °C showed reduced filtration times compared to the reference malt that had the highest β-glucan content. For Tipple malts, an improvement could be observed up to the 30 °C-sample. In correlation to the highest β-glucan content of this cultivar, the 35 °C-sample showed the slowest filtration. For illustrating the influence of the different steeping temperatures on the cytolytic modification, exemplarily, the β-glucan contents and the mealiness values of both barley varieties are plotted against the applied steeping temperatures in figure 2.

When summarising these date, the optimal steeping temperature was observed to lie between 20 and 25 °C for the barley Tipple and 20 up to 30 °C for the barley Marthe.

The standard methods Calcofluor according to Carlsberg and development of the acrospires in the final malts [17], which both offers the possibility to express the homogeneity, were used to evaluated the homogeneity of the produced malts. For clarification of the trends, their results (Table 2 and 3) are also shown in figure 3.

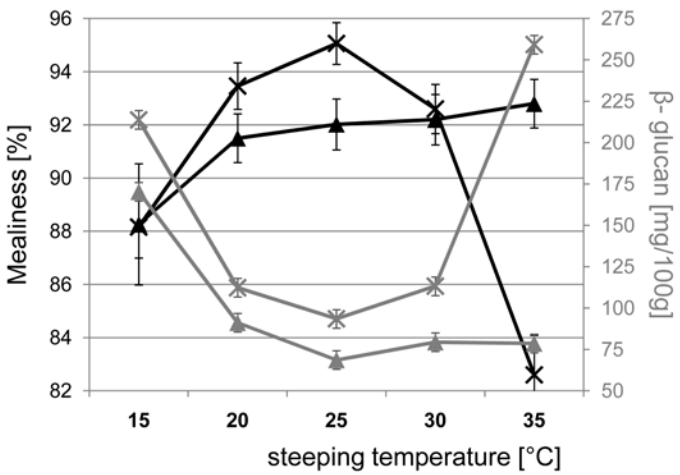


**Fig. 2 Comparison of mealiness (black lines) and β-glucan content (grey lines) for both cultivars: ▲ – Barley Marthe; x – barley Tipple (standard deviation according to MEBAK analyses)**

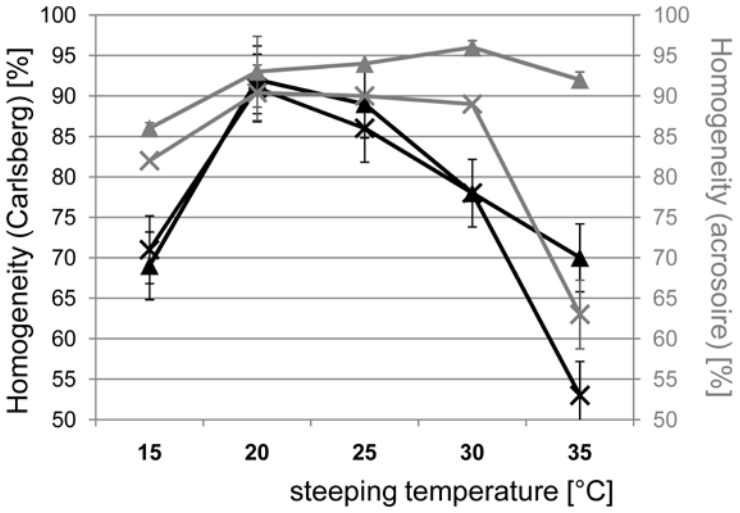


**Fig. 3** **Comparison of the homogeneity according to Carlsberg (black lines) and the homogeneity of the acrospires length (grey lines) for both cultivars: ▲ – barley Marthe; x – barley Tipple (Carlsberg-standard deviation according to MEBAK analyses; acrospire standard deviation of duplicate determination)**

By means of both methods, higher homogeneities up to 30 °C and 35 °C compared to the cold steeping at 15 °C could be observed for the barleys Tipple and Marthe, respectively. In reference to the 15 °C-malt, the homogeneity (Carlsberg method) of both varieties could be improved by about 20–23, 15–20 and 78 % at 20, 25 and 30 °C, respectively. Nevertheless, the homogeneities were slowly decreased by higher steeping temperatures above 20 °C. The homogeneities of the acrospire length of all Marthe malts and up to the 30 °C-sample of the Tipple malts were improved by 7–10 %. An optimal steeping temperature range concerning

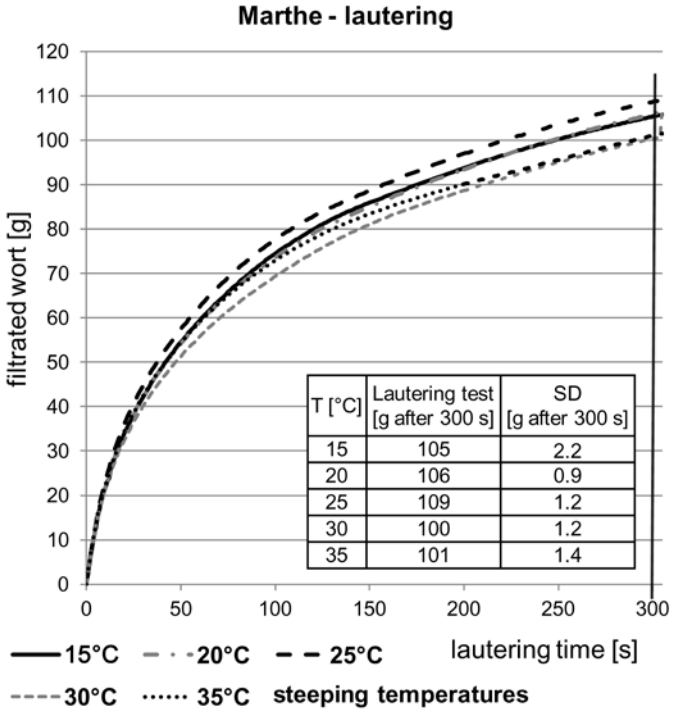


**Fig. 4** **Comparison of the lautering properties of the different steeped malts from barley Marthe, evaluated by an in-house laboratory lautering test; (SD = standard deviation of the triplicate determination).**

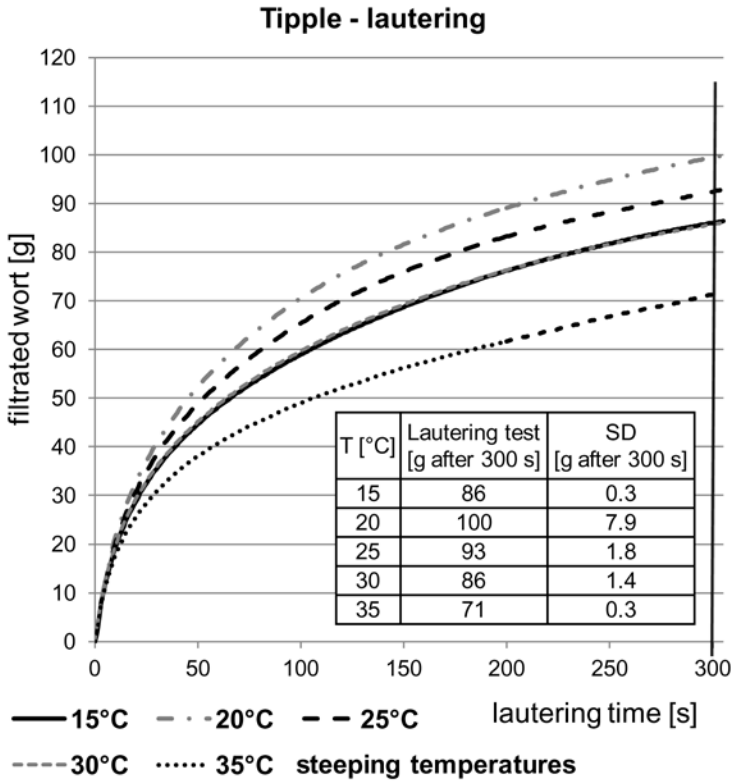


**Fig. 5** **Comparison of the lautering properties of the different steeped malts from barley Tipple, evaluated by an in-house laboratory lautering test; (SD = standard deviation of the triplicate determination)**

the homogeneities, determined with the Calcofluor method, can be recommended within 20 and 25 °C for both barley varieties. Considering the homogeneity of the acrospires, an optimum temperature for Marthe was not apparent because there were no clear differences visible between 30 °C and 35 °C. The homogeneities of the more heat sensitive barley Tipple were steady between 20 and 30 °C, followed by a tremendously reduced homogeneity of the 35 °C-malt.

'Good' malt qualities as suggested by analytical data do not necessarily imply an adequate lautering time in the breweries [27]. The lautering performance is influenced by many factors and published literature claims are ambiguous. The findings of Baxter et al. and Reeves et al. [4, 5, 26] showed tremendously reduced rates of congress wort separation analysing malts steeped at high temperatures of 20, 25 and 30 °C compared to 16 °C. To examine the influence of the steeping temperature on the lautering performance of the produced malts in the present study, an in-house method was developed (see materials and methods section) and used to check the produced malts. The obtained curves of the tests are displayed in figures 4 and 5. The trials were done in triplicate.

The malt's lautering properties are evaluated by comparing the curve shapes as received when plotting collected wort volume against filtration time and by analysing the total volume after 300 seconds filtration time.

The Marthe malts generally showed a better lautering performance than the malts produced from the cultivar Tipple; however, they showed no correlation with the analytical data (Tables 2 and 3), and thus must have its origin in the different properties of the

barley varieties or in different cultivation conditions. Considering the results of the Marthe malts, all mashes were lautered quite similarly with a good lautering rate. The fastest lautering could be observed for the 25 °C-malt and the performance was slightly reduced applying 30 and 35 °C. The Tipple malts showed improved lautering rates up to 25 °C in comparison to the reference malt, whereas for the 20 °C-malt the fastest wort separation could be observed. Temperatures higher than 20 °C led to a reduction of the lautering property again, resulting in a lautering rate which was equal to the 15 °C-malt and considerably lower than the 30 and 35 °C-malt, respectively. Generally, the results fitted well with the overall malt quality of each cultivar and also with the evaluation of the germination performance (see Fig. 1).

Summarised, the lautering performance was not negatively affected by higher steeping temperatures up to 30 °C for both barley varieties. In contrast, the lautering rate of the Tipple malts was considerably improved by applying higher steeping temperatures up to 25 °C as compared to 15 °C.

All findings of this present study are summarised in table 4.

## 5 Conclusion

The influence of high steeping temperatures on the germination performance, malt quality and homogeneity, and lautering performance was investigated using the two two-row summer barley cultivars Marthe and Tipple. Constant steeping temperatures between 15 and 35 °C were applied during the first wet steeps and dry rests. Achieving even steeping degrees after the dry rest, after the second wet steep and during the germination was thereby a basic requirement for investigating in the exclusively influencing factor steeping temperature. Taken together, data from the present study suggest that optimal steeping temperatures lie between 20 and 25 °C for both cultivars (Table 4). However, applying steeping temperatures above 20 °C led to a slightly increased malting loss by 0.5 % in comparison to steeping at 15 °C which is explained by enhanced growth. This should be compensable by a time reduction of the germination process which appears to be possible while similar or better malt qualities can be achieved. Improved germination properties resulting in improved malt qualities, and particularly the cytolytic modification, malt homogeneities and lautering performances when applying higher steeping temperatures up to 25 °C as compared to steeping at 15 °C stay in contrast to several findings [4, 5, 11, 26, 31]. Here, decreased malt qualities, considerable increased malting losses and lautering problems were found applying higher steeping temperatures up to 30 °C.

Narziss et al. [21, 24] showed a great positive influence of the dry rest time on the cytolytic modification, the attenuation degree, the amylolytic enzyme activities and the homogeneity (Carlsberg Calcofluor method) and therefore suggested a dry rest of at least 12–13 hours. Literature data implies immersing the malt not longer than 8 h at 25 °C, 6 h at 30 °C and 3.5 h at 35 °C [16]. The previously discussed trials [4, 5, 11, 26] about higher steeping temperatures of more than 21 °C up to 35 °C were performed using short dry rests of 1–10 hours, often combined with long wet phases. Based on this, short initial wet steep durations of 2.75 h, 2 h and 1.5 h for steeping at 25, 30 and 35 °C, respectively, and dry rests of 14–15 hours were applied as these regimes were identified in preliminary trials to be most favourable for achieving similar steeping degrees and to avoid extended wet phases at higher temperatures. Furthermore, the today's barley varieties, whose properties have been steadily improved during the last decades, may less heat sensitive and more suitable for applying high steeping temperatures.

In dependency on the climatic conditions and the steeping equipment of the malting plant, high steeping temperatures, especially during warm seasons may be unpreventable, but during cold seasons recommendable. Hence, steeping equipment with sufficient air suction capacity for aerating the barley during the dry rests is necessary for applying higher steeping temperatures. According to the findings in the present study, steeping temperatures above 30 °C should generally be avoided. In addition, barley cultivars should be checked before malting if they are suitable for an accelerated steeping regime applying higher temperatures.

**Table 4 Summarised comparison of all findings**

| Barley | Marthe | | Tipple | |
|---|---|---|---|---|
| | Optimal temperature range [°C] | Improved compared to 15 °C [°C] | Optimal temperature range [°C] | Improved compared to 15 °C [°C] |
| Germination performance | 20–25 | up to 30 | 20–25 | up to 25 |
| Malt quality (in sum) | ~ 25 | up to 35 | 20–25 | up to 30 |
| Amylase activities | 20 | up to 20 | 20 | up to 20 |
| Cytolytic modification | 20–25 | up to 35 | 20–25 | up to 30 |
| Losses | not evaluated | | 15; 30; 35 | – |
| Homogeneity (Carlsberg) | 20–25 | up to 30 | 20–25 | up to 30 |
| Homogeneity (Acrospire) | 20–30 | up to 35 | 20–25 | up to 30 |
| Filtration time (MEBAK) | 20–35 | 20-35 | 20 | up to 30 |
| Lautering performance (laboratory lautering test) | 25 | up to 25 | 20 | up to 25 (30 similar) |

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