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The Influence of the Withering Temperature on the Resulting Proteolytic and Cytolytic Modification of Pale Malt

During kilning, the germinated malt has to be dried from moisture contents of 42–48 to 3–6 % to interrupt the growth and to make the malt storable. Therefore, the green malt is firstly dried by blowing air with moderate temperatures between 45–65 °C through the grain bed. This first of two steps during kilning is called withering and it is important to ensure highest possible enzyme activities in the malt which are mandatory for later brewing process. During withering, the enzyme formation and activities are accelerated and a lot of biochemical reactions, e.g. the enzymatic degradation of cell wall substances hemicelluloses (cytolysis) and protein (proteolysis), occur especially at a stage of still high grain's moisture content. The withering temperature has a remarkable influence on the final malt quality. After withering, when a moisture content of 10–15 % is reached, the malt is cured at higher temperatures between 75–90 °C for some hours for pale malt like Pilsener malt.
Laboratory withering trials in a grain layer height of 35 cm applying isotherm temperatures between 30 and 60 °C were carried out to investigate the influence on the resulting pale malt quality especially by means of the cytolytic and proteolytic modification. The curing process, 4 hours at 80 °C, was kept constant for all trials. The cytolysis was enhanced by reducing the withering temperature. Comparing the 30 and 60 °C samples, an about 60 mg/L lower β-glucan content, an about 8 % higher mealiness and an about 5 % higher modification according to Carlsberg could be observed. The proteolysis could be reduced as indicated by a 2.8 % lower Kolbach-Index comparing the lowest and the highest applied withering temperatures of 30 and 60 °C. Therefore, an optimal withering temperature regarding the cytolytic and proteolytic modification in present study was found to range between 30 and 37 °C. Additionally, the influence of the withering temperature on different layers of the grain bed was investigated. The upper layer stayed moist for a longer period, thus enzymatic activities, by means of a higher cytolytic and proteolytic modification, could take place in a higher extend. Thereby, the malt quality deviation between the upper and lower layer increased with higher temperatures. The disadvantages of lower withering temperatures are an extended kilning process and a slightly higher energy consumption of the kilning fan.

Descriptors: kilning program, withering temperature, cytolysis, proteolysis, grain layers

1 Introduction

During kilning, as the last main step in malt production, the water content of the germinated green malt is dried from about 42–48 % to 3–6 % by a hot air stream which is blown through the grain bed from the bottom up whereby in most cases recirculated air is used when outcoming air is not saturated with water vapour during the last hours in order to save energy [19, 31].

The aims of the drying process are an interruption of the growth and enzymatic modification as well as the warranty of a shelf life for a long storage stability of the easily perishable green malt. Furthermore, the enzymes, formed during germination, have to be treated gently for keeping highest possible activities due to the importance for the brewing industry [27, 31, 26]. Therefore, the grain is normally pre-dried at temperatures of 45–65 °C kept for 10–24 hours depending on the air flow until a humidity of 10–15 % is reached during the so-called withering process. At that stage, the enzymes are more robust against higher temperatures due to the lower grain's humidity and the temperature can be increased to the curing temperature of about 75–90 °C for pale malt which are kept for 3–6 hours to further reduce the moisture content [11, 23, 26, 31].

The biochemistry of kilning can roughly be divided into three phases which are defined according to the range of temperature grain humidity and the ongoing reactions. The first one is the "germination" phase in which the acrospire and rootlets are still growing. The ongoing catabolism and anabolism take place up to a moisture content of 20 % and a temperature below 40 °C in the grain bed [4, 16, 19, 23, 26]. *Reinikainen et al.* [30] demonstrated a two to fourfold respiration by measuring the CO_2 production

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during the first hours of withering compared to the germination proving the enhanced growth in the "germination" phase. After that, the "enzymatic" phase follows. The growth is interrupted but the enzymatic degradation of high molecular substances like starch, hemicelluloses and protein continues resulting in an accumulation of sugars and amino acids. Proteases and amylases work up to a grain temperature of 60–70 °C whereas β-glucanases are inactivated at lower temperatures. At grain temperatures higher than 70 °C, chemical reactions take place, exclusively. During this "chemical" phase, colour components by means of caramelised sugars, oxidised polyphenols and melanoidins as well as aroma components, the last two due to Maillard reactions, are formed [4]. According to *Barrett et al.* [3], the free amino nitrogen (FAN) decreases during the curing phase because they act as precursors for the Maillard reactions.

Furthermore, DMS precursors (S-Methylmethionine = SMM), synthesised during germination, are degraded and formed DMS (Dimethylsulfid = DMS) is evaporated whereby a higher withering and curing temperature accelerate the degradation [2, 7, 8]. These claims stand in contrast to Forster's findings [9] of which lower withering temperatures led to a higher DMS-P degradation. Forster explained that by an increased degradation at longer lasting higher moisture contents.

In general, many parameters influence the drying process. The commonly used kilning technique of aeration from bottom to top leads automatically to different conditions between upper and lower layers in the grain bed increasing with higher grain beds. During the passing of incoming air through the grain bed, the air is humidified by the wet grain in the lower layers and thus the upper layers are dried slower or not at all in case of saturation. Therefore, biochemical metabolism can longer take place in the upper layer of the grain bed due to longer lasting higher moisture contents which leads to inhomogeneities of a malt batch [23, 27]. Next to the grain layer height, the air flow rate, the conditions of outdoor air by means of temperature and relative humidity, the pressure difference between the incoming and exhaust air, in turn influenced by the grain weight and the empty space between the kernels, the length of the rootlets and mainly the temperature of incoming air influence the duration of the kilning process [11, 33]. In addition, *Schuster et al.* [33] and *Abrahamson* [1] stated that the parameter temperature is much more important than the kilning time for reaching low moisture contents because the reachable moisture content in the malt itself depends on the kilning temperature due a temperature dependant gradient of vapour pressure between the kernel and the kilning air. *Narziss and Stippler* [23] further explained that reaching a moisture content below 10 % is difficult because the moisture gradient and the water transport from inside to outside of the kernel is counteracted by a temperature gradient in the other direction resulting from the evaporative cooling inside the kernel. Therefore, the temperature has to be increased after the drying of adhesive water and moisture on the outer parts of the kernels which can easily be removed.

Grebe et al. [10] simulated the batch-wise kilning process and calculated a lower energy requirements when drying at higher temperatures as an advantage next to the reduced process time. On the other hand, *Bathgate* [4] and *Harris et al.* [13] claimed a remarkable β-glucan degradation during kilning which is important for avoiding filtration problems during brewing because β-glucan can form gels blocking pores of the beer filter [5]. Further investigations [9, 11, 14, 24] showed increasing cytolytic modification when applying lower temperatures during kilning especially during withering. *Narziß and Stippler* [24] evaluated the cytolysis by determining the extract difference, whereby up to 1 % lower values were found when reducing the withering temperature from 65 to 50 °C. Gromus et al. [11] found an up to 3.5 % increased mealinesses when withering between 25 and 35 °C as compared to withering at 50 °C. The enhanced cytolysis can be explained by a relatively high heat sensitivity of hemicelluloses degrading en-zymes, especially with regards to exo-β-glucanases [5, 6, 21, 24, 29]. Nevertheless, *Preece and Hoggan* [29] found that β-glucanase activities vary extremely in different barley cultivars and also observed a barley variety dependant inactivation of β-glucanases between 30 and 75 %. *Zahn* [35] observed a higher β-glucan degradation when applying a more moderate withering by reducing the air flow. The degradation takes place in the first hours of withering when the grain water content is still high and this phase is prolonged by the air flow reduction. In contrast to these findings, *Schuster et al.* [33] could not find changed extract differences and mealiness up to a withering temperature of 70 °C. Others authors [3, 14] observed reduced degrees of final attenuation of worts produced from malts kilned at higher temperatures. This was explained by an enhanced enzyme inactivation of α-amylases and especially β-amylases, which is markedly more heat sensitive compared to the α-amylase, resulting in lower starch degradation during mashing. Therefore, *Narziss and Rusitzka* [26] claimed that in general lower withering temperatures are of advantage for higher enzyme activities. In contrast to this, *Schuster et al.* [33] observed that the β-amylase, indicated by the parameter diastatic power, is only reduced at higher temperatures than 60 °C and the optimal range for its activity during kilning lies between 40 and 60 °C.

The proteolytic enzymes, especially the carboxypeptidases and endoproteases, are known for a relatively high heat stability and for higher catalytic activities at higher temperatures above 50 °C up to 70 °C. Higher withering temperatures thus result in higher protein degradation indicated by higher Kolbach-Indices and higher FAN contents [3, 16, 21, 22, 24, 25, 26, 31].

The kilning temperature also strongly influences the malt colour which is increasing when applying warmer withering as well as curing temperatures due to accelerated Maillard reactions yielding in a higher melanoidin formation [3, 9, 14, 15].

Despite of the discussed economical aspects of withering at higher temperatures by means of the kilning time, the energy consumption and up to 0.6 % lower malting losses [33], the aim of this study was to investigate the influence of the relatively low withering temperature down to 30 °C on the resulting quality of pale malt, especially the cytolytic and proteolytic modification. Therefore, laboratory withering trials at 30 and 60 °C with a grain layer height of 35 cm were carried out using the same frozen green malt and curing the malt for 4 hours at 80 °C for all trials to assess the withering temperature's influence, exclusively. Furthermore, malt samples from two grain layer heights were analysed to evaluate the

resulting homogeneity of the malt when applying different withering temperatures which may be improved at lower temperatures due to more similar conditions in all layers. Previous studies on similar topics dealing about the influence of the withering temperature, especially applying relatively low temperatures down to 30 °C, were done several decades ago, thus modern barley cultivars whose quality changed a lot during the last decades may behave different nowadays.

2 Materials and methods

2.1 Pilot plant trial

For investigating the influence of the withering temperature on the resulting malt quality, the two row summer barley cultivar Marthe (water 13.9 %, protein 10.5 %, germination energy 98 %, water sensitivity 35 %) was steeped and germinated in a "Heyl" small scale malting. The "Heyl" system consists of two steeping/germination wheels each subdivided into quarters which can be filled with up to 25 kg barley. The wheels are housed in an insulated chamber which is ventilated with temperated 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 steeping (1st wet steep: 6 h, air rest: 19 h, 2nd wet steep: 2.5 h) and germination (5 days) temperature was kept at 14 °C. 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 determined by the drying method. It was sprayed onto the baskets on the first and second germination day. After germination, the barley was deep frozen by liquid nitrogen in order to have a constant green malt quality to investigate the influence of the withering temperature, exclusively. The withering trials were done with the kilning unit of a laboratory malting plant (system model A1-2008, no. 176/1, Schmidt-Seeger, Beilngries, Germany). For this, an extra basket, closable by sieves at the top and the bottom, was manufactured to have the highest practicable grain layer in the used kilning unit compared to the original baskets of the plant. 4200 g frozen green malt was filled into the basket resulting in a grain layer height of 35 cm before kilning. A third sieve could be placed in the middle of the basket to separate the upper and lower grain layer in order to be able to run malt analyses from the different layers afterwards. Two temperature loggers recorded the temperatures in the height of 2 and 33 cm of the grain bed. The withering temperatures of 30, 37.5, 45, 52.5 and 60 °C was kept as long as the water content was higher than 13 % which was determined by weighing the basket every 1–2 hours or more often. When a water content of 13 % ± 0.3 % was reached, the same curing program (4 hours at 80 °C) was started for all trials. The energy consumption of the heating system and fan were recorded and the room temperature and humidity were measured for calculating the air's enthalpy and absolute humidity. The trials were done without recirculation of air in order to get more comparable results.

2.2 Malt analyses

The malt analyses moisture content, mealiness, modification and homogeneity (Carlsberg method) were analysed from final malts according to MEBAK [20]. The parameters extract, degree of final attenuation, filtration time, turbidity, colour of boiled wort, pH value, Kolbach-Index, free amino nitrogen (FAN), viscosity, ß-glucan content and DMS-P content were analysed from congress wort produced of the final malts according to MEBAK [20]. The activities of α- and β-amylases and β-glucanases were determined with commercial assay kits (Megazyme, Bray, Ireland). All analyses were done in duplicate.

2.3 Laboratory lautering tests

To get further information about the processability of the produced malt, an in-house-method of a laboratory lautering test was used to determine the lautering properties of the mashes produced from the respective malt samples. The lautering test was performed in triplicate at 20 °C using a Filtercheck®-apparatus (Stabifix, Gräfelfing, Germany). 50 g malt were ground with a DLFÜ-mill (Bühler, Uzwil, Switzerland) at a disk gap of 0.8 mm and mashed in with 180 mL bi-distilled water of 45 °C. For mashing, the congress mashing apparatus (Bender & Holbein, Bruchsal, Germany) and regime according to MEBAK [20] were used. After cooling the mash to 20 °C, bi-distilled water was added to the mashes to adjust the beaker contents to 200 g. After filling the mash onto a steel mesh with a gap size of 0.25 mm placed on the bottom of the Filtercheck®-apparatus, followed by a lautering rest of 2 minutes, the filtrate was collected on a scale and the filtrate volume was recorded during the test and afterwards plotted against the lautering time. Comparing the curves and the filtrate volume after a certain time of 300 seconds provided information about the malt's lautering properties.

3 Results and Discussion

The drying rate was accelerated by higher withering temperatures and a linear response of R^2 = 0.90 between withering time and applied withering temperature of 30–60 °C could be observed (see Fig. 1). The results rather showed a very strong 3rd order polynomial

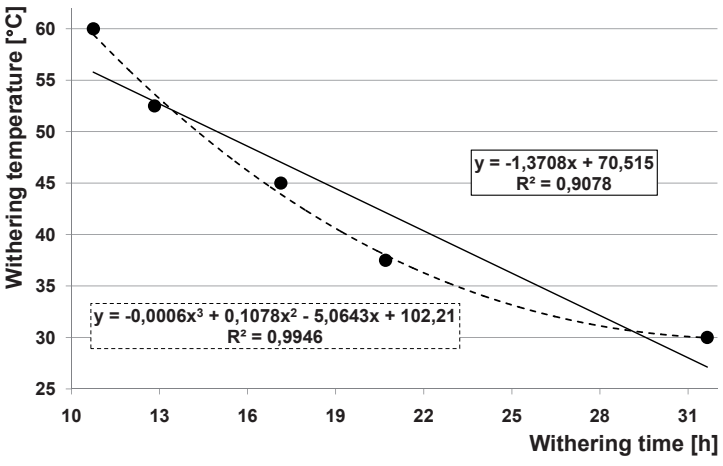

Fig. 1 Correlation between withering temperature and the withering time until a reached moisture content of 13 %

Table 1 Data of kilning time, energy consumption and outdoor conditions (absolute humidity and enthalpy gained from h,x-diagram)

Withering temperature [°C]	Withering time [h]	Heating energy for withering [kWh]	Fan energy for withering [KWh]	Heating and fan energy for withering [kWh]	Mean room temperature [°C]	Mean relative humidity of room air [%]	Mean absolute humidity [g/kg]	Mean enthalpy of room air [kJ/kg]
30.0	31.6	9.5	0.95	10.4	18.8	59.0	8.0	39.2
37.5	20.7	10.6	0.62	11.2	14.9	59.2	6.2	30.8
45.0	17.1	10.4	0.51	10.9	17.0	75.1	9.1	40.1
52.5	12.8	9.2	0.39	9.5	17.8	68.4	8.7	40.0
60.0	10.7	9.1	0.32	9.4	17.7	70.4	8.9	40.4

function because remarkably slower drying could be observed when applying a withering temperature of 30 °C. The deviations from a linear correlation can be explained by water transport through the capillaries of the porous kernel which is dependent on the vapour pressure gradient which in turn is dependent on the drying temperature [1, 23, 33]. Also, *Schuster et al.* [33] found really slow drying rates at 20 and 30 °C. Comparing isotherm kilning temperatures between 20 and 85 °C, a potential correlation between the time and temperature was observed, thus a correlation seems to be strongly dependent on the used system, grain bed height, air flow etc.. Due to the vapour pressure gradient, responsible for the water transport from the inner kernel, the retardation of the drying occurs earlier at lower temperatures. At temperatures below 30 °C, a recommended breakthrough moisture of 10–13 % is said to be difficult to reach [23]. In present investigations (see Table 1), the applied withering temperature of 37.5 °C was capable to reduce the moisture content to the aimed 13 % in less than one day.

In general, the withering at 60 °C led to the lowest energy consumption which had been expected due to the energy requirements of the fan which ran constantly but longer with decreasing withering temperature. Nevertheless, the energy consumption did not correlate with the withering temperature. In contrast, *Grebe et al.* [10] simulated the batch-wise kilning process and found a lower energy consumption when drying at higher temperatures as an advantage next to the reduced process time. In present study, little difference of energy consumption were caused by an influence of the incoming air's conditions by means of the relative humidity, the temperature and resulting the enthalpy. Lower air temperatures of the 37.5 and 45 °C trials might have led to an increased energy consumption for heating up the incoming air.

Temperature loggers were placed in the heights of 2 and 33 cm of the 35 cm grain bed for recording the heating progress in two different layers. *Harnoy et al.* [12] found increasing temperature differences between the lower and upper layer when drying at higher temperatures which could partly be compensated by increasing the air flow. The result of the present trials confirmed these findings as demonstrated in figure 2. Therefore, an inhomogeneity of the kilning process should be reducible when applying lower withering temperatures due to more comparable conditions in different grain layers for a more even duration of biochemical and chemical reactions [23, 27]. Despite of the applied low grain bed height of 35 cm compared to industrial green malt heights of 80–120 cm, the found temperature differences of about 10–28 °C with increasing withering temperatures are remarkable.

The different layer heights also influenced the malt quality independently from the varied withering temperature despite of a three to fourfold lower grain height in comparison to industrial kilns (see Table 2). Next to expected slightly higher moisture contents, up to 0.4 % higher extracts were found in the malts of the upper layer, although the activities of α- and β-amylase did not show considerable differences. A cause could be the slightly higher cytolytic

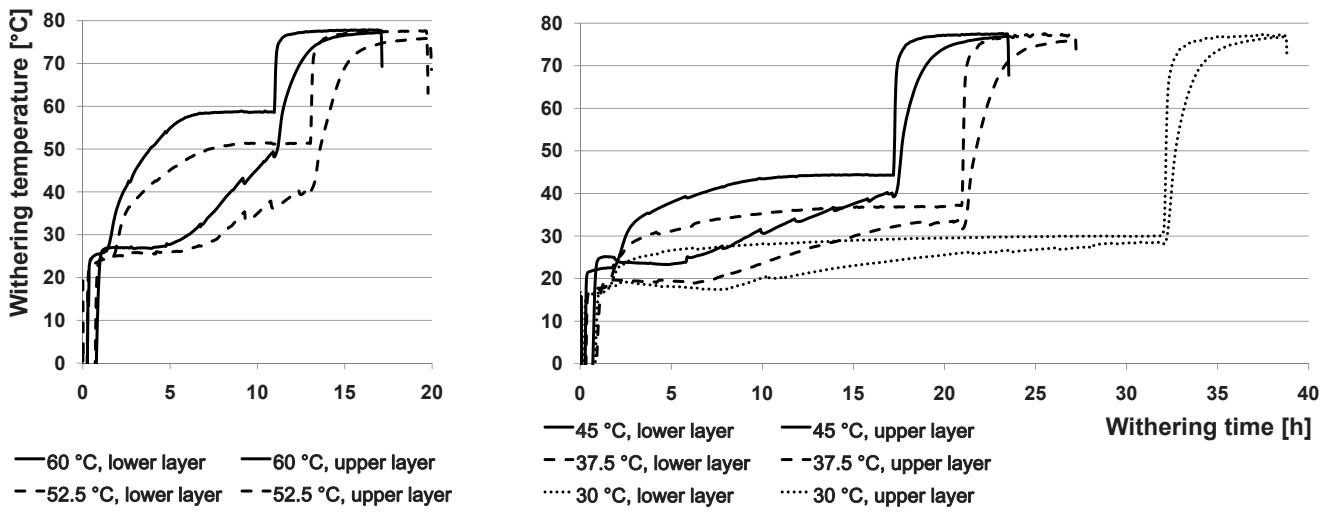

Fig. 2 Comparison of temperature differences between the lower and upper grain layers

modification determined by the parameters viscosity, mealiness, modification and β-glucan which in turn probably resulted from the longer lasting lower temperature at higher moisture contents at the start of withering in the upper layer. Nevertheless, higher activities of the heat sensitive β-glucanases [5, 6, 21, 24, 29] were observed in the final malts of the lower layer which can be explained by a higher inactivation due to higher moisture contents at increased temperatures during the curing phase. Furthermore, slightly higher turbidities could be found in the congress worts produced from the malts of the upper layers, but the congress worts' turbidities did not correlate with the withering temperature. This stays in contrast to findings of *Isebaert et al.* [15] in which the turbidity increased with higher withering temperatures. In case of the temperature insensitive proteases, whose catalysing activities are enhanced at higher temperatures, higher moisture contents when increasing curing temperatures may have led to found slightly higher proteolytic modification in the final malts of the upper layer indicated by the parameters Kolbach-Index and FAN content [3, 16, 21, 22, 24, 25, 26, 31]. Due to the higher FAN contents, which comprise precursors for the Maillard reactions forming colouring substances like the slightly acidic melanoidins, the colours of boiled wort increased and the pH decreased in the upper layers [3, 9, 14, 15]. Generally, the colour of this Pilsener type malt was out of the range of the MEBAK recommendations. Possibly, a cause for this was the freezing and thawing procedures of the green malt before kilning that might have led to an increased oxidation of polyphenols due to a partly destructed fabric structure of the husks. The parameter filtration time did not correlate with the degree of cytolytic modification and also did not show a clear influence of the varied withering temperature. Nevertheless, a slightly improved filtration was found for the lower layer malts of all trials.

Slightly lower DMS-P contents could be observed when applying increasing withering temperatures. Also other authors [7, 8] showed a faster DMS-P degradation when applying higher temperatures. Astonishingly, the differences between the upper and lower layers in the different trials were higher than the difference between the samples withered at different temperatures. Possibly, the kilning time compensated the lower temperature. The higher temperatures in the lower grain bed layers led to significantly reduced DMS-P contents with differences of about 1.5 mg/kg due to an earlier stopped DMS-P formation and/or earlier degradation caused by the higher temperature exposure.

The parameter homogeneity according to Carlsberg normally provides information about the germination performance of barley and should not be influenced during kilning; however, in these trials lower values were found in the upper layer for all trials. This can be explained by an analysis method dependant influence of cytolytic modification on the parameter homogeneity. Nevertheless, considering the β-glucan, Kolbach-Index and colour, greater differences between the malts of the two layers were observed when applying higher withering temperatures which implied a higher inhomogeneity (see Fig. 2). As a logical consequence, withering at lower temperatures should be even more positively affecting the homogeneity in industrial scale with grain heights of 80–120 cm instead of the 35 cm as used in present study.

In figures 3–6, the mean results of both layers of the most important analyses parameters are graphically presented to compare the influence of the withering temperature on the malt quality, exclusively. *Kolbach and Schild* [16] observed an optimal proteolysis between 50 and 70 °C depending on the moisture content of the grain which explains the higher Kolbach-Indices and slightly higher

Table 2 Data of malt analyses; comparison of two different grain bed layer heights (0–17.5 and 17.5–35 cm)

Analysis	30 °C top	30 °C bottom	37.5 °C top	37.5 °C bottom	45 °C top	45 °C bottom	52.5 °C top	52.5 °C bottom	60 °C top	60 °C bottom
Moisture [%]	4.5	4.2	4.3	4.0	4.5	4.2	4.4	4.2	4.7	4.4
Extract fine (dry) [%]	81.5	81.3	81.7	81.3	81.7	81.3	81.6	81.6	81.7	81.3
Final attenuation [%]	84.5	80.8	79.2	79.5	78.8	78.8	79.3	80.3	79.7	78.0
Filtration time [min]	37	30	77	37	55	65	58	42	67	55
Turbidity 90° [EBC]	5.6	4.4	5.3	5.2	6.8	5.4	6.4	5.0	5.5	4.3
Colour of boiled wort [EBC]	10.6	9.0	10.6	9.3	11.2	11.7	14.4	11.7	15.4	12.5
pH value [1]	6.04	6.06	6.06	6.06	5.98	6.00	5.97	6.00	5.93	5.96
Kolbach-Index [%]	43.5	42.8	44.5	43.0	45.3	44.3	45.4	44.3	46.9	45.0
FAN (dry) [mg/100g]	150	140	153	143	156	144	157	155	159	148
Viscosity (8.6 %) [%]	1.46	1.47	1.45	1.46	1.46	1.47	1.46	1.47	1.45	1.47
Mealiness [%]	91.6	88.5	90.0	88.0	88.3	86.7	86.4	84.5	82.8	81.1
Modification [%]	95	95	99	95	98	89	93	92	93	92
Homogeneity [%]	83	77	91	76	84	73	77	76	82	77
β-glucan [mg/L]	121	175	143	192	145	194	158	221	174	247
α-amylase (dry) [U/g]	194	190	187	187	175	180	172	203	187	188
β-amylase (dry) [U/g]	786	793	968	948	905	836	722	832	866	876
β-glucanase (dry) [U/kg]	588	606	380	472	192	354	190	218	77	71
DMS-P (dry) [mg/kg]	6.1	4.7	6.8	5.2	6.3	4.6	5.7	4.3	5.9	4.7

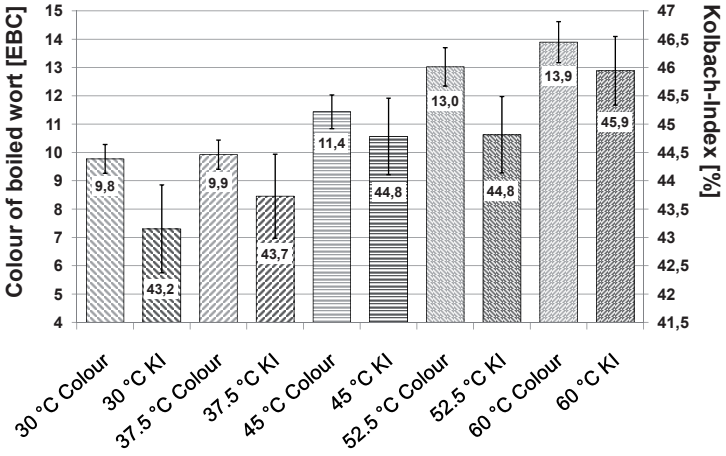

Fig. 3 Comparison of boiled wort's colour and Kolbach-Index (mean of both layers; standard deviation according to MEBAK)

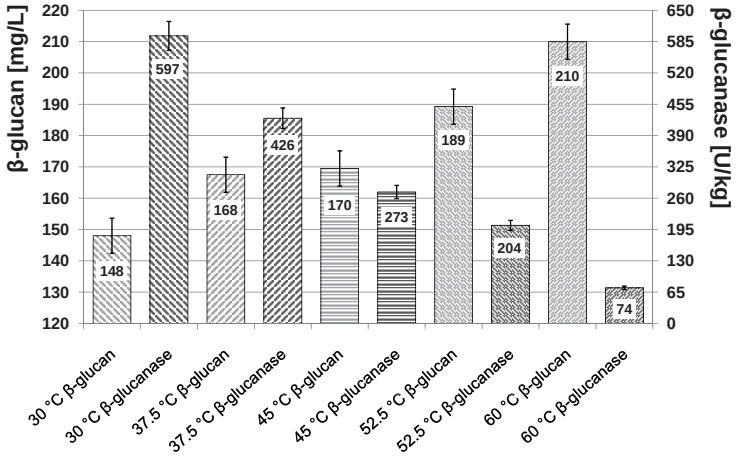

Fig. 5 Comparison of β-glucan and β-glucanase activity (mean of both layers; standard deviation according to MEBAK and Megazyme analyses)

FAN contents when applying higher withering temperatures in the present investigations (see Fig. 3). Next to the influence of the temperature, thereby more precursors for a colour formation via the Maillard reactions were available. Again, it can be proposed that the resulting increased formation of slightly acidic melanoidins led to the slight pH reduction of about 0.1 when increasing the withering temperature to 60 °C (see Table 2). This confirmed the findings of *Isebaert et al.* [14] in which lower pH values were found when applying higher withering temperatures, too. In respect to the oxidative flavour stability, these slightly higher pH values should easily be compensated by a 40 % lower colour of the more moderately withered malts. According to *Kunz et al.* [17, 18], the colour correlates very well with the content of reductones which are also generated during the Maillard reactions and were shown to act pro-oxidative by their strong reduction potential against specific oxidised metal ions like Fe^{3+}. The oxidized iron ions can be reduced in a faster reaction rate to Fe^{2+}. In logical consequence, more Fe^{2+} is available for the oxygen activation via electron transfer and the catalytic effect in the generation of pro-oxidatively acting radicals by the Fenton-/Haber-Weiss reaction systems.

Concerning the cytolytic modification, different samples' viscosities were not influenced (see Table 2) by the different applied withering temperatures. The values were quite low and thus sufficient for all samples. The parameters mealiness, modification according to Carlsberg and the β-glucan, which are graphically shown in figure 4 and 5, imply a reduced cytolytic modification with increased withering temperatures and an optimal withering temperature between 30 and 37.5 °C. From 30 to 60 °C, the β-glucan content of the final malts was increased by about 60 mg/L. Nevertheless, also the highest value of 210 mg/L can be rated as sufficient [20]. In direct correlation, up to 8 % and 5 % higher mealiness and modification, respectively, could be observed. For the parameters mealiness and β-glucan, a linear coefficients of (a linear coeffizient $R^2 > 0.94$ could be found) could be found. Surprisingly, an extreme inactivation of β-glucanases of about 88 % was observed when comparing the 30 and 60 °C-sample only resulting in an about 30 % higher β-glucan content. These results again underline an already discussed remarkable heat sensitivity of cell wall degrading enzymes [5, 6, 21, 24, 29].

In figure 6, the activities of the starch degrading enzymes α- and β-amylase are compared. It is obvious, that the α-amylase, as a relatively heat stable enzyme [3, 14], was not influenced by the withering temperature. Also the β-amylase did not show a clear trend or significant differences. *Schuster et al.* [33] claimed that the

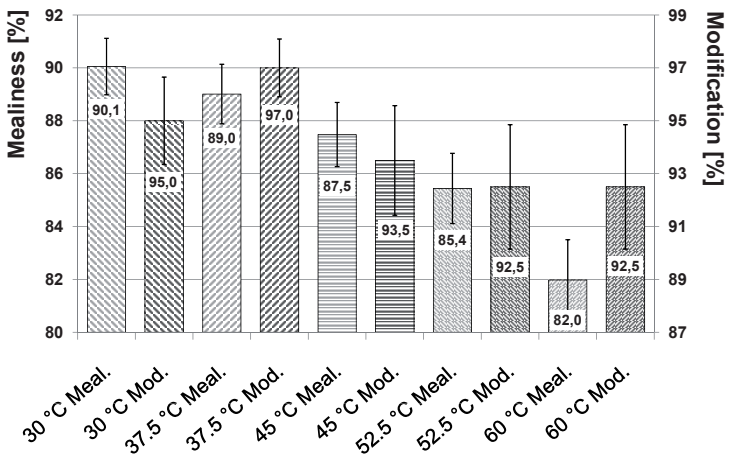

Fig. 4 Comparison of mealiness and modification (mean of both layers; standard deviation according to MEBAK)

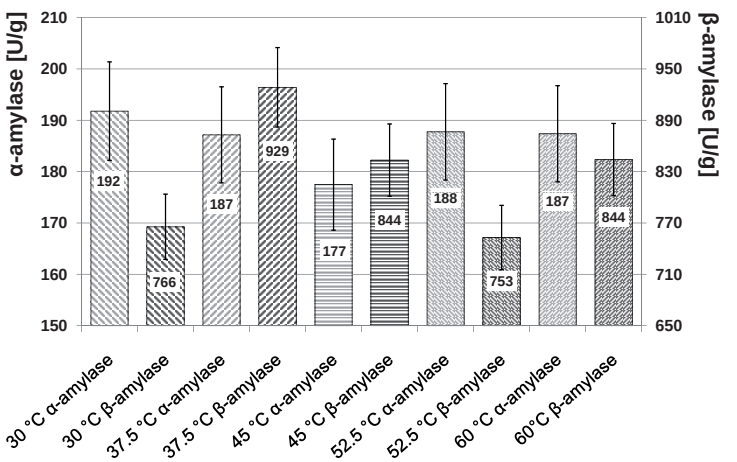

Fig. 6 Comparison of α- and β-amylase activities (mean of both layers; standard deviation according to Megazyme analyses)

β-amylase is only reduced at higher temperatures than 60 °C and the range for an optimal activity lies between 40 and 60 °C, thus this could be a reason no clear trend was observed. In combination with the results of the degrees of final attenuation, that did not show a clear trend, constant mean extract values were found (see Table 2), and thus an influence of the withering temperature on the starch degradation could not be detected in this study.

The cytolytic modification is said to correlate with the processability in terms of lautering and filtration performance in the brewing process because a too low modification can lead to lautering and filtration problem. This results from increasing the wort's viscosity and the formation of β-glucan gels which can block the pores of the beer filter [5]. Sufficient malt qualities according to MEBAK [20], in terms of the cytolysis describing parameters mealiness, modification, β-glucan, filtration time and viscosity, do not necessarily imply an adequate lautering time, because the lautering performance is influenced by many factors and published literature claims are ambiguous [32, 34, 36]. In present study, all analysed parameters showed values within the recommended MEBAK specifications (except colour of boiled wort for pale malt). Due to a high standard deviation of the analytical method filtration time of the congress wort, no clear trend could be observed and the values showed big variations (see Table 2). In addition, the parameter filtration time is said not to be an adequate malt quality parameter for forecasting the lautering performance of malt [32]. Therefore, the withering temperature's influence on the lautering performance was evaluated with an in-house laboratory lautering test (see materials and methods section). The results of the tests, which are evaluated by determining the total run-off volume after 300 seconds, done in triplicate, are displayed in figures 7. The results imply that there was no significant influence of withering temperatures between 37.5 and 60 °C, but a slight trend to improved lautering performances when applying higher temperatures could be observed. Despite the lowest measured β-glucan contents (see Table 2), both 30 °C-samples (top and bottom) showed a significantly reduced lautering behaviour. Therefore and due to extended kilning times, such low withering temperatures should not be applied according to the present trials. In most cases, except the 52.5 °C-samples, the malt of the upper layers showed slightly better lautering performances which in this comparison correlated with the cytolytic modification.

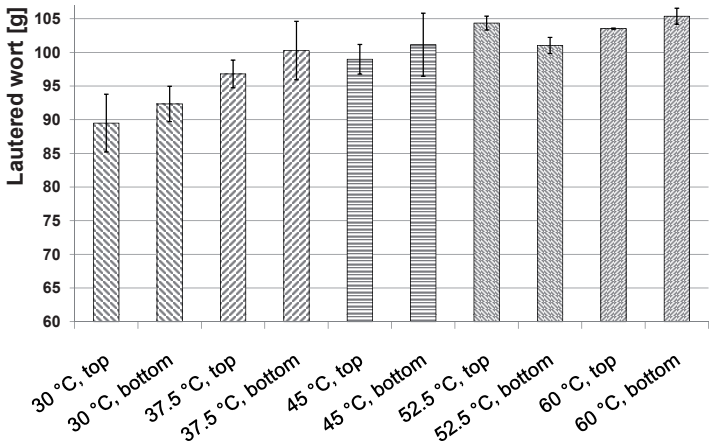

Fig. 7 Comparison of the lautering properties for the important malt samples achieving comparable malting losses, evaluated by an in-house laboratory lautering test (standard deviation of the triplicate determination)

4 Conclusion

By using the same deep-frozen green malt and applying constant curing program (80 °C for 4 hours) for all trials, the influence of the withering temperatures' impacts could be obtained, exclusively. Summarising the findings, varying isotherm withering temperatures between 30 and 60 °C in laboratory scale remarkably influenced the cytolytic and proteolytic modification of the final malt. When applying 30 °C, the cell wall degradation was enhanced compared to withering at 60 °C which was indicated by an about 60 mg/L lower β-glucan content as well as up to 8 % and 5 % higher mealiness and modification, respectively. Furthermore, a too high Kolbach-Index of 45.9 % could be reduced by 2.7 % and 2.2 % when applying 30 and 37.5 °C, respectively. Especially the enhanced cytolytic modification hints at a possible germination time reduction which may compensate the extended kilning time when applying more moderate withering temperatures.

Future trials should be done in pilot scale or in industrial scale to obtain if the found advantages of applying low withering temperatures can be confirmed when kilning in grain heights of 70-110 cm. Furthermore, such trials should be done trials using green malt which has not been frozen before kilning. With the present trials, the influence of different withering temperatures on the malting losses could not be investigated due to the use of deep-frozen green malt that certainly was unable to grow during the germination phase of withering. Unfortunately, a kilning procedure using lower withering temperatures should also be practicable in industrial scale malting because the malting plants normally are run with daily batches and applying low withering temperatures will probably result in kilning processes lasting longer than one day. Therefore, at least the first hours of withering should be kept at 35–40 °C when the moisture content of the green malt is still high, adhesive water is easily removed and therefore at a time when the temperature gradient is not so important for a fast and ongoing drying. This may combine the advantages of low withering temperatures by means of an enhanced cytolytic modification during the phase of still high moisture contents with a still relatively fast withering procedure in comparison to withering at low isotherm temperatures. Furthermore, applying moderate withering temperatures until a moisture content of about 20–30 %, when enzyme activities start to retard [23], may be a tool for keeping the degree of protein degradation (Kolbach-Index) low due to suppressed activities of proteases.

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