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Investigation of Filtration-inhibitory Substances in German Wheat Beer

Although production of crystal wheat beer represents only a small group in German beer market, major problems could be observed during these clarification processes. Because of a proportion of at least 50 % wheat malt, beer composition is not comparable to bottom fermented lager beer. Thus, this study aimed to investigate filtration-inhibitory substances during wheat beer filtration. Besides determination of filterability, beer composition was analysed investigating α-/β-glucans, arabinoxylans, proteins, polyphenols and yeast cell count. Furthermore industrial scale pressure rise at filter inlet and turbidity at filter outlet were determined. Enzymatic hydrolysis of rough beer samples and subsequent membrane filtration observed nearly 55 % increase by degradation of proteins and 45 % degrading hemicellulose ingredients. Significant correlation could be determined between pressure rise and rising yeast cell count ($r = –0.635$, $P<0.05$) as well as decreasing iodine value ($r = 0.727$, $P<0.01$). Laboratory determined filterability resulted in significant correlation to pressure rise of diatomaceous earth candle filter ($r = 0.564$, $P<0.05$). Typical filtration inhibitory substances like β-glucan, arabinoxylan or protein content showed no correlation to laboratory filtration or pressure rise in industrial scale. Obtained results show the impact of wheat malt grist load and its effect on beer composition and filter properties.

Descriptors: Diatomaceous earth, membrane filtration, barley, wheat, *Saccharomyces cerevisiae*

1 Introduction

Yeasty, cloudy wheat beers have become very popular all over Germany and are thus third largest beer brand in the country [5]. Typical aroma is influenced by 4-vinyl-guajacol, a phenolic flavour, as well as different fruity and yeasty flavours [29, 34]. These volatiles are entered because of raw material selection consisting of barley and wheat malt as well as used top-fermenting *Saccharomyces cerevisiae* yeast strains. In addition to these yeasty types a filtered wheat beer style has been established, which is characterized besides the haze-free condition particularly by its sparkling type (up to 7 g/l CO_2). It was first developed in 1924 by the brewery Farny (Kißlegg) and termed Champagne wheat beer. In middle of the 1960, the term Champagne wheat beer was protected under EU law for the champagne farmers in France [9]. For this reason, crystal wheat beer was the designation of this type of beer.

Manufacturing method is similar to a normal wheat beer. Fermentation is carried out with *Saccharomyces cerevisiae* strains and a proportion of at least 50 % wheat malt is necessary for the production of German top-fermented beer types. Due to this characteristic composition influenced by budding associations of yeast and the significant proportion of wheat malt, filterability is affected by particular substance groups. Especially hemicelluloses have a special composition in wheat malt (see Table 1). Higher contents of arabinoxylans and lower proportion of β-glucans (0.06–0.68 %) result in higher beer viscosities in comparison to lager beer. Wheat β-glucans are characterized by a lower amount in cereal as well as a worse water solubility in comparison to barley-β-glucans (see

Table 1 Comparison of barley and wheat malt regarding chemical composition of brewing relevant bio-polymers and enzymes [11, 16, 20, 26]

	Barley malt	Wheat malt
Protein content [%dry weight]	9.5–11.5	11–13
Viscosity [mPa×s]	<1.56	<1.8
β-Glucan [%dry weight]	0.05–1.1	0.06–0.68
Water soluble β-glucan [%]	~65 %	< 3
Ratio cellotriosyl:cellotetrasyl units in β-glucans	1.8–3.5:1	3.0–4.5:1
Arabinoxylan [%dry weight]	0.14–1.2	5.8–7.4
Starch content [%TrS]	48–55	60–70
Ratio amylopectin:amylose	3:1	2.5:1
α-Amylase-Activity	40–100 ASBC	> 30 ASBC
β-Amylase- Activity	~40.1 U/g	~20.3 U/g

~medium value

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Table 1) [16]. Because of a regular ratio of cellotriosyl:cellotetrasyl units in wheat malt an increased aggregation potential could be detected in comparison to barley β-glucans [16]. Furthermore arabinoxylan composition has slight changes in xylose:arabinose ratio (1:11) and the amount of ferulic acid [6, 14]. Both, kind and amount of arabinose-substituent as well as amount of ferulic acid have an influence on degree of cross-linking [7]. These flavour-active compounds have three potential reactive sites: two on an aromatic ring and one double bond that held be responsible for oxidative gelation [18]. In addition to hemicellulose composition, extract yields are higher in wheat malts (see Table 1) [26]. This difference between barley and wheat is expressed further in variations in starch granule distribution [12], different degree of polymerization of amylopectin and thus higher gelatinization temperatures [3]. Additionally, lower α- and β-amylase activity could be determined in wheat malt (compare Table 1). Besides a modified polysaccharide composition, wheat malt has a higher protein content than barley malt. Thus, total nitrogen (600–900 mg/l) and especially high molecular nitrogen (65–320 mg/l) have higher concentrations in wheat beer, whereas total polyphenol concentration (60–130 mg/l) decreases in comparison to lager beer [26]. At last used top-fermented yeast build budding associations and yeast management may be affected by frequent multiple yeast generations up to 100 times [1]. This occurs in high variability of vitality and viability of yeast cultures.

Because of these multiple variations in beer composition in difference to lager beer, aim of this study was the investigation of filtration inhibiting substances in wheat beer. Besides determination of potential improvement of filterability, comparison between laboratory and industrial scale filtration was performed. These filtration data was used for statistical examination of filtration influencing substances.

2 Material and methods

2.1 Materials

Wheat beer of a southern German brewery was used as sample material, whereas a trial period of 6 months was examined to detect inconsistent raw material qualities. In addition, coarse, medium fine and fine diatomaceous earth (DE; Lehmann&Voss, Germany) grades were provided by the brewery for filter experiments in laboratory-scale.

2.2 Methods

2.2.1 Examination of filter performance and filterability

2.2.1.1 Determination of filterability with Raible-test

Dead-end filtration trials were performed on an automated laboratory filter system [33]. Automatic filter consists of two stainless steel vessels with cooling jacket. Pressure and temperature sensor as well as an automatic valve are connected via a controller with a computer. For data recording and controlling the program Virtual Expert (Gimbo mbH, Freising) is used. The measured variables are, in addition to temperature and pressure, filtrate mass and time. Filterability was determined calculating specific filtrate volume F_{spez} (see Equation 1, a-filter cake factor) [24] using MATLAB (Mathworks, Ismaning).

Because DE filtration is the most applied method in the brewing industry, these filtration trials were performed to compare with filter performance in industrial scale. For DE precoat 0.98 g/l coarse DE diluted in 1.7 l distilled water (1 kg/m² filter area) were dosed into the precoat vessel. A body feed of 0.8 g medium fine DE per litre beer (160 g/hl) was chosen for filtration. Beer (0.5 l) was cooled to 5 °C, mixed with the filter aid and transferred into sample vessel. The stirrer kept DE to be in suspension. Filtration pressure was 1 bar. After precoating on a 15 μm steel mesh sieve, the sample was filtered through the coarse DE layer by switching the automatic valve. Calculation of specific filtrate volume was performed using equation 1.

$$F_{spez}\left[\frac{hl}{m^2 \times h}\right] = \sqrt{\frac{3600}{a} \times 0.1} \qquad \text{(Eq. 1)}$$

2.2.1.2 Evaluation of filtration-inhibiting substances using enzymatic Esser-Test

Filtration-inhibiting substances were analysed using an enzymatic membrane filter test. Before enzymatic hydrolysis, beer samples were centrifuged at 3000 U/min for 3 min to remove yeast cells. Thus, beer samples were inoculated with enzymes to break down potential filtration-inhibitory substance groups. For this purpose technical enzyme mixtures Chill (Peptidyl-peptide-hydrolases), Penta (endo-1,4-β-D-mannanase, endo-1,4-β-D-xylanase, endo-1,3-β-D-xylanase, exo-1,4-β-D-xylosidase, endo-1,3(4)-β-D-glucanase, endo-1,4-β-glucanase) and Crystal (endo-1,4-α-D-glucan-glucanohydrolases) of manufacturer Erbslöh (Erbslöh Geisenheim AG, Germany) were used. Incubation of inoculated and non-treated samples was performed at 40 °C for 24 h [31]. Following percentage improvement in comparison to non-treated samples was determined calculating G_{max}-values (see Equation 2).

$$G_{max}[g] = \frac{t_2 - t_1}{\frac{t_2}{G_2} - \frac{t_1}{G_1}} \qquad \text{(Eq. 2)}$$

2.2.1.3 Determination of filter performance in industrial scale

Industrial scale filtrations were performed using candle filter with a first precoating of course DE and a body feed of fine filter aid.

Table 2 Investigated beer ingredients and properties in dependence to analysing method

Analysing method	EBC or MEBAK method
Photometric iodine value	MEBAK WBBM 2.3
Total nitrogen (Kjeldahl method)	EBC 9.9.1, MEBAK WBBM 2.6.1.1
High molar mass nitrogen ($MgSO_4$-precipitable nitrogen)	MEBAK WBBM 2.6.3.1
Total polyphenols	EBC 9.11, MEBAK WBBM 2.16.1
Viscosity (glass capillary viscometer (Anton Paar, Graz))	EBC 9.38
Yeast cell count	EBC 3.1.1

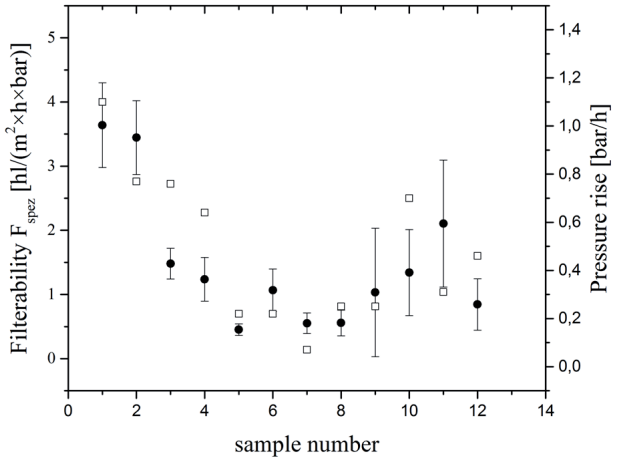

Fig. 1 Filterability F_{spez} determined using modified Raible-Test (●)(n = 3) and pressure rise of candle filter (□) of wheat beer samples

Beer samples were separated before filtration. Pressure rise on filter inlet and turbidity at filter outlet were recorded to obtain quality information on filtration performance.

2.2.2 Investigation of beer composition

Wheat beer samples were characterized according to their chemical composition using analysing methods described in Table 2. Furthermore β-glucan content (section 2.2.2.1) as well as arabinoxylan concentration (section 2.2.2.2) were determined.

2.2.2.1 β-Glucan, high molecular weight β-glucan and β-glucan-gel

In order to ensure a greater sample throughput and simultaneous high measurement accuracy, fluorometric and colorimetric methods (high molecular weight β-glucan) were transferred to BioTek synergy H4 multiwell-reader (BioTek, Bad Friedrichshall, Germany) using 96 microwell plates. Initially 15 µl of Skandinavisk Bryggeri Laboratorium (SBL) β-glucan calibration standard (R02) was transferred into a 96-well plate by means of pipetting robot BioTek Precision XS (BioTek Instruments, Bad Friedrichshall, Germany) to create a 7-point calibration. 300 µl dye solution containing 5 ml calcofluor (Sigma-Aldrich, Germany) and 495 ml degassed Tris-HCl buffer (0.1 mol/l pH 8.0) were pipetted into each cavity of the 96-well plate [40]. Fluorescence intensity was recorded at an excitation wavelength of 360 nm and an emission wavelength of 445 nm. For calculation of β-glucan content of beer samples, a second order non-linear regression curve converting fluorescence intensity in dependence to β-glucan concentration of 7-point calibration curve was created. All measurements were performed in quadruple [30].

Furthermore, congo red staining method was applied at multiwell reader of Biotek using SBL calibration standard. 15 µl of sample was mixed with 300 µl of congo red solution consisting of 100 mg/l congo red dye (C6767 Sigma, Sigma-Aldrich, Germany) solved in Tris-HCl buffer pH 8.0. Congo red dye was filtered through filter paper circles (black ribbon, Whatman Schleicher & Schuell, Dassel Germany). After incubation at 25 °C for 20 min absorbance was measured at 550 nm using BioTek synergy H4. Concentration could be calculated using second order non-linear regression. All measurements were performed in quadruple [30].

β-Glucan gel content was determined according to Krüger et al. [27]. The method is based on the break-down of hydrogen bonds between agglomerated β-glucans via heat exposure, which allows a dye reaction of separated β-glucan chains with Calcofluor [32]. One part of each beer model sample was heated to 80 °C for 20 min. The concentration differences between heated and non-heated samples are corresponding to gel-content. All measurements were performed in quadruple.

2.2.2.2 Arabinoxylan

Arabinoxylan content was determined using acid hydrolysis and staining of resultant furfural residues with phloroglucinol according to the Douglas-method [8, 21]. Calibration curve using xylose standard (100 mg D(+)-xylose in 100 ml distilled water) with a concentration between 0 mg/l to 0.3 mg/l in distilled water was used for quantification. Reaction reagent for acid hydrolysis consisted of 110 ml glacial acetic acid and 2 ml hydrochloric acid (fuming, 37 %) as well as the dye phloroglucinol (2 g, 79330 Aldrich, Sigma-Aldrich) dissolved in 10 ml of pure ethanol. Beer samples were diluted 1:

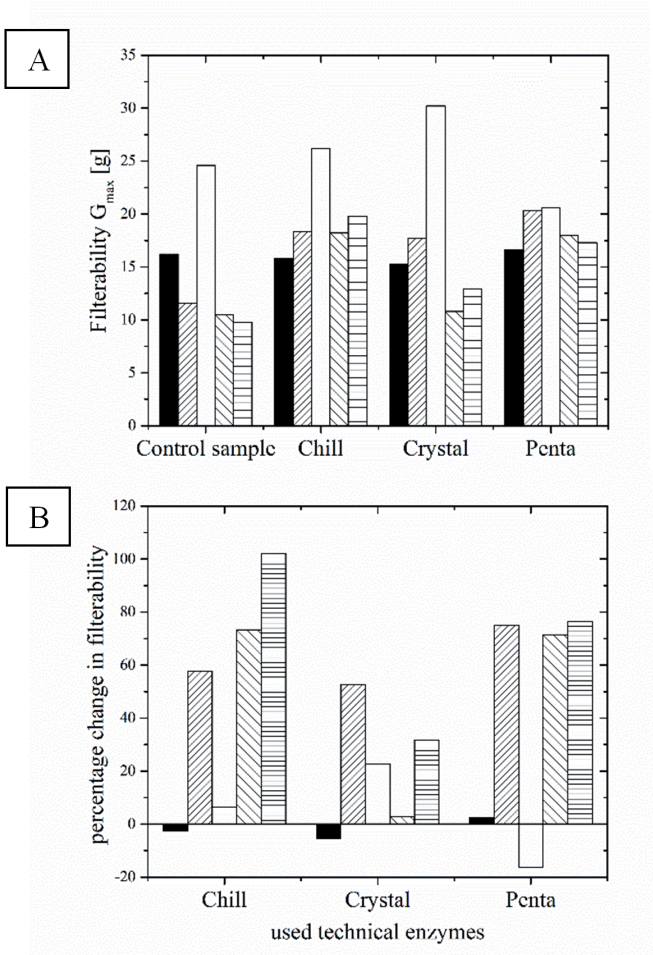

Fig. 2 Filterability G_{max} determined using Esser-test (Fig. A, n = 3) of five beer samples, as well as percentage increase in filterability (Fig. B, n = 3) of wheat beer sample after treatment with different technical enzymes: sample 1 (■), sample 2 (▨), sample 3 (□), sample 4 (▧) and sample 5 (▤)

4 and pipetted in brown test tubes. 2 ml of sample or calibration standard were mixed with 10 ml reaction reagent. Samples were boiled for 25 min and immediately cooled in ice water. Measurement of absorbance was performed at 550 nm and 505 nm. Concentration was determined using 2-degree polynomial regression of delta absorbance and concentration of calibration standards. These results were multiplied with dilution factor and factor 0.88 (pentose sugar) to correct incorporation of water during hydrolysis [22]. All measurements were performed in triplicate. Entire hydrolysis and measurement was checked using arabinoxylan standard (wheat AX Megazyme, Ireland) in a defined initial weight, which was performed in duplicate.

2.2.3 Statistics

Statistical analyses were carried out using OriginPro 2015G (OriginLab Cooperation, Northampton, USA) to determine Pearson correlation coefficients, averages and standard deviations.

3 Results

For the investigation of filterability of wheat beer, filtration experiments were performed in laboratory scale using modified Raible-tests. Furthermore pressure rise at filter inlet and turbidity at filter outlet were determined in industrial scale candle filter (see Fig. 1).

Comparable results between industrial and laboratory scale are recognizable. Medium pressure rise could be determined as 0.55 ± 0.37 bar/h (n = 12), whereas medium specific filtrate volume achieved 1.46 ± 0.96 hl/(m²×h×bar) (n = 12×3). Total filtered amount ranged between 110 hl to 720 hl filtered volume (average: 394 hl) with an average filtration time of two hours. Similarly turbidity of filtered beer ranged from 0.5 to 2.1 EBC with an average of 1.1 EBC (n = 12; 90° measurement angle). Observed filter performance was very low with high beer turbidity in comparison to lager beer [24]. Laboratory tests exhibited low values with partly poor repeatability despite a doubling of filter aid amount of used fine DE in comparison to MEBAK specification [19]. An increase of DE amount was required due to high initial turbidity (partly > 200 EBC) in beer samples.

For a first identification of filtration-inhibitory substances, an enzymatic membrane filter test was performed at five beer samples. These preliminary tests should observe the impact of proteins and polysaccharides on filtration behaviour of wheat beer. The applied test uses enzymatic hydrolysis and subsequent membrane filtration to examine the impact of investigated polymeric substances on filtration performance [31]. Figure 2 shows filterability (A) as well as percentage changes in filterability determined as G_{max} (B) of five beer samples. Medium filterability of beer without enzymatic hydrolysis was examined as 15 ± 6 g (n = 3×5, see Fig. 2A). In average, hydrolysis of proteins resulted in a filterability increase of 55 %. Furthermore, degradation of malt cell wall ingredients like β-glucans and arabinoxylans increased filterability by 45 % and degradation of α-glucans increased filterability by 23 %. This shows potential of the particular ingredients to affect the filterability of wheat beer. Nevertheless, varying effects of enzymes were observed in studied beer sample.

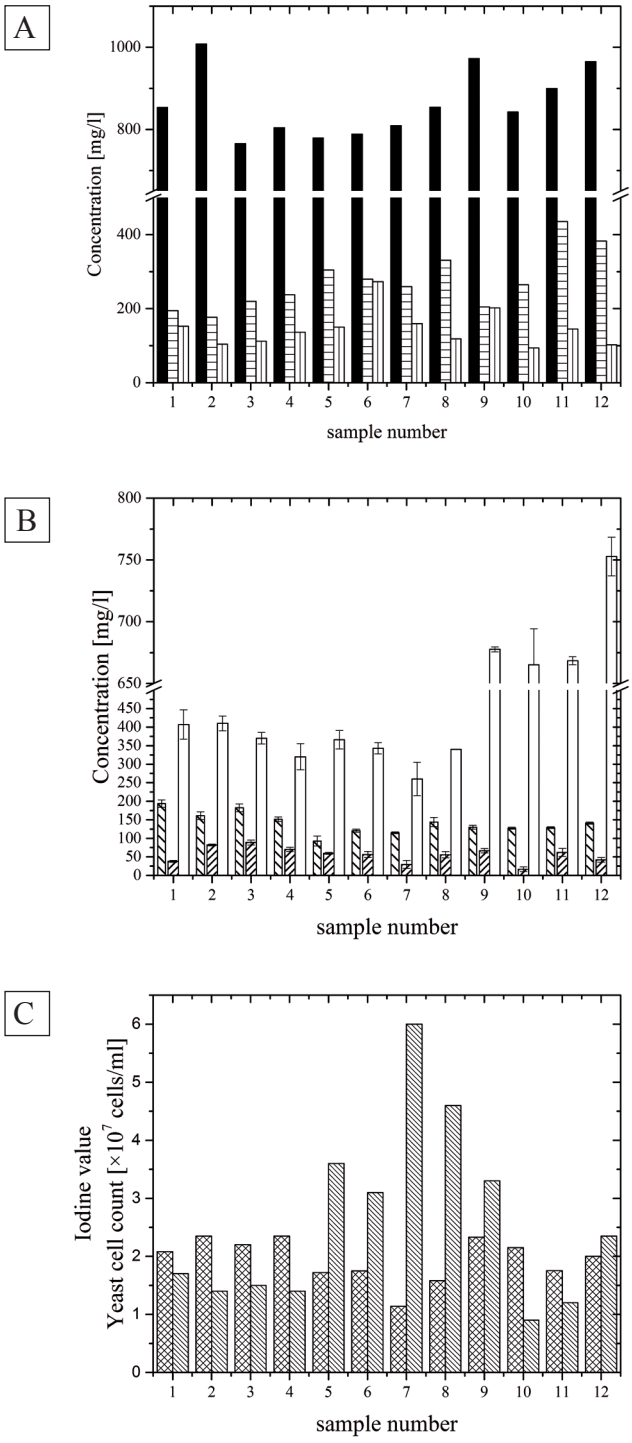

Fig. 3 Total nitrogen content (■, n = 3), high molar mass nitrogen (▤, n = 3) and total polyphenol content (▥, n = 3) (A), arabinoxylan concentration (□, n = 3), β-glucan content (▨, n = 4) and high molecular weight β-glucan content (▩, n = 4) (B) as well as iodine value (▦) and yeast cell count (▧) (C) of investigated wheat beer samples

Due to the hydrolysis of proteins resulted in an increasing filterability, total nitrogen and high molar mass nitrogen were observed in all beer samples. Total nitrogen resulted in a medium value of 860.3 ± 75.5 mg/l (n = 12×3, range: 765.7–1007.9 mg/l, see Fig. 3A), whereas high molar mass nitrogen analysed as $MgSO_4$-precipitable nitrogen had an average value of 287.4 ± 85.1 mg/l (n = 12×3, range: 176.4–435.4 mg/l, see Fig. 3A). Furthermore average

Table 3 Viscosity influencing properties in wheat and barley wort solubilized using an iso-65 °C mashing procedure (n = 3)

	β-Glucan [mg/l]	β-Glucan-gel [mg/l]	Arabinoxylan [mg/l]
French wheat malt	45.4 ± 3.1	3.9	1585.0 ± 60.7
German wheat malt	38.4 ± 3.1	2.4	1350.0 ± 4.7
Barley malt	169.5 ± 4.8	4.8	1168.9 ± 36.4
Dark barley malt	209.1 ± 9.6	6.8	634.2 ± 8.5
Malt grist load brewery	110.1 ± 1.1	2.0	1306.5 ± 91.3

polyphenol concentration was determined with 137.2 ± 46.4 mg/l (n = 12×3, range: 93.5–272.9 mg/l, see Fig. 3A). Although average value was examined in a comparable range to lager beer, some samples had markedly increased polyphenol concentrations.

All investigated dissolved beer ingredients can be summed up using viscosity measurement. Average viscosity of beer samples using micro-viscometer was measured as 1.787 ± 0.052 mPa × s (n = 12×4) with a range between 1.654 – 1.847 mPa × s. These measurement results are comparable to standard values (1.7–1.8 mPa × s) in wheat beer reported in literature [26]. In this case especially gel-forming substances influence the measurement of viscosity. For this reason, next to β-glucan, β-glucan-gel content and high molar mass β-glucan content, arabinoxylan concentration of beer were investigated (see Fig. 3B). Average β-glucan concentration was observed with 167.3 ± 51.2 mg/l (n = 12×4, range: 105.2–321.0 mg/l), whereas high molar mass β-glucan content was quantified with 55.6 ± 20.2 mg/l (n = 12×4, range: 16.6–88.8 mg/l). In comparison arabinoxylan content had an average of 477.0 ± 165.2 mg/l (n = 12×3, range: 260–742 mg/l). Especially last four samples had a high content above 700 mg/l (Fig. 3B).

These measured hemicellulose substances originating mainly from beer raw materials like barley and wheat malt. Because different malts were used for wheat beer production, investigation of β-glucan and arabinoxylan contents using isothermal 65 °C mash procedure were performed. Table 3 shows concentration in malt sample each individually and in mixture according to malt grist load of brewery. Very low β-glucan and -gel contents could be observed, whereas a drop in β-glucan content resulted in an increasing arabinoxylan concentration. Especially wheat malt observed high contents of arabinoxylan above 1300 mg/l.

Besides hemicellulose content, iodine value was determined resulting in a medium value of 2.0 ± 0.4 (n = 12, range: 1.1–2.5, see Fig. 3C). Yeast count ranged between 0.9–6.0×10^7 cells/ml (average: 2.5 ± 1.5×10^7 cells/ml, n = 12, see Fig. 3C). Due to longer storage period cell count dropped in beer. Extension in storage could result in higher yeast cell stress due to increasing ethanol content, drop in content of metabolizing ingredients like sugar or amino acids and fermentation temperature changes over time. Yeast stress could cause a release of glycogen from cells resulting in rising iodine values in beer [24].

Table 4 Pearson correlation coefficients of investigated beer properties (n = 12 × 3)

	β-Glucan	β-Glucan-gel	High molar mass β-glucan	Iodine value	High molecular nitrogen	Total nitrogen	Polyphenols	Arabinoxylan	Viscosity	Yeast count	Filterability F_{spez}	Pressure rise	Turbidity
β-Glucan	1	–0.006	–0.020	–0.418	0.004	–0.050	–0.376	–0.433	0.046	0.475	–0.116	–0.141	–0.129
β-Glucan-gel		1	–0.393	–0.733**	–0.104	–0.395	0.451	–0.436	0.141	0.776**	–0.553	–0.662*	–0.511
High molar mass β-glucan			1	0.281	–0.013	–0.057	–0.385	–0.022	0.252	–0.470	–0.099	0.422	0.357***
Iodine value				1	–0.154	0.316	–0.226	0.531	–0.127	–0.754**	0.406	0.727**	0.621*
High molecular nitrogen					1	–0.025	–0.091	0.352	0.104	0.008	–0.364	0.014	0.388
Total nitrogen						1	–0.213	0.506	–0.706**	–0.184	0.381	0.030	0.066
Polyphenols							1	–0.160	–0.145	0.339	–0.167	–0.369	–0.491
Arabinoxylan								1	–0.556*	–0.524	0.286	0.386	0.641*
Viscosity									1	–0.040	–0.242	0.123	0.029
Yeast count										1	–0.589*	–0.635*	–0.537
Filterability F_{spez}											1	0.564*	0.204
Pressure rise												1	0.837***
Turbidity													1

*P < 0.05, **P < 0.01, ***P < 0.001

Using the obtained measurement results, correlation analysis in dependence to industrial scale filter performance and filtrate turbidity after DE precoat filtration could be performed (see Table 4). Industrial scale pressure rise correlated significantly with β-glucan-gel content ($r = –0.662$, $P < 0.05$) and yeast cell count ($r= –0.635$, $P < 0.05$). Best information was achieved analyzing iodine value ($r = 0.727$, $P < 0.05$). Besides dextrins of amylose or amylopectin, iodine value could also determine glycogen content, an α-1.4/1.6-branched polysaccharide in beer [24, 36]. However, differentiation of glycogen and amylopectin was not possible investigating photometric iodine value. Furthermore β-glucan-gel content had a high impact on filter performance. Beer viscosity was mainly influenced by total nitrogen content (see Table 4; $r = –0.706$, $P < 0.01$) and arabinoxylan content ($r = –0.556$, $P < 0.05$). This is accompanied by high concentrations of these polymers, often above critical thresholds (compare Table 1) [26]. Turbidity of filtered beer samples was mainly influenced by high molar mass β-glucan ($r = 0.357$, $P < 0.001$), arabinoxylan content ($r = 0.604$, $P < 0.05$) as well as iodine value ($r = 0.621$, $P < 0.05$) and correlated significantly with pressure rise ($r = 0.837$ $P < 0.001$) during DE precoat filtration.

Laboratory scale filterability and pressure rise had a low significant correlation ($r = 0.564$, $P < 0.05$), indicating differences in filtration procedure and used DE composition for precoating and body feed. Coincident to industrial scale was a significant correlation between filterability and yeast cell count ($r = –0.589$, $P<0.05$). Investigated beer samples had very high yeast contents in comparison to bottom fermented beer samples before filtration [2, 15]. Thus, filterability in laboratory scale was mainly influenced by solid content.

4 Discussion

Investigation of filtration-inhibiting substances for DE precoat filtration of wheat beer resulted in a main impact of polysaccharides. However, the obtained results showed major differences in composition of filtration-inhibitory substance in comparison to lager beer. Especially substances like arabinoxylans, α-/β-glucans as well as total nitrogen and $MgSO_4$-precipitable nitrogen observed varying concentration. According to literature, DE filtration performance of lager beer could be affected by total nitrogen content and $MgSO_4$-precipitable nitrogen [10, 23, 46]. This impact could not be shown during correlation analysis, but in enzymatic membrane filter test. Due to a removal of yeast cells by centrifugation during sample preparation, the positive effect of protein degradation got evident. Comparable results could be achieved with degradation of polysaccharides like β-glucan and arabinoxylan. Again, the effect could not been demonstrated by correlation analysis. Negative impact of arabinxoylans on membrane filtration performance is well known from literature [37, 41, 44], wherein an impact on DE precoat filtration is not described. Nevertheless, an increasing effect on beer viscosity with rising arabinoxylan content could be determined, which is consistent with literature [41]. Here, a high viscosity had a further negative effect on beer filtration. But beer viscosity is not only influenced by arabinoxylan, but also by β-glucan concentration. During membrane filtration, especially high molar mass β-glucans affected filter performance [44], which could not be confirmed for DE precoat filtration. *Reed* [39] discussed a masking effect of β-glucans due to higher contents of further beer ingredients during DE beer filtration. Particularly, β-glucan-gel content achieved a negative impact on DE filtration behaviour [24, 28, 32, 35]. This is consistent with the shown measurement results, wherein a significant correlation between pressure rise in industrial scale and β-glucan-gel content was determined. The measured high negative concentrations can arise in wheat beer due to the special β-glucan composition in wheat malt. Because of the regular β-1,4-cellotriose and –tetraose distribution, these polysaccharides tend to a stronger gel formation compared to barley malt [13, 45]. This is accompanied by a lower measurable β-glucan concentration (< 200 mg/l) due to a worse water solubility [16], which was also examined in the shown experiments.

Besides arabinoxylan and β-glucan, degradation products of α-glucans analysed using photometric iodine value had significant impact on pressure rise and turbidity in industrial scale. *Schur* [42] demonstrated a negative effect of high iodine values of wort or beer on filterability. This was verified by *Wange* [46], who could find significant influence on beer filterability due to large variations in iodine value. Nevertheless, it could be shown that malt polysaccharides do not cause drop in filter performance applying an accurate mashing process investigating lager beer [38]. However, due to a lower α-amylase activity in wheat malt a poor saccharification and higher turbidity could be observed because of higher contents in limit dextrins [4, 25]. Furthermore, not only malt polysaccharides but yeast polysaccharides like glycogen could have an impact on iodine value [17, 24]. According to literature [24, 43] an increasing beer turbidity (90° measurement angle) could be found with rising glycogen content in beer, which is consistent with the shown data. This increase resulted furthermore in a steeper pressure rise of candle filter filter, which could not be confirmed by laboratory filtration experiments performed by *Kreisz* [24]. However, independent on polysaccharide origin high iodine values had the greatest negative influence on beer filtration.

5 Conclusion

The shown data exhibited that especially viscosity increasing substances reduce DE filtration performance in wheat beer production. In addition to β-glucan-gels particularly high levels of arabinoxylan have been detected in wheat beer as well as malt samples. Implementation of enzymatic filter test allowed quick and specific statements regarding the filtration-inhibiting potential of substance groups in beer. Furthermore, it could be proven that particularly high yeast cell counts and iodine values adversely affect filterability of wheat beer. Proportion of yeast viability and vitality as well as the existing budding associations could not be clarified in this context. In summary, it was shown that the composition of filtration-inhibiting substances in top-fermented wheat beer was quite different from bottom fermenting lager beers. Main reason were high levels of wheat malt and its special composition regarding β-glucan, arabinoxylan and starch as well as composition of malt enzymes. For this purpose, profound studies on the influence of molar mass and polymer structure of the individual polysaccharides must be performed. Furthermore, concepts for an improvement of filter performance should be developed in the context of wheat beer filtration.

Acknowledgement

Thanks to the participating brewery and the staff that had provided the sample material.

6 Abbreviations

DE	diatomaceous earth
F_{spez}	specific filtrate volume
G_{max}	maximum filtrate weight
SBL	Skandinavisk Bryggeri Laboratorium

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