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High-Gravity Brewing of Bohemian Lager with Wheat Adjuncts

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Abstract: High gravity brewing (HGB) and adjunct use are common practices in industrial breweries. This work studied the impact of HGB and wheat adjuncts on beer characteristics. Parameters were evaluated in full-malt beer and beers prepared with 30 % wheat grits (WG) and wheat flakes (WF) in the grist and the effect of HGB was examined. Five beers were prepared; one control, two with different original gravity (OG) with WF and two with WG. Beers with higher OG were diluted to a lower OG and control beer was prepared too. The application of wheat adjuncts increased foam stability but HGB did not affect the beer foam. HGB beers had a remarkably higher ester concentration than other samples, and beers with WG also had a significantly higher ester content. Decreased higher alcohols to esters ratio in HGB beers affected the balanced flavour profile of the lager beer. There was a significantly lower content of unwanted volatiles such as vicinal diketones and dimethyl sulphide in HGB beers. The application of HGB mostly did not affect the beer ageing characteristics such as carbonyl compounds and thiobarbituric acid number.

Keywords: beer; high-gravity brewing; wheat adjuncts; flavor; foam

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1. Introduction

Bohemian lager is a traditional beer style popular for its unique flavour profile and high drinkability. It typically uses a more complicated production technique including no surrogation, decoction mashing, low fermentation temperature and long lagering. Due to the demand for brewing process efficiency and environmental aspects, traditional bohemian lager producers are now starting to use progressive modern brewing methods such as high-gravity brewing (HGB) and the use of adjuncts.

HGB is a manufacturing technique using higher wort original gravity (OG) with respect to the final beer OG. For HGB technology, typically 13 – 18 °P worts are used to produce the beer with 8 – 12 °P final OG [1]. Within HGB, dilution with de-oxygenated water is usually a part of beer filtration, therefore almost the whole production (brewing process, fermentation and maturation) operates with lower volumes than the final volume of packaged beer. HGB enables a significant decrease in operational and capital costs. Savings in energy consumption (heating in the brewhouse, cooling in the fermentation area) can reach from 5 to 50 %. There are also very important savings in employee salaries and effluent processing (lower number of rinsings and sanitation). Due to the need for lower brewing capacity, there are remarkable savings in the purchase of brewery equipment and the built-up area.

HGB technology is very often connected with the use of adjuncts to reach even lower operational costs [2]. The cheapest and most commonly used adjuncts are unmalted cereals. Malting of barley and other grains is an energetically and environmentally demanding process; thus malt price is increasing [3]. Brewers are replacing malt with locally accessible cereals or processed cereals (flakes, grits, flour). The most frequent malt surrogates used worldwide are unmalted rice and corn, but in central Europe, the most commonly grown cereal is wheat [4]. Wheat was also historically the first

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cereal used for malting and beer production in Europe before the year 1600 AD, when barley was introduced to brewing. Nowadays unmalted wheat is a traditional ingredient for several Belgian beer styles (eg. Witbier) [5].

Both, HGB and the use of adjuncts have an effect on beer quality and flavor [6]. In the case of HGB technology, the higher ester content of the beer, beer body decrease, foam and colloidal stability changes are the most discussed [7-10]. Replacing malt with a proportion of unmalted wheat is often connected with an increase in grain odour and a refreshing taste of beer, a change in aroma profile and changes in foam and colloidal stability [11].

This paper follows up on HGB experiments without adjuncts [8], and the impact of HGB with wheat adjuncts on beer properties is the subject of this study. The content of aromatic compounds, foam stability and other quality characteristics were examined in order to compare beer samples prepared with or without the HGB technique.

2. Materials and Methods

2.1. Wort and Beer Production

Several brews of bottom-fermented beer were prepared in a pilot plant brewery (volume 50 L of wort) at the Department of Biotechnology, University of Chemistry and Technology in Prague. The brewing process was comparable for all batches - mashing-in temperature 40 °C, a two-mash decoction mashing technique was used with 90 minutes of wort boiling [8]. The wort was cooled to 10 °C and pitched with dried lager yeast SafLagerTM W-34/70 (Fermentis by Lesaffre, France) with prior rehydration in water. The pitching rate was the same for all brews according to the supplier's recommendation of 1 g of yeast for 1 L of cold wort, which is equal to 6 million yeast cells per 1 mL. Fermentation temperature was 10.5 °C and the time of fermentation was 8 days for batches with lower OG and 10 days for batches with higher OG. The maturation process took place at 1 °C for 21 days [8].

There were two brews with 70 % of pilsner malt and 30 % of wheat flakes in the grist, one with lower and one with higher OG, two brews with 70 % of pilsner malt and 30 % of wheat grits in the grist, one with lower and one with higher OG, and one control brew made with 100 % pilsner malt grist to compare batches of wheat adjuncts.

The brew with higher OG of beer made with wheat flakes and grits was diluted with deaerated water (prepared by vigorous bubbling of water with CO_2) to the OG of the less concentrated batch [8]. Beers were analysed for determination of their basic parameters for a dilution ratio calculation and beer samples after dilution were analysed to control their basic parameters [8] (Table 1).

Table 1. Basic analytical parameters of all beer samples not requiring dilution (UDB), before dilution (HGB before) and after dilution (HGB).

Beer Sample	OG (% wt.)	ABV (% vol.)	RDF (%)
WF UDB	10.36 ± 0.03	4.39 ± 0.01	66.3 ± 0.2
WF HGB before	18.15 ± 0.03	7.61 ± 0.01	63.3 ± 0.2
WF HGB	10.54 ± 0.03	4.26 ± 0.01	63.1 ± 0.2
WG UDB	10.26 ± 0.03	4.23 ± 0.01	64.6 ± 0.2
WG HGB before	15.90 ± 0.03	6.35 ± 0.01	60.9 ± 0.2
WG HGB	10.57 ± 0.03	4.12 ± 0.01	60.9 ± 0.2
C UDB	10.77 ± 0.03	4.57 ± 0.01	66.2 ± 0.2

Results represent mean values ± standard deviation (SD), n = 3; OG–original gravity, ABV–alcohol by volume, RDF–real degree of fermentation, WF–beer with wheat flakes, WG–beer with wheat grits, C–control beer, UDB–undiluted brewing, HGB–high gravity brewing.

2.2. Beer Analysis

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Beer extract analysis (original, real, and apparent extract and original gravity of beer) was measured on a DMA 5000 (Anton Paar GmbH, Austria) according to the EBC method 9.4 [8,12]. Beer alcohol content was measured on an Alcolyzer by NIR spectroscopy (Anton Paar GmbH, Austria) according to the EBC method 9.2.6 [8,13]. Beer foam stability was measured by NIBEM foam stability tester (Pentair Haffmans, Netherlands) according to the MEBAK method 2.18.2 [8,14]. Other beer parameters were analysed in analytical laboratories of the Research Institute of Brewing and Malting in Prague. Diacetyl content was measured by gas chromatography according to the EBC method 9.24.2 [8,15]. Lower boiling point volatile compounds in beer were evaluated by gas chromatography according to the EBC method 9.39 [8,16]. Carbonyl compounds as chemical indicators of beer aging were analysed according to the developed method [8,17]. Thiobarbituric acid number (TBA) was measured according to the MEBAK method 2.4 [8,18]. All analyses were carried out in triplicate and average values were used.

2.3. Statistical Analysis

All analyses were performed in triplicate and results were expressed as means ± standard deviations (SD). The student's T-test was used to evaluate differences between the results, with statistical significance set at $p < 0.05$.

3. Results

3.1. Foam Stability

The foam stability was evaluated (NIBEM) and there was a significant increase in wheat adjunct beers compared to the control sample. The measured characteristics of UDB and HGB beers were similar for both WF and WG surrogates, and there was no significant difference between WF and WG beer samples (Table 2).

Table 2. Foam stability (NIBEM) of beers made with wheat flakes (WF), wheat grits (WG) not requiring dilution (UDB), after dilution (HGB) and a control beer.

Adjunct Type	Beer Sample	NIBEM (s)
Wheat Flakes	UDB	212.7 ± 3.4
	HGB	210.2 ± 2.5
Wheat Grits	UDB	215.8 ± 2.0
	HGB	216.8 ± 4.7
Control Beer	UDB	197.0 ± 4.2

Results represent mean values ± standard deviation (SD), $n = 3$.

3.2. Volatile Compounds Content

The significant difference in acetaldehyde content between UDB and HGB beers in both WF and WG samples. All of these values were beneath the sensorial threshold (Table 3). Ester concentrations were significantly higher in HGB beers compared to UDB samples. The increase in ester concentrations in HGB beers was especially significant in the case of ethyl acetate, isoamyl acetate and ethyl decanoate, which were the major esters in all samples analysed (78 – 89 % of total esters). Total ester concentrations in HGB beers were 48 % higher using WF and 61 % higher using WG adjuncts. In UDB beers, the total ester concentration was significantly higher in WG beer compared with WF, as well as control beer, where only analysed compounds were compared. The total concentration of higher alcohols was lower with HGB processing, but significantly more so with the WG adjunct. In both WF and WG beers there was a significant decrease in 2-phenyl ethanol concentration in HGB samples, and this was the major higher alcohol in all beer samples analysed. In UDB beers, the total higher alcohol concentration was significantly lower with the WF adjunct compared with WG, as well as the control beer, where only analysed compounds were compared.

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Table 3. Volatile compounds in beers made with wheat flakes (WF), wheat grits (WG) and 100 % malt control sample (C), not requiring dilution (UDB), after dilution (HGB), and a control beer with a sensory threshold (TH).

Compound (mg/L)	WF Beer		WG Beer		C Beer	TH Beer (mg/L)
	UDB	HGB	UDB	HGB	UDB	
Acetaldehyde	7.85 ± 0.20	6.16 ± 0.13	5.34 ± 0.12	7.60 ± 0.33	n.e.	10–25
Esters						
Ethyl acetate	17.06 ± 0.45	27.80 ± 0.57	24.21 ± 0.98	34.63 ± 1.71	19.57 ± 1.27	25–30
Isoamyl acetate	0.99 ± 0.08	1.99 ± 0.08	1.37 ± 0.14	2.94 ± 0.12	1.15 ± 0.12	1–2
2-Methylpropyl acetate	0.04 ± 0.02	0.05 ± 0.00	0.04 ± 0.01	0.07 ± 0.02	n.e.	0.5–1.6
Propyl acetate	0.02 ± 0.01	0.02 ± 0.00	0.02 ± 0.02	n.d.	0.02 ± 0.00	30
Butyl acetate	n.d.	n.d.	n.d.	n.d.	n.d.	7.5
2-Phenylethyl acetate	1.30 ± 0.08	1.01 ± 0.16	1.43 ± 0.11	0.24 ± 0.03	1.00 ± 0.16	0.2–3.8
Ethyl formate	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	n.e.	150
Ethyl-2-hydroxy propanoate	0.03 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	n.d.	n.e.	25
Ethyl butyrate	0.15 ± 0.02	0.24 ± 0.05	0.18 ± 0.03	0.12 ± 0.03	0.14 ± 0.03	0.4
Ethyl hexanoate	1.15 ± 0.08	1.16 ± 0.13	1.26 ± 0.13	1.80 ± 0.16	1.19 ± 0.08	0.2
Ethyl octanoate	2.59 ± 0.17	1.95 ± 0.12	3.19 ± 0.16	3.42 ± 0.25	2.85 ± 0.12	0.5–1.0
Ethyl decanoate	0.48 ± 0.06	0.92 ± 0.08	0.70 ± 0.08	9.10 ± 0.16	0.85 ± 0.20	0.6–1.5
Ethyl dodecanoate	0.02 ± 0.00	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.00	n.e.	2–3.5
Ethyl tetradecanoate	n.d.	n.d.	n.d.	n.d.	n.e.	2.5
Ethyl hexadecanoate	n.d.	n.d.	n.d.	n.d.	n.e.	5
Esters total	23.84	35.19	32.46	52.34	26.77 [1]	
Higher alcohols						
n-Propanol	20.60 ± 1.71	16.20 ± 1.47	21.60 ± 1.31	14.50 ± 0.82	n.e.	600–800
Ethylhexanol	1.10 ± 0.16	0.70 ± 0.12	1.00 ± 0.41	0.30 ± 0.16	n.e.	400
Isobutanol	5.60 ± 0.49	4.18 ± 0.15	5.73 ± 0.73	4.08 ± 0.49	5.95 ± 0.41	100–200
Isoamyl alcohol	32.20 ± 0.98	31.10 ± 0.90	31.52 ± 1.22	29.89 ± 0.73	30.04 ± 0.82	50–70
Furfuryl alcohol	0.11 ± 0.02	0.11 ± 0.01	0.23 ± 0.09	0.06 ± 0.05	0.10 ± 0.04	3000
2-Phenyl ethanol	60.21 ± 1.64	49.16 ± 3.68	74.01 ± 1.63	10.93 ± 1.23	81.12 ± 1.71	20–40
2-Methyl butanol	14.69 ± 0.65	12.76 ± 0.82	14.58 ± 0.90	12.53 ± 0.57	14.59 ± 0.49	65
2,3-Butanediol	1.01 ± 0.33	2.12 ± 0.49	1.35 ± 0.29	2.08 ± 0.41	1.35 ± 0.29	4500
Higher alcohols total	135.52	116.33	150.02	74.37	133.15 [1]	
Higher alcohols - esters ratio	5.68	3.31	4.62	1.42	4.97 [1]	

Results represent mean values ± standard deviation (SD), n = 3; n.d.–not detected; n.e.–not evaluated.
[1] Values from the evaluated compounds.

The concentration of vicinal diketones (VDK) was measured in all adjunct samples, where the content of diacetyl as well as the sum of diacetyl and 2,3-pentanedione were lower in HGB beers for WF and WG adjuncts (Table 4). In UDB beers, the VDK concentration was significantly lower in WF beer compared with WG. The content of dimethyl sulphide (DMS) was significantly lower in HGB compared with UDB beers for both WF and WG samples. There was no significant difference in DMS content between WF and WG beer.

Table 4. Important flavour-active compounds in beers made with wheat flakes (WF) and wheat grits (WG), not requiring dilution (UDB), after dilution (HGB), and with a sensory threshold in beer (TH).

Compound (mg/L)	WF Beer		WG Beer		TH Beer (mg/L)
	UDB	HGB	UDB	HGB	
Diacetyl	334 ± 11	281 ± 15	387 ± 20	286 ± 29	150
2,3-Pentanedione	76 ± 3	109 ± 8	95 ± 12	54 ± 3	900
Dimethyl sulphide	14 ± 1	11 ± 1	16 ± 1	11 ± 0	50

Results represent mean values ± standard deviation (SD), *n* = 3.

3.3. Beer Aging Markers

Premature beer ageing markers such as minor carbonyl compounds and thiobarbituric acid number (TBA) were evaluated (Table 5). There were no significant differences in total carbonyl content between UDB and HGB beers, neither in WF nor in WG beer samples and there was no significant difference between WF and WG beers. TBA values were similar in all samples analysed except for WG UDB beer, which had a significantly lower value.

Table 5. Carbonyl compounds and thiobarbituric acid number (TBA) in bottom-fermented (BF) and top-fermented (TF) beers not requiring dilution (UDB) and after dilution (HGB).

Compound (μg/L)	WF Beer		WG Beer		TH Beer (mg /L)
	UDB	HGB	UDB	HGB	
2-Methylpropanal	2.76 ± 0.12	2.58 ± 0.06	2.40 ± 0.49	3.60 ± 0.41	1000
3-Methyl-2-butanone	2.67 ± 0.14	3.65 ± 0.20	3.31 ± 0.24	n.d.	60000
2-Methylbutanal	2.76 ± 0.20	2.26 ± 0.14	2.18 ± 0.15	4.60 ± 0.33	1250
3-Methylbutanal	11.07 ± 0.82	8.24 ± 1.02	8.09 ± 0.24	10.23 ± 1.06	600
Trans-2-butenal	0.80 ± 0.12	1.00 ± 0.16	1.00 ± 0.16	0.60 ± 0.16	8000
Hexanal	1.25 ± 0.04	1.37 ± 0.12	1.56 ± 0.13	1.29 ± 0.24	350
Furfural	2.81 ± 0.20	1.53 ± 0.12	2.83 ± 0.19	2.83 ± 0.11	150000
Heptanal	0.18 ± 0.02	0.21 ± 0.04	0.27 ± 0.06	n.d.	16
Oktanal	0.52 ± 0.08	0.36 ± 0.04	1.01 ± 0.08	n.d.	40
Benzaldehyde	2.40 ± 0.16	2.50 ± 0.08	2.60 ± 0.24	1.70 ± 0.41	2000
Trans-2-octenal	0.02 ± 0.00	0.03 ± 0.01	0.03 ± 0.02	0.02 ± 0.01	0.20
Trans-2-nonenal	0.05 ± 0.00	0.04 ± 0.00	0.04 ± 0.02	0.01 ± 0.01	0.11
Phenylacetaldehyde	3.11 ± 0.24	4.14 ± 0.51	3.61 ± 0.24	7.74 ± 0.33	1600
Carbonyls total	30.40	27.91	28.93	32.62	
TBA	19 ± 1.63	18 ± 1.39	13 ± 0.82	17 ± 1.22	

Results represent mean values ± standard deviation (SD), *n* = 3; n.d.–not detected.

4. Discussion

Lager is the predominant beer type produced worldwide and nowadays modern production methods such as HGB and the use of adjuncts are applied widely. This study therefore evaluates the impact of HGB technology when wheat adjuncts are used. From the analysis of basic beer parameters (Table 1) it was apparent that OG and ABV of all UDB samples, and HGB samples after dilution, were similar; these beers were thus comparable in other parameters.

4.1. Foam Stability

In the context of HGB technology, other authors usually report a deterioration in beer foam stability associated with hydrophobic protein degradation during fermentation, when proteolytic enzymes are released from yeast cells under stress [7,10]. As a result, hydrophobic proteins that promote foam stability, are partially degraded. In addition, more foam is formed during HGB

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fermentation, so that more foam-stabilising components can stick to the inner surface of the fermenter [19]. The foam stability was similar in UDB and HGB beers and there was no difference between beer samples made with WF and WG. Higher foam stability in beers with wheat adjuncts compared to the control all-malt beer is in agreement with other authors [20,21]. Wheat and wheat products stabilize the foam because of the higher content of foam-stabilizing polypeptides and other components that increase the viscosity of beer foam, thus the drainage of foam is slower. The lack of influence of HGB technology on beer foam stability is in agreement with the previous study [8] and contrasted to this paperf [19]. It points to the importance of technological details other than just HGB, such as decoction mashing, direct fire vessel heating, brewhouse vessel top filling, long wort boiling, low fermentation temperature and long maturation.

4.2. Volatile Compounds Content

A very important attribute of beer for customers is the flavour profile, which is formed mainly by volatile flavour-active compounds: esters, higher alcohols, carbonyl compounds, some organic acids and sulphur compounds. Most of these are products of yeast secondary metabolism, especially by-products of amino acid (nitrogen) metabolism [8,22].

Acetaldehyde is the major carbonyl compound in beer (up to 95 % of all carbonyls), being a member of the group of volatiles, and its formation is not connected to amino acid metabolism but to basic saccharide catabolism or ethanol oxidation [23]. The concentration of acetaldehydein WF beer was 21 % lower after HGB processing than UDB, but in WG beer, it was 27 % higher in the HGB sample. All measured values were comparable (5.34-7.85 mg/L) and below the sensory threshold (25 mg/L) [8,24]. Besides biotechnological reasons for the presence of acetaldehyde in beer (by-product of primary metabolism), oxidation of ethanol during beer processing (beer transfers, filtration or packaging) can significantly increase its concentration. Within the HGB process, the quality of deaerated water used for beer dilution also affects the acetaldehyde concentration in the finished beer and variations in values measured in beers can be caused by natural differences between every fermentation batch or the beer dilution operation under laboratory conditions.

From among beer volatiles, esters are the most important aroma substances forming the final beer character due to their very low sensory threshold and synergistic or antagonistic effects of different compounds [22,25]. Findings of this study agree with previous descriptions of the effect of HGB on ester production [1,6,8,10,25-28]. Ethyl acetate, the major beer ester, was only present at a concentration above the sensory threshold [29] in HGB samples, which supports the statement that HGB technology modified the beer aromatic profile into a fruity and solvent-like character, which is unwanted, especially in lager beers. Isoamyl acetate provides beer flavour with banana tones and in all beer samples analysed, was present above its sensory threshold but with the application of HGB, its content was more than 100 % higher. A significant decrease in the concentration of 2-phenylethyl acetate with HGB is contrary to the study of [30], who suggest that mainly acetate esters are overproduced during using of HGB technology. This ester carries a flower- and honey-like aroma [31], thus its decreased content possibly highlights the fruity and solvent-like beer character. Abundantly present ethyl esters of hexanoic, octanoic and decanoic acids (in almost all beer samples analysed at above the sensory threshold concentrations) did not show a massive increase in content with HGB, which is also in agreement with the finding of previous studies [8,30]. The ethyl decanoate content in WG HGB beer, however, was much higher than the WG UDB beer, but this was an exception and may be associated with non-specific deviations in fermentation. These esters aromas are described mostly as sweet-fruit or brandy-like [32] and a comparable content in HGB and UDB beers points to a part of the flavour profile that does not change with the use of HGB technology. In WG beers there is a remarkably higher ester content compared to WF and C beers, which points probably to an effect of ingredient composition. The aroma of wheat surrogated beer is usually more intense [5] but the ester content of WF UDB beer was similar to the C beer, which shows that wheat flakes can be a suitable adjunct for lager production, not changing the ester composition. This effect is perhaps due to the technology of flake production, where grains are steam steeped [33]. High temperature can cause non-specific protein denaturation and structural changes leading, consequently, to lower ester precursors (by-products of amino acid metabolism) in the wort.

The most present volatile compounds in beer are higher alcohols, which create the final beer sensory profile, especially through ester formation, for which they are precursors. The impact of higher alcohols on beer aromatic profile is weaker because the sensory threshold of these compounds is relatively high compared to esters [8,29], but these compounds affect the texture of beer and contribute to the full-bodied and warm perception while drinking [34]. Among higher alcohols, only 2-phenyl ethanol, the by-product of phenylalanine metabolism, was present above its sensory threshold in the majority of samples analysed. This compound contributes a rose-like aroma to beer [35]. The lower content of higher alcohols in WF beers compared to WG and C beers has possibly the same cause as the lower ester content, which is connected with flake production technology. A very significant decrease in the concentration of higher alcohols in WG HGB beer compared with the UDB beer correlates with massive ester production, for which these are precursors. These results show that the use of WG in grist provides more precursors for sensorial-active yeast metabolic by-products and therefore is not a suitable adjunct for lager production.

Beside higher alcohol and ester concentrations, the higher alcohols-to-esters ratio is an important parameter predicting and describing the beer sensorial character [36]. Lighter character and stronger aroma are the most abundant sensorial changes described with the application of HGB technology [6,8,9], which may be connected with the decrease in the higher alcohols-to-esters ratio. Also the results of this study show that the ratio of higher alcohols-to-esters was significantly higher in UDB and C beers compared to HGB samples. Especially in the case of WG beer, the decrease was notable, probably connected with the very high ester content in WG HGB beer.

Among beer volatiles, vicinal diketones (VDK) such as diacetyl and 2,3-pentadione are frequently mentioned unwanted flavour-active compounds in bottom-fermented beers, so they are suitable markers of the effect of HGB technology. These compounds carry a butterscotch like off-flavour with a very low sensory threshold (diacetyl 100 µg/L and 2,3-pentadione 900 µg/L) [29]. VDK content was significantly lower in the HGB beer sample than the UDB beer for both adjunct types, WF and WG. This result is in agreement with previous studies [8,30], where authors proposed several reasons including more active yeast cells in suspension to degrade diacetyl within HGB fermentation, or amino acid limitation in UDB beer fermentation. It is very probable that the diacetyl concentration is correlated with the time of fermentation, where the longer fermentation of HGB wort enables more effective degradation of VDK by active yeast in suspension. The difference in VDK concentration in WF compared to WG beers can be caused by different amino acid availability in worts but this possibility must be examined further.

Dimethyl sulphide (DMS) is another unwanted volatile compound strongly affecting the beer flavour profile [23]. The DMS content in the beers analysed correlates with the finding of a previous study [8], where the application of HGB technology significantly decreased its concentration. This supports the theory that the DMS content in the wort is similar regardless of the original gravity (OG). Then, after dilution of the beer to the desired OG, the DMS concentration decreases with the extract content and may be of benefit in lager beer production using HGB technology.

4.3. Beer Aging Markers

In comparison with acetaldehyde and vicinal diketones, other carbonyl compounds are usually present in beer just in traces. Nevertheless, these compounds are considered as markers of beer aging [37-39]. TBA is also used for the prediction of beer sensorial stability, as a marker of wort thermal load, and to describe thermal degradation of malt components [8,23]. The evaluation of these parameters prior to filtration, stabilisation, pasteurisation and packaging is just a limited description of potential sensorial stability properties of the beer but it can show the effect of the application of HGB technology. The results in this experiment mostly follow the findings of the previous study [8], where beer without adjuncts was analysed. The total level of carbonyl compounds and the TBA value did not differ significantly between UDB and HGB beer samples (Table 5), which indicates a weak impact of HGB technology on premature beer aging. The only exception is a lower TBA value in WG-

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UDB beer, which may be caused by a non-specific difference in the heat load during the brewing process and should be the subject of further examination.

5. Conclusions

This study confirms that HGB technology changed the content of flavour-active compounds in beer. The results also acknowledge that the application and choice of wheat adjunct affects the composition of volatiles, which should have an impact on the beer aromatic profile. The content of higher esters and the significant decrease in the higher alcohols-to-esters ratio are proven consequences of HGB technology and it disrupts the desired character of the Bohemian lager typical for its malty character and full beer body. From the wheat adjuncts examined, wheat flakes seem to be more suitable for lager production compared to wheat grits, which had a stronger tendency to change the aromatic profile into a fruity and solvent-like character. With an expanding application of HGB and adjunct use, it is essential to define process changes in beer production that will help to attain the desired sensory profile. However, this study concludes that the use of HGB technology and wheat adjuncts in beer production does not affect foam stability, TBA and the content of carbonyl compounds as premature beer aging markers. Moreover, within the conditions of this experimental work, the application of HGB technology decreased the content of vicinal diketones and dimethyl sulphide in the final beer.

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