Wheat Variety and Barley Malt Properties: Influence on Haze Intensity and Foam Stability of Wheat Beer

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ABSTRACT

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Laboratory wheat beers were brewed with different wheat varieties of different protein content (8.7–14.4%) and with five different barley malts, varying in degree of modification (soluble protein: 3.9–6.9%). In a first series of experiments, it was investigated whether wheat positively influences the foam stability, a major characteristic of wheat beers. NIBEM and Rudin (CO_2) foam analyses revealed that the effect of wheat on foam stability depended on the barley malt used for brewing. When using malt with high foaming potential, wheat exerts a negative influence. However, wheat added to over-modified malt with less foam promoting factors, ameliorates beer foaming characteristics proving that wheat contains foam active compounds. In addition, Rudin (N_2) values suggested that wheat positively influences foam stability by decreasing liquid drainage, probably caused by a higher beer viscosity and/or a finer foam bubble size distribution.

Furthermore, the haze in wheat beers, which is another important quality characteristic of these beers, was investigated. Permanent haze readings of the 40% wheat beers were lower than 1.5 EBC haze units. For 20% wheat beers, an inverse relation between the permanent haze (9.4–19.3 EBC haze units) and the protein content of the wheat was established. The barley malt used for brewing also influenced permanent haze readings. A positive correlation between the modification degree of the malt and the permanent haze intensity was found. It was concluded that the choice of raw materials for wheat beer brewing considerably influences the visual properties of the beer.

Key words: Foam, haze, malt, wheat variety.

INTRODUCTION

Wheat and wheat derivatives such as wheat malt, flour and starch are commonly used as adjuncts in the brewing industry. In the production of Belgian white beers 60% barley malt and 40% unmalted wheat is generally used. Although wheat characteristics can vary greatly depending on the variety, the brewers set no strict specifications for wheat. The major factors used to distinguish wheat varieties are the protein content, hardness or softness of the grain, winter or spring variety and red or white bran. Hough et al.[21] stated that wheat used for brewing is usually of a soft variety, having a mealy or floury endosperm and a protein content of up to 11%. This variety is easily milled leading to a maximal extract yield. Baetslé[3] claimed that preferably soft wheat varieties should be used for the production of wheat beers. In contrast, some brewers believe that, for the production of a hazy white beer, a hard wheat variety with high protein content should be used. This is based on the assumption that hard wheat varieties contain more haze active proteins of high molecular weight[27,35].

The use of unmalted cereals such as wheat results in a lowered beer pH, due to a reduced buffering potential, and a paler beer, caused by the absence of a kilning process. Another quality characteristic ascribed to these beers is the presence of an attractive and stable head of foam. It has been claimed that the use of wheat, as part of the grist, improves the head formation and stability[4,27]. However, elaborate views on how wheat influences beer foam characteristics are scarce. Although wheat does not necessarily have a higher overall protein content than barley, wheat contributes more high molecular weight proteins to the wort[27,34]. These wheat proteins[4,27,35], more specifically wheat glycoproteins[2], have been suggested to be related to the superior foam characteristics of wheat beers. Wilde et al.[38] and Clark et al.[10] isolated lipid binding proteins from wheat (puroindolines) which can bind to free lipids in beer, reducing lipid induced destabilisation of beer foam. However, Lusk[29] questioned whether lipid binding proteins survive the brewing process because they are poorly water soluble. Bryce et al.[8] found that the addition of wheat malt to the grist increased the hydrophobic polypeptide content and foam stability of high gravity brewed beers, though wheat malt had little effect on these parameters in low gravity brewed beer. Cooper et al.[11] found no significant increase in hydrophobic proteins in beers brewed with 10% wheat or wheat malt.

High molecular weight non-starch polysaccharides such as β-glucans and arabinoxylans are known to increase beer viscosity and are likely to reduce the drainage of liquid from foam, thereby increasing foam stability. Kolbach and Kremkov[25] claimed that wheat arabinoxylans have foam-enhancing properties. Furthermore, Kakui et

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al.[24] estimated the bubble size distribution in wheat and barley malt beer by using microscopy. They found that the bubble size of wheat beer was much smaller than that of barley beer, which may account for the creaminess of wheat beer foam.

While in Pilsner beers turbidity is unacceptable, in white beers both the observed intensity and stability of the haze are quality characteristics. The major constituents of the colloidal haze in white beers are, as in Pilsner beers[20,28], proteins in conjunction with polyphenols and starch or degraded starch[12]. It has been claimed that high molecular weight wheat proteins contribute to haze formation [16, 35, 37]. In addition, replacement of barley malt by unmalted wheat or wheat flour in lager beers resulted in an increased colloidal stability[26,31]. This might be caused by the overall reduction in particular soluble nitrogenous fractions and polyphenols[6,21]. Delvaux et al.[14] showed that wheat gluten proteins are haze active and interact with polyphenols and protein-polyphenol complexes with the formation of haze particles. When a large proportion of wheat is used, these particles become too large and settle, resulting in a decrease in haze intensity. The importance of altering the wheat gluten level by altering wheat variety or level is therefore transparent.

The use of unmalted wheat also results in wort α-amino nitrogen dilution[27,32]. This is due to the limited hydrolysis of wheat proteins by barley malt proteolytic enzymes[7]. The amino nitrogen content of wort influences yeast growth and metabolism and thus the flavour profile of beer mainly via higher alcohol and ester formation. It also affects the production of beer off-flavours, such as diacetyl and dimethylsulphide[32]. Low amino nitrogen content may further result in a lower wort fermentability[26].

The objective of this study was to investigate the influence of wheat and wheat varieties on several wheat/white beer physico-chemical properties such as colour, pH, haze intensity and foam stability. To this end, laboratory scale wheat beers were brewed with different wheat varieties and barley malts.

MATERIAL AND METHODS

Raw materials

Scarlett barley malts were supplied by Cargill Malt Division (Herent, Belgium) and Esterel malt by De Wolf-Cosyns (Leuven, Belgium). Tinos wheat was supplied by Kumps (Leuven, Belgium), Vivant wheat by Clovis Matton (Avelgem, Belgium) and Kinto, Corvus, Biscay, Skater, Beaufort, Claire, Genghis, Drifter and Legat wheat varieties were obtained from AVEVE (Landen, Belgium). Northern Brewer hops (5.1% α-acids, Analytica EBC[1]) were used for brewing.

Barley malt and wheat analysis

Conventional malt and wheat analyses were performed according to Analytica EBC[1]. The soluble protein content of wheat was calculated based on protein analysis of 60% malt and 40% wheat congress worts. The applied nitrogen-protein conversion factor was 5.7 for wheat and 6.25 for barley. Viscosity was determined at 20°C with a Delta-Viscosimeter® MK1 (Kraainem, Belgium).

Brewing

Brews (800 mL, 11.5°P) were prepared in four fold on laboratory scale as previously described by Delvaux et al.[12] An all-Scarlett malt beer and several wheat beers were made, the latter based on 60% or 80% Scarlett malt and 40% or 20% unmalted wheat respectively. Barley malt and wheat were milled with a DFLU Disc Mill (Buhler, Braunschweig, Germany) at setting 1.2 mm and 0.2 mm respectively and mashed in with deionised water. The pH of the mash was adjusted with sulphuric acid (0.2 N) and the following specific temperature-time profile was used: 30 min at 50°C, increase to 63°C (1°C/min), 45 min at 63°C, increase to 73°C (1°C/min), 15 min at 73°C, increase to 80°C (1°C/min). After separation of the wort and the spent grains in a small scale lauter tun, the wort was adjusted to pH 5.3, hopped to obtain a bitterness of 13 EBU, boiled for 60 min in a glycerol bath (106°C) and rested for 1 hour. Two 800 mL worts were decanted and combined in a 2L fermentation vessel. The wort was further cooled to 20°C, oxygenated to 8 ppm oxygen, pitched with *Saccharomyces cerevisiae* (5×10^6 cells/mL) and fermented at 20°C for 14 days. The beers were bottled in 250 mL bottles with addition of *Saccharomyces cerevisiae* (5×10^5 cells/mL) and 2.0 g sucrose (0.8°Plato). The beers were refermented at 20°C for 3 weeks.

Additional all-malt beers (800 mL, 11.5°Plato) and 60% malt–40% Vivant wheat beers were prepared with Scarlett, Scarlett Lux (L), Scarlett Oise (O), Scarlett Witness (W) and Esterel malts using the same equipment.

Beer analysis

Standard beer analyses were according to Analytica EBC[1]. The haze was determined nephelometrically at 20°C with a Haffmans (Venlo, The Netherlands) nephelometer (range 0–100 EBC haze units) and expressed in EBC haze units (Analytica EBC). Foam stability was measured with a NIBEM foam stability tester (supplied by Haffmans). The NIBEM values quoted are for foam collapse over 30 mm. This measurement was highly reproducible in the individual experimental beer samples with a mean difference of 5.4 s (range 1.0–8.1 s). The head retention value (HRV) was determined by the Rudin[33] method using carbon dioxide gas to generate the foam and a modified Rudin method in which nitrogen gas is used for foam generation[15]. The mean differences between duplicates were 19.6 s (range 3.0–35 s) and 2.8 s (range 1.0–4.2 s) for the Rudin testing with carbon dioxide and nitrogen gas respectively. All analyses were carried out at least in duplicate.

RESULTS AND DISCUSSION

Influence of wheat varieties on beer characteristics

To study the influence of wheat on beer characteristics, laboratory scale wheat beers were brewed based on 60% Scarlett barley malt and 40% of the different wheat varieties. An all-Scarlett malt beer was used as a control.

Raw materials. Total protein content and water soluble protein level of Scarlett barley malt was 9.1% on dry

Table I. Analysis of eleven European wheat varieties.

Analysis	Vivant	Kinto	Corvus	Biscay	Skater	Beaufort	Claire	Genghis	Drifter	Legat	Tinos
Moisture content (%)	14.0	11.1	11.3	10.3	11.4	11.3	13.5	10.7	11.0	13.9	13.3
Extract on dry wheat (fine) (%)	86.9	79.4	76.4	76.0	80.3	77.2	80.8	76.8	77.7	81.2	75.0
Total protein on dry wheat (%)	8.7	9.6	9.7	9.7	10.2	10.8	11.2	11.6	11.9	12.8	14.4
Soluble protein on dry wheat (%)	2.07	2.60	1.88	2.00	2.22	2.60	2.37	2.67	2.86	2.86	3.90

Table II. Beer analysis of an all-Scarlett malt beer and beers brewed with 60% Scarlett malt and 40% of different European wheat varieties.

	Scarlett	Vivant	Kinto	Corvus	Biscay	Skater	Beaufort	Claire	Genghis	Drifter	Legat	Tinos
Original extract (°P)	12.4	12.3	12.3	12.2	12.3	12.4	12.3	12.3	12.2	12.2	12.2	12.4
Apparent attenuation (%)	93.3	91.1	88.2	89.1	89.3	88.8	90.1	89.0	87.1	88.7	89.2	88.8
CO_2 (g/L)	6.1	6.0	5.7	5.8	6.0	6.0	5.8	5.7	5.8	5.8	5.8	6.0
pH	4.3	4.0	3.9	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.0
Colour (EBC Units)	7.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Nitrogen (mg/L)	656	576	624	576	560	560	592	608	640	640	656	720
Polyphenols (mg/L)	263	142	138	135	131	131	130	132	130	129	133	125
Viscosity (cP)	1.55	1.61	1.56	1.55	1.57	1.63	1.62	1.57	1.60	1.60	1.61	1.64
Foam stability[a] (s/3 cm)	261	236	213	223	217	221	211	252	225	228	243	255
HRV[b] (N_2) (s)	477	522	498	485	470	520	495	542	474	484	569	571
HRV[c] (CO_2) (s)	106	99	95	93	93	102	99	97	99	98	99	102

[a] NIBEM foam stability.
[b] Rudin Head Retention Value with N_2 as foaming gas.
[c] Rudin Head Retention Value with CO_2 as foaming gas.

basis (d.b.) and 4.0% (d.b.) respectively. Extract was 80.3% (d.b.), fine-coarse difference 1.5%.

Eleven European *Triticum aestivum* wheat varieties with a varying protein content were selected for the experiment. Kinto, Legat and Tinos are known to be wheat varieties with a high bread making value. The others are regular wheat varieties used for bread making or feed. Extract yields and analyses of the wheat varieties are given in Table I. Congress wort analysis (based on 60% barley malt and 40% wheat) showed a large difference in the extract yields of the wheat varieties, varying between 75.0 and 86.9% (d.b.). The total protein content varied between 8.6 and 14.4% (d.b.).

General beer analysis. Analyses of the experimental beers are presented in Table II. Although 11.5°P brews were made, original extract of the beers was approximately 12.3°P, because saccharose (0.8°P) was added to the bottle for refermentation. Thereby, CO_2 contents between 5.7 and 6.1 g/L were obtained. Apparent attenuation of the wheat beers was lower than that of the all-malt beer showing that more fermentable sugars were present in the latter. The pH of the wheat beers was lower than that of the all-malt beer, because wheat has a lower buffering potential than barley malt[33]. The use of unmalted wheat also results in a paler product. The colour of the wheat beers was 2.5 EBC units lower than that of the all-malt beer. Protein analysis revealed lower nitrogen contents of the wheat beers. However, nitrogen content of the wheat beers increased with an increase of the total protein content of the wheat. To be precise, a linear relationship ($R^2 = 0.90$; $P < 0.01$) was found between the nitrogen content of the wheat beers and that of the respective congress worts (Table I). Polyphenol levels of the centrifuged wheat beers were low compared to the level of the all-malt beer. A negative correlation ($R^2 = 0.62$; $P < 0.01$) was found between the polyphenol level of the wheat beer and the total protein content of the wheat used for brewing. This can be ascribed to a polyphenol diluting effect of wheat that contributes few polyphenols to the beer. However, it has also been reported that wheat proteins easily interact with polyphenols and form precipitates, which settle during fermentation and lagering or can be removed by centrifugation of the beer[14]. In the light of the above, it is reasonable to interpret the decrease in polyphenol level with increasing protein content of the wheat, as an increased formation of insoluble particles.

The results in Table II furthermore show that the viscosity values of the wheat beers were higher than the viscosity of the all-malt beer.

Wheat versus foam. Several methods have been developed for foam stability assessment[23], though none of them is generally accepted. In this study, foam stability was determined by the two most commonly used methods in the brewing industry, namely the NIBEM and the Rudin method. In the latter, carbon dioxide and nitrogen gas were used for foam production. Caution is recommended with the interpretation of the results as both foam assessment methods are based on different principles. From the results of the NIBEM testing, it was obvious that amongst the wheat beers the foam stability varied considerably. The foam stability of the Tinos wheat beer was 21% higher than that of the Beaufort wheat beer. However, except for the Tinos wheat beer, the foam stability of the wheat beers was significantly lower than that of the all-malt beer. Replacement of 40% barley malt by wheat reduced foam stability by 2–19%. Similar results were obtained by the Rudin analyses with CO_2 as foaming gas. Foam stability of the wheat beers was 4–12% lower than that of the all-malt beer. Nevertheless, it needs to be stressed that, as mentioned above, the Rudin testing with CO_2 was less reproducible than the NIBEM testing. Probably because the differences between the Rudin (CO_2) measurements were low, no correlation was found with the NIBEM testing at a significance level of 90%. HRV measurements with nitrogen as a foaming gas were in marked contrast to the results of the previous foam measurements. A broad

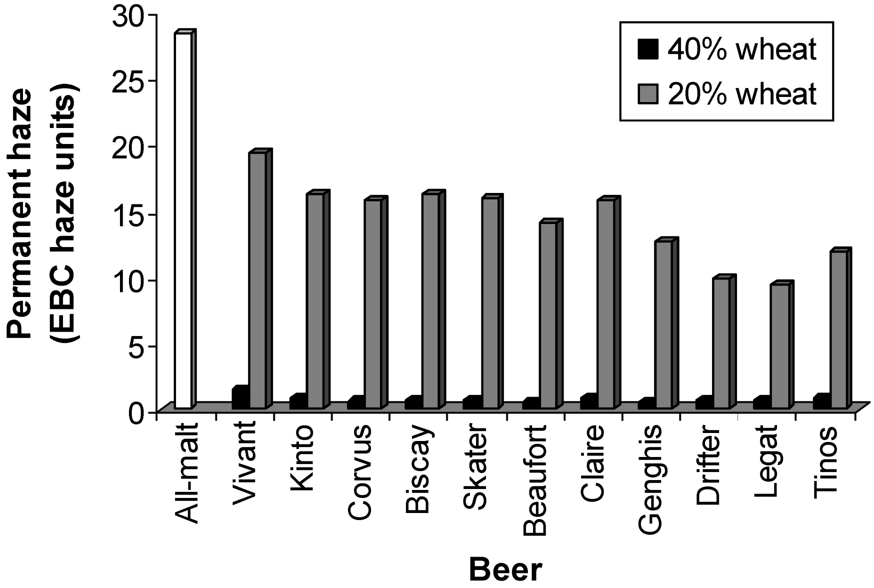

Fig. 1. Permanent haze intensity of an all-Scarlett malt beer and wheat beers brewed with 40% and 20% of different European wheat varieties.

range of Rudin values (N_2) for the wheat beers was obtained. The foam stability of the wheat beers was equal to or higher than that of the all-malt beer. Using Tinos wheat for brewing increased the head retention of the beer by 20%. Remarkably, in the wheat beers, the nitrogen HRV were related to the NIBEM ($R^2 = 0.65$; $P < 0.01$) and CO_2 Rudin ($R^2 = 0.45$; $P = 0.06$) values obtained.

Although it seems to be generally accepted that wheat has a positive influence on foam stability, confirming evidence is scarce. Birtwistle et al.[6] and Hudson[22] found that beers brewed from grist containing 25% wheat flour possessed superior Rudin (CO_2) foam stability compared to all-malt beers. Leach[27] reported that the use of 22.8% wheat flour increased the HRV (CO_2) from 95 to 107 s (13%). Stewart et al.[36] reported that inclusion of 10% wheat malt into the grist improved foam stability (Rudin, CO_2) of low and high gravity brewed wheat beers by approximately 5% (HRV: 92 to 97 s), compared to the 100% barley malt samples. Later, these researchers only found an improved foam stability (NIBEM and Rudin, CO_2) for the high gravity brewed wheat beers[8]. The studies that ascribe a positive foaming property to wheat are mainly based on foam stability measurements by the Rudin method (CO_2). Our investigation only confirms a positive effect by the Rudin method using nitrogen gas. However, it is not illogical that wheat has a positive influence on the foam stability using the Rudin method in general. In this method the drainage of the liquid out of the foam is measured. Liquid drainage is slowed down by an increased viscosity and smaller foam bubbles. The latter parameter has been shown to be favoured by wheat[24].

Bamforth[5] questioned the accuracy of the different foam measurements. Wheat might show foam stabilising effects with the Rudin test, but this does not necessarily mean that wheat shows foam stabilising properties when other methods are used.

Not only foam generation, but also the gas used for foam generation determines foam stability. The use of nitrogen gas reduces the bubble size, resulting in a creamy foam texture[9]. Because nitrogen gas diffuses much slower than carbon dioxide, the disproportionation process, i.e. the diffusion of the gas from small bubbles in the foam to larger bubbles, is strongly reduced. Disproportionation is one of the major processes that contribute to foam instability. Wheat beer head retention values were lower than the all-malt beer head retention values when using CO_2 as foaming-up gas, though, with the exception of two values, the opposite was found when N_2 was used. Because disproportionation is minimised when using nitrogen, these differences indicate that the use of wheat as part of the grist has a negative influence on foam stability by increasing disproportionation processes in the foam. However, since the Rudin (N_2) values of the wheat beers are higher than that of the all-malt beer and since they are related to the respective NIBEM and Rudin (CO_2) values, this suggests a positive influence of wheat on foam stability processes other than disproportionation. For instance, an increased viscosity and a finer bubble size distribution decrease liquid drainage and thus increase foam stability. These processes are counteracted by an increased disproportionation when using CO_2 as foaming-up gas. This might explain the lower foam stability of the wheat beers than that of the all-malt beer determined by NIBEM and Rudin (CO_2). Based on this assumption it can be expected that the overall effect of wheat on the foam stability is influenced by the malt properties.

Wheat versus haze. An intense and stable haze is one of the most important characteristics of wheat beers. Permanent haze readings of the all-malt beer and the different wheat beers are shown in Figure 1. Three weeks after bottling, the Scarlett all-malt beer had a haze intensity of 28 EBC haze units. Adding 40% wheat, regardless of the protein content, diminished the haze intensity to values close to 1 EBC haze unit. Previous research has shown that the haze intensity in wheat beers is mainly governed by the wheat gluten content of the beer, which in turn de-

Table III. Analysis of malts.

Analysis	Esterel	Scarlett	Scarlett W	Scarlett L	Scarlett O
Moisture content (%)	5.5	6.1	8.2	4.6	5.9
Extract on dry malt (%)	80.1	80.3	82.0	82.6	80.4
Fine-coarse difference (%)	1.6	1.5	1.0	0.8	0.6
Total protein on dry malt (%)	10.3	9.1	10.4	10.9	13.0
Soluble protein on dry malt (%)	3.9	4.0	4.3	6.0	6.9
Kolbach index[a] (%)	38.4	44.5	41.2	55.0	53.3
Viscosity (cP)	1.44	1.56	1.46	1.47	1.49

[a] Kolbach index = (soluble protein)/(total protein) × 100.

pends on the wheat level and the protein content of the wheat[14]. It was repeatedly shown that the use of 40% unmalted wheat leads to beers with almost no permanent haze[13,14]. Therefore, additional brews were made based on 20% wheat. Due to the lower wheat level, the permanent haze intensity of these beers was significantly higher. Furthermore, an inverse relation was found between the permanent haze and the protein content of the wheat (R^2 = 0.69; $P < 0.01$). The results above confirm the importance of the wheat level and the protein content of wheat with regard to the haze intensity of wheat beers.

Influence of barley malt varieties in combination with wheat on beer characteristics

Above it was suggested that the influence of wheat on beer characteristics varies with the variety of wheat but also with the type of malt used for brewing. Therefore, 40% Vivant wheat beers were brewed with five different barley malts and compared to the respective all-malt beers.

Raw materials. Table III summarizes the malt quality parameters of the barley malt varieties. The modification of the malts varied from low to high, which is reflected in the wide range of extract yields (80.1–82.6%, d.b.), fine-coarse values (0.6–1.6) and soluble protein levels (3.9–6.9%, d.b.). Although the use of malt, with a Kolbach index (KI) higher than 45, is unusual in the brewing industry, it was anticipated that this range of variability would provide the best opportunity to study the impact of wheat on wheat beer characteristics. Vivant wheat specifications were as presented in Table I.

Beer analysis. pH and colour values of the all-malt beers were higher than those of the corresponding 40% wheat beers (Table IV). Furthermore, the colour of the beer increased with the degree of malt modification. Colour readings of the beers brewed with Scarlett L and Scarlett O malt were extremely high, which is attributable to an overmodification particularly due to proteolysis. Obviously, increasing soluble protein malt content results in an increase of the nitrogen content of the all-malt beers. The nitrogen and polyphenol content of the wheat beers was lower in comparison with the corresponding all-malt beer. These observations confirm both previously reported results[14] and the observations obtained in the experiment described above. The CO_2 content of the beers varied between 5.6 and 6.1 g/L and wheat beer viscosities were higher than all-malt beers.

Foam. In the experimental set-up, it was assumed that low-malt modification (low KI) improves foam quality[19]. Indeed, the brewing trials showed that malt quality and addition of 40% wheat influence foam stability (Table IV). NIBEM foam stability of the all-malt beers decreased by 15% due to increasing malt soluble protein content. The same phenomenon was observed for the Rudin (CO_2 and N_2) foam values. A positive correlation between the different foam measurement techniques is thus well established and a negative correlation between these methods and the soluble protein content of malt or beer can be observed. Narziss et al.[30] also stated that an appreciable decrease in NIBEM foam stability can be attributed to an overmodification of the malt used. Evans and Hejgaard[17] and Evans et al.[18] found a negative correlation between foam stability (Rudin HRV) and the Kolbach Index.

For the NIBEM measurements, the effect of wheat addition depends on malt characteristics. When brewing with low or normal modified malt with a high foaming

Table IV. Beer analyses of all-malt (Esterel, Scarlett, Scarlett W, Scarlett L, Scarlett O) beers and 40% wheat (Vivant) beers.

	Esterel		Scarlett		Scarlett W		Scarlett L		Scarlett O	
	—	Vivant	—	Vivant	—	Vivant	—	Vivant	—	Vivant
Original extract (°P)	12.3	12.5	12.4	12.3	12.2	12.5	12.5	12.5	12.4	12.3
Apparent attenuation (%)	93.2	91.2	93.3	91.1	93.0	90.8	92.2	92.5	92.1	92.3
CO_2 (g/L)	6.1	6.1	6.1	6.0	5.6	5.6	6.0	5.8	6.0	5.7
pH	4.3	3.9	4.3	4.0	4.2	4.0	4.3	4.2	4.3	4.2
Colour (EBC Units)	7.0	4.5	7.0	4.5	5.5	4.5	10.0	7.5	12.5	9.0
Nitrogen (mg/L)	656	592	656	576	752	608	1008	800	1296	992
Polyphenols (mg/L)	240	138	263	142	205	105	241	123	246	140
Viscosity (cP)	1.45	1.53	1.55	1.61	1.47	1.56	1.47	1.50	1.46	1.52
Foam stability[a] (s/3 cm)	253	247	261	236	254	241	239	261	222	242
HRV[b] (N_2) (s)	505	503	477	523	444	481	459	521	420	420
HRV[c] (CO_2) (s)	101	102	106	99	102	96	96	98	94	91

[a] NIBEM foam stability.
[b] Rudin Head Retention Value with N_2 as foaming gas.
[c] Rudin Head Retention Value with CO_2 as foaming gas.

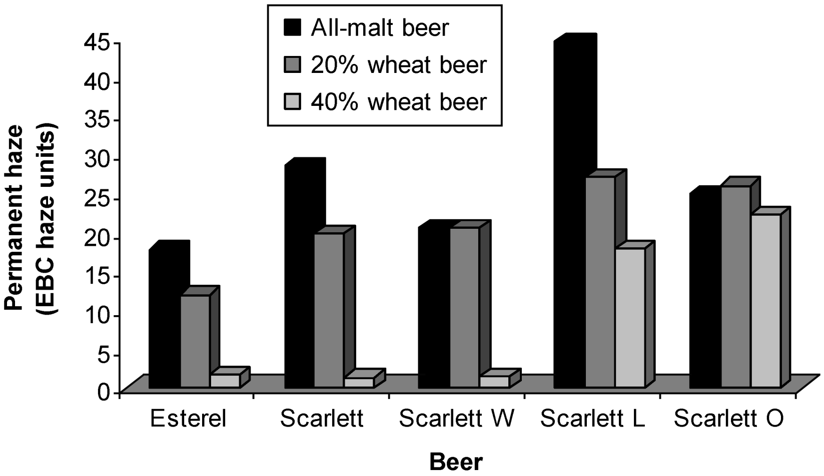

Fig 2. Permanent haze intensity of all-malt and 40% and 20% wheat (Vivant) beers brewed with Esterell, Scarlett, Scarlett W, Scarlett L and Scarlett O malts.

potential (Esterel, Scarlett and Scarlett W), replacement of part of the malt by wheat resulted in a loss in foam stability from 2–10%. But with a Scarlett L and Scarlett O overmodified malt, adding wheat ameliorated foaming characteristics with approximately 9%.

According to the Rudin results, incorporation of wheat into the grist had a negative or no significant influence on HRV with CO_2 as foaming gas. In contrast, nitrogen HRV of the wheat beers were at least the same or higher in comparison with those of the corresponding all-malt beers. These findings confirm the results discussed above. An overall positive effect of wheat was not found. However, when the effect of disproportionation on foam stability was minimised by the use of nitrogen as a foaming up gas, foam stability was not or positively influenced by the use of wheat.

Haze. Permanent beer haze intensities, three weeks after bottling, are illustrated in Figure 2. The haze intensity of the all-malt beers varied between 18 and 45 EBC haze units. With the addition of 40% Vivant wheat the haze intensity decreased, which was more pronounced in beer brewed with a normal modified malt than in beers brewed with a high-modified malt. Due to the use of malt with a higher proteolytic activity (Scarlett L and Scarlett O) an increased breakdown of (wheat) protein occurs during brewing. Indeed, Brijs et al.[7] showed that wheat gluten proteins are degraded during brewing. Smaller proteins will lead to smaller haze particles, which have fewer tendencies to settle. As a consequence, the permanent haze of the 20% wheat beers increased with increasing modification of the barley malt. The data furthermore showed that when using a high-modified malt, the effect of the wheat level on haze intensity was less pronounced. However, it is of note that the high-modified malts were not within brewers' spectra.

CONCLUSIONS

Unmalted wheat used as an adjunct can yield high extract, but reduces not only wort fermentability, but also the colour, pH, level of soluble nitrogen and polyphenols in the beer. The viscosity of 40% wheat beers is higher than that of all-malt beers. Obviously, these parameters play an important role in wheat beer haze intensity and foam stability. Despite the limited literature, it is generally accepted that wheat has foam-enhancing properties. Our results suggest that wheat contains foam active compounds. However, the overall influence of these compounds is not easily detected. Moreover, replacement of barley malt by wheat as part of the grist increases disproportionation processes in the foam. Therefore, it can be suggested that wheat should have a positive influence on other foam stability determining factors like bubble size distribution and drainage effects. However, the role of barley malt properties cannot be neglected. The overall effect of wheat on foam stability therefore depends on the foaming potential of the barley malt and wheat variety used for brewing.

Furthermore, the importance of the wheat gluten level with regard to wheat beer haze intensity was confirmed. Wheat gluten proteins are haze active and interact with polyphenols and protein-polyphenol complexes to form haze particles. The level of wheat gluten determines whether the haze particles stay in suspension or settle. The results extended our previous findings, namely that not only wheat gluten levels influence haze intensity, but also barley malt properties. Based on the observation that wheat beers brewed with a high modified malt contain more haze than those brewed with a low modified malt, it is tempting to speculate that due to higher proteolytic activity in malt, wheat proteins are more degraded during brewing. Smaller proteins lead to smaller particles and thus more particles remain in suspension, resulting in a more stable haze.

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