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The Use of Oats in Brewing

Oats (*Avena sativa*) are one of the most popular cereals for human consumption. In the middle ages oats were the brewing cereal par excellence. Over the centuries they were substituted by other cereals and their brewing properties were nearly forgotten. Today oats are popular once more because of their excellent health-related properties. For people who suffer with celiac disease oats are also of interest. Based on their historical use in brewing and their health-related properties pilot malting trials were carried out with different varieties, followed by brewing trials with a selected variety. The results obtained showed that oat malt is an appropriate choice for brewing.

Descriptors: Avena sativa, beer, brewing, malting, oats

Abbreviations:

DLG – Deutsche Landwirtschaftsgesellschaft (German Agricultural Society)

dm – dry matter

DMS – dimethylsulphide

DMS-P – dimethylsulphide precursor (S-methylmethionine)

EBC – European Brewery Convention

FAN – free alpha-amino nitrogen

MEBAK – Middle Europaen Analysis Commission on Brewing Technology

TBI – thiobarbituric index (thiobarbituric acid reactive substances)

VZ – Hartong index

1 Introduction

Today the specifications for brewing cereals are apart from moderate protein and high starch contents a high enzyme activity and low b-glucan content. Oats are known to be rich in protein, lipids and b-glucan and low in starch (1). So today, they would appear to be a far from ideal brewing ingredient.

The role of oats as a brewing cereal has changed through history. In the middle ages their use for brewing was popular. It is known that monks in Switzerland and England used huge quantities of oats for malting and brewing. With publication of the German purity law in 1516 their brewing properties were forgotten and their use outside of Germany was limited (2, 3). Beer brewed from oats was considered inferior and was only used for brewing cheaper beers (4, 5).

During World War II there was a return to the use of oats because of the rationing of barley. Oats were mainly used in flake form at this time and only together with good malt (6).

Some writers suggest the addition of oats owing to their high husk contents. The husks give a more open texture to the mash and accelerate wort separation (2, 7, 8, 9).

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Tables see Appendix

Beers brewed with oats were different in colour, body and strength to others. As a result of the low extract the beers obtained were weaker (5). A rough taste was often criticized. In Sweden brewers were advised to use oats to save two thirds of the hops (3). Hopkins (6) described the taste of the beers brewed with oat flakes as soft, bitter, dry and characteristically with only slight differences to other beers. Habich (7) described a prickly taste with a specific, but pleasant, acidity. Beers brewed with a high proportion of oats exhibit a distinct tendency to haziness (7). In the 19th century Pelz and Habich (8) recommended using a maximum of 9 % oats to make use of the advantages without the risk of hazy beers.

Beside its brewing history this cereal is also interesting with respect to its physiological properties. Oat products have a lowering effect on serum cholesterol concentration (10, 11). This is owing to the fraction of non-starchy polysaccharides (12). Oats are also recommended for people who suffer with celiac disease. Celiac disease is a food induced, immunological disease which is owing to an intolerance of certain amino acid sequences of the prolamin fraction of wheat gluten and corresponding fractions of other related cereals (*e.g.* barley, rye, triticale). The therapy is solely dietetic and involves a gluten-free diet (13, 14). In Germany one person in thousand is affected by this disease (15).

The intake of prolamin causes damage to the intestinal mucosa and therefore a malabsorbtion of nutrients (13, 14). In terms of its tolerance for celiac patients it is an intensively published topic. Studies published in the Fifties describe detrimental effects. In later studies it could not be confirmed that moderate consumption of oats over a longer period of time was harmful to patients with celiac disease (16). Although barley, rye, wheat and oats contain approximately the same amount of protein they do not contain the same amount of prolamin. Oat prolamin accounts for only 10–15 % of total protein whereas other cereals are higher (wheat 40–50 %, barley 35–45 %) (14).

2 Experimental

For the malting trials ten different husked oat varieties from the harvest of 2002 were used from the Nordsaat Saatzucht GmbH (Granskewitz/Germany). All samples were malted in the institute's pilot malting plant for 7 and 8 days. The germination was isothermal at 14.5 °C with a maximum water content of 45 %. After germination the malts were kilned according to the following procedure. 50 °C (16 h), 60 °C (1 h), 70 °C (1 h) and 80 °C (5 h). A Munich malt was also made according to the following procedure: 50 °C (5.5 h 100 % circulating air), 50 °C (15.5 h 100 % fresh air), 65 °C (1 h), 85 °C (1 h), 105 °C (5 h).

The activity of the a- and b-amlylase was determined with the

Ceralpha and Betamyl diagnostic kits (Megazyme Ltd., Bray/Ireland). From congress wort the contents of long-chain fatty acids and the hydroperoxides of the linoleic and linolenic acids were estimated according to the methods from *Schuetz* et al. (17, 18).

For brewing the 8-day malt from the Duffy variety was taken. Five beers with different grist to liquor ratios were brewed. Brew 1 and 2: 1 : 5, brew 3 and 4: 1 : 4.25, brew 5: 1 : 4. For the brews 1-3 the following infusion mashing method was used: 35 °C (20 min), 45 °C (20 min), 52 °C (15 min), 62 °C (5 min), 72 °C (10 min), 78 °C (5 min). For brew 4 the step at 62 °C was missed out. The mashing procedure for brew 5 was as follows: 45 °C (10 min), 52 °C (10 min), 72 °C (15 min), 78 °C (5 min). Beer 5 was brewed with a 60 % fraction of the Munich malt from the Duffy variety.

Following lautering the wort was boiled for 90 min (brew 1–4) or 55 min (brew 5). The hop addition was divided into two parts. The first addition (80 % of total hops) was given at the beginning and the second addition was 5 min before the end of boiling. Total addition was calculated for 25 bitterness units in the beer. Before pitching the hot break was removed and the wort was cooled to pitching temperature. The top-fermenting pitching yeast was cultivated in oat malt wort and was added to the wort after cooling. Fermentation temperature was 10 °C (brew 1–4) and 16 °C (brew 5). After the main fermentation the green beer was matured for one week at 16 °C. Before filtration (Seitz-K 900, Pall SeitzSchenk GmbH, Bad Kreuznach/Germany) and bottling the beer was stored for at least 3 weeks at 0 °C. To get a higher extract yield for production of beer 5 only the first wort was taken for boiling. The last running from lautering was taken as mashing-in water. The average extract content was 4.4 % mas.

The malts, worts and beers were analysed according to the EBC and MEBAK standard methods (19, 20, 21, 22). The forced ageing procedure was 24 h shaking followed by 4 day storage at 40 °C.

For sensory evaluation of the beers the criteria of the DLG were used (20).

3 Results and Discussion

3.1 Pilot malting results

All oat malts showed low extract contents between 59.6 % dm and 64.5 % dm. The protein content was, except for one sample, always above 10 % dm (max. 12.6 % dm). The concentration of soluble nitrogen showed great variation between varieties. Varieties which were low in FAN were also low in soluble nitrogen. All oat samples showed little change in wort colour after boiling. The colours of congress wort were between 3.3 EBC and 5.5 EBC and between 5.0 EBC and 6.5 EBC in the boiled wort. A prediction of the lysis of the kernel is possible by the change in viscosity and ß-glucan content from congress wort to Hartong index (VZ) 65 °C. The very low b-glucan contents increase slightly and the viscosity remains nearly constant. This shows good cell wall degradation during malting.

In Table 1 mean value and range of the parameters are shown from all used varieties. All malts distinguished from other by the content of unsaturated fatty acids in the congress wort. The concentration of linolenic acid was not included for calculation of the total fatty acids because it could only be determined imprecisely with < 0.25 mg/l in the majority of the samples. Varieties with low linoleic acid concentrations had low concentrations of the homologous hydroperoxide as well. So there could be a possible correlation.

The 8-day malts differ only little from the above described 7-day malts. The extract and FAN contents showed a slight decrease. This is dispositional to the consumption of dry matter by respiration of the seedling. Independent of the germination time the FAN content was at a similar level. According to *Narziss* (23) there will be an increase in FAN with an increase in time because of the degradation of macromolecular proteins to low molecular compounds. If the germination time is increased significantly he describes a decrease in FAN ascribed to the consequent losses to the growth of rootlet and acrospire. The soluble nitrogen concentration increased by 20 mg/100 g dm compared to the 7-day malts. In all 8-day malts higher concentrations of anthocyanogens were found, but the level was still low compared to barley. In addition, the concentration of tanning agents was very low and not more than 41 mg/l. Because of the low b-glucan content in congress wort and Hartong index 65 °C as well as the behaviour of the viscosities good cell wall degradation in all malts took place.

For saccharification of the mash the activities of the amylolytical enzymes are of special interest. b-amylase activity was determined in the range 68–186 Units (U)/g dm, depending on the sample. Weichherz (24) stated that the diastatic power is approximately one third of that of barley malt. The a-amylase activity was in the range 70–152 U/g dm. We need to verify that the analytical methods, which are designed for barley malt, can be applied completely or partially to oat malt. After verifying this, a conclusion about the relative enzyme activities of oat compared to barley should be made. This seemingly low enzyme potential is seen to some extent in the saccharification time of the congress wort. Varieties with low activity needed up to 25 min to saccharify the mash whereas varieties with a higher potential needed only 10 min. Malts with high diastatic power logically had higher attenuation limits. Those attenuation limits were on a similar level as the 7-day malts. During the one day germination expansion the fermentability increased to a maximum of 88.1 %. This is an indication of a good utilisation of malt ingredients by yeast. The mean value and the range of the 8-day malts are presented in Table 2.

With respect to the fatty acid contents presented in Table 2 it is remarkable that the change with increasing germination time is a variety dependent phenomenon. The behaviour of single fatty acids is different but a decrease with increasing time prevails. A similar pattern gave the determination of the crude lipid concentration of Duffy variety. In the unmalted grain 4.45 % dm of crude lipid was detected. After 7 days germination a lipid content of 3.59 % dm was detected as well as 3.39 % dm after 8 days of germination.

The concentrations of hydroperoxides in Table 2 compared to Table 1 also showed differences. The majority of samples showed a decrease of all hydroperoxides, so that a decrease with time was assumed. Compared to barley the concentration of hydroperoxides was low. In barley congress worts a concentration of linoleic acid hydroperoxide was found in the range 100–250 µM/l and linolenic acid hydroperoxide 25–65 µM/l. This is a multiple concentration of the oat worts. Oats exhibit only a small activity of lipoxygenase (25, 26). The results obtained reflect this difference, too. Fatty acids and their degradation are seen as precursors to sensory active carbonyls and so they have influence on flavour stability in beer.

The researched oat varieties had a low lipid degrading potential but they also had high concentrations of lipids. Those could also influence beer flavour during photo- or autoxidation.

Looking at the results in Table 3 the current demand for barley malt is presented in comparison to selected results of the Duffy variety which was used for brewing trials. Characteristically was the high protein content as well as the low extract. In contrast were the very low b-glucan concentrations. This is remarkable in a positive way because high b-glucan concentrations could lead to lautering and filtration problems as well as extract losses in brewery (27).

3.2 Brewing trials

3.2.1 Results of the worts

The production of the different oat malt worts was comparable to barley malt worts. Noticeable was the high spent grain volume, which comes from the husk content, and the acceleration of mash filtration. Worts showed low turbidity. As seen in Table 4 the original gravity conformed to the particular beer type (beer 1 and 2: low gravity beer (light beer), beer 3 and 4: lager, beer 5: strong beer). Owing to the relatively high amounts of low molecular nitrogen compounds the wort colour was quite intense. The wort of beer 5 had a more intense colour because of the Munich malt.

Concentrations of total soluble nitrogen were in the normal range of 700 to 1600 mg/l. Differences in soluble nitrogen were in consequence of the differences in gravity. The change in the mashing procedure was responsible for the small increase in soluble nitrogen. In pale worts the content of FAN should be in the range of 200 to 240 mg/l. Owing to the extensive protein stand light beers were on the upper limit. The other beers had higher grist loads and so they had higher FAN-concentrations. Ratios of FAN to total soluble nitrogen were 23–27 %. A high level of coaguable nitrogen was also observed in wort of beer 5.

The concentrations of dimethylsulphide (DMS) and dimethylsulphide-precursor (DMS-P) were high. These compounds came from the malt because in the 8-day malt of Duffy variety 10.5 ppm (limit 7 ppm) were detected. This is owing to the kilning temperature of the pilot malting plant with its maximum temperature of 80 °C. At this temperature level no adequate split of DMS-P into DMS is possible. High DMS and DMS-P levels were also observed in the cast worts. An increase in kilning temperature should decrease the DMS-P content in the malt.

Considering the high concentration of the Munich malt in beer 5 a thiobarbituric index (TBI) of 45 was normal. Beers 3 and 4 also showed normal values.

The greatest difference to barley malt worts was the high zinc content (0.23–0.64 mg/l). Zinc is an essential micro element to yeast and a deficiency in it could lead to fermentation defects. To prevent such defects a minimum of 0.1–0.15 mg/l should be available to yeast. Also remarkable, but predictable, were the low b-glucan concentrations in the worts. The change in the mashing procedure did affect noticeable attenuation limits. Beer 4 (73.4 %) had a 10 % lower attenuation degree than the beers 1–3 (84.2–87.2 %). The high attenuation degrees show a good fermentability.

The carbonyls of the Strecker degradation were on a similar level in beers 3–5 (< 280 µg/l). Pentanal is known as a product of the oxidative degradation of linoleic acid (28). Its concentration in all worts is approximately 4 µg/l and this concentration was above the average value of barley malt worts. So a high concentration of linoleic acid is assumed in the cast worts. *Moonjai et al*. showed that a supplementation of unsaturated fatty acids could lead to a better yeast propagation during fermentation (29, 30). Conspicuous were the high concentrations of the amino acid tryptophan and the high amount of total amino acids.

3.2.2 Results of the beers

The results of the chemical-technical analysis are listed in Table 5. Original gravity and alcohol conformed to the beer type. All beers were nearly fermented to completion and there was less than 1 % fermentable extract. pH-values were higher than normal because of yeast autolysis.

The reducing power is an indicator of fast reducing substances in beer, which have great influence on beer stability. Compared with a commercially available pilsener style beer (21.2 %) the reducing power of beers 3 and 4 were high. Beer 5 (61.9 %) exceeded these and reached a value which is possible outside the German purity law under addition of antioxidants. Because of the lack of tannoids and the very low concentrations of tanning agents and anthocyanogens the high reducing power comes from unknown oat ingredients. In addition to this, fermentation also influences reducing power.

The TBI correlates with ageing relevant compounds. High TBI values will lead to losses in flavour stability. Beer 2 had a TBI of 15, beer 3 and 4 of 20 and beer 5 of 28. Most of the commercially available beers have 30–40 so that the TBI of the oat beers could be seen as low. The decrease of the TBI from wort to beer is understandable because of its segmentation by *Thalacker* (31). The staling will be influenced by the antioxidative properties. All forced aged beers showed a doubling in ageing indicators. This was owing to the increase of 2-furfural, 2-phenylethanol and g-nonalacton (see Table 6). Beer 5 showed a good ageing stability based on the good reducing power. It can be said that all fresh and aged beers had low concentrations of ageing indicators.

Unusual compared to barley malt beers, was the concentration of ethyl-nicotinate in the fresh and aged beers. This ester increased during ageing but it was unaccounted for the total ageing indicators even though it could be seen as an indicator for temperature and ageing (32). The threshold is approximately 2000 µg/l (33). Above this, it causes a papery and grainy flavour (34). In beer a maximum concentration of 750 µg/l is reported (32), so no direct but an indirect contribution to flavour by synergistic effects could be possible. The niacin as a part of the ester could be found in the media (wort) or it could be synthesized by yeast in an aerobic pathway from tryptophan (35). In a fermenting wort the aerobic pathway could be excluded but tryptophan as precursor should be kept in mind because of the particularly high tryptophan concentrations in the cast wort. During baker's yeast propagation a secretion of niacin into the media is possible under certain propagation conditions as described by *Wihervaara* (35). Tryptophan concentration and the nitrogen composition with increased amounts of ethyl-nicotinate could be unique for brewing using oats and requires more scientific research. The exact synthesis of this ester during the brewing process and its influence to beer properties is also worthy of further investigation.

The tasting of the fresh beers according to the DLG-standards (criteria: quality of flavour (odour and taste), quality of bitterness, mouthfeel, rezens) yielded a weighted DLG-score of 4.44 for beer 3 and 4. Beer 5 was evaluated with 4.31. This is a good sensory evaluation. Likewise the evaluation of the forced aged beers gave DLG-scores above 4.00, so they were marginally inferior to the fresh ones. Only a light staling could be detected. The acceptance of all beers was quite high. The sensory evaluation (see Table 5) reflects the good reducing power and the slight increase in ageing compounds.

The taste of all of the beers was described as slightly top-fermenting with a special taste, which was not unpleasant. Some tasters noted a lingering bitterness.

3.3 Prospects and problems

For a hundred per cent use of oat malt for brewing some technical and technological principles should be considered. As a result of the greater quantity of husks after milling a greater grist volume is produced. Small pipelines between mash tun and lauter tun could lead to problems because of blocked pipelines or remaining mash in the mash tun. A grist to water ratio of 1 to 4 will be the minimum. At a higher ratio (*e.g.* 1 to 3.5) whole grist will not be covered with water and this could lead to the formation of lumps. Lumps are responsible for an unbalanced conversion during mashing and losses in extract. A grist to water ratio of 1 to 4 gives an approximately 12%-wort. Only low sparging volumes could be applied to the spent grains and for production of lager or even stronger beer types the lixiviation will not be satisfying. So it will be more economic to re-use the sparging water of the previous brew as mashing-in water of the following brew.

Beside this there are a lot of advantages of a 100 % or less use of oat malt. Indeed the husks are a little bit problematic in storage or during mashing but the husks give a more open texture to the mash and this accelerates lautering. An addition of 5–10 % of oat malt to brews with a high contingent of wheat could be lautered in a faster way. Furthermore an oat malt addition could affect the zinc content of the wort, the reducing power of the beer as well as flavour stability of top-fermenting beers in a positive way. Beers brewed in this way offered a pleasant top-fermenting flavour which still differs from the familiar top-fermenting flavour.

On the basis of the data presented it can be seen that there is a requirement for more scientific research regarding oats. In addition to the white oat Duffy variety, it is possible to use black husked oats or naked oats. Like wheat, naked oats lose husks during harvesting and so will provide higher extract contents. For best use of the husks an addition of 10–15 % husked oat is suggested.

Further research is required into the decrease of the protein induced haze in the bottled beers. On the other hand, this could be one solution to the colloidal stability of unfiltered top-fermented beers.

It is desirable to increase extract and enzyme activity and lower lipid and protein contents. For brewing only varieties with low β-glucan contents (here: Duffy variety) should be used to prevent the problems mentioned.

Concluding, the disadvantages of oats are the low extract and high lipid content as well as their tendency to produce hazy beers, and the high grist volume. On the other hand the fast lautering, the zinc content of the wort, the high reducing power, low β-glucan contents of the varieties used, and a stable haze could be seen as advantages in using oats.

4 Summary

The favourable brewing properties of oats have been almost lost with the passage of time. Today their use is becoming increasingly popular, because of discussions about their tolerance to celiac patients and some positive advantages to health of using these particular cereals. With ten different varieties from the Saatzucht Nordsaat GmbH (Granskewitz/Germany) pilot malting trials were carried out. All malts were low in extract and positively low in ß-glucan as well. From the auspicious Duffy variety, brewing trials were made to produce different types of top-fermenting beers. The processing of the malt was carried out without any technological problems. The worts produced had higher zinc and nitrogen contents and in this way they were different from normal worts. All the beers showed a low staling and a high reducing power. Flavour was different from the known top-fermenting flavour.

Therefore oat malt is suitable for brewing various innovative specialities. On the other hand, it could be used as lautering aid or for improving the colloidal stability of unfiltered top-fermenting beers. If it is confirmed that oats are safe for people who suffer with celiac disease the diet of those people could be improved. In this way oats could play an important role to produce a beer for those people which is low in gluten or gluten-free.

Oats are a cereal with unrealized brewing potential.

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Appendix

Table 1 Results of the 7-day malts

	7 days germinated		
	min	**mean**	**max**
protein dm [%]	9.5	11.0	12.6
congress wort			
extract dm [%]	59.6	62.4	64.5
apparent attenuation limit [%]	77.3	80.6	87.1
pH	5.9	6.0	6.1
colour [EBC]	3.3	4.1	5.0
boiled wort colour [EBC]	5.0	5.7	6.5
viscosity [mPa·s] 8.6 %	1.503	1.546	1.605
FAN [mg/100 g dm]	101	123	147
soluble nitrogen [mg/100 g dm]	514	593	686
total polyphenols [mg/l]	23	30	40
anthocyanogens [mg/l]	3	7	16
β-glucan [mg/l]	20	44	79
saccharification time [min]	<10	–	20–25
Hartong index 65 °C			
viscosity [mPa·s] 8.6 %	1.467	1.536	1.642
β-glucan [mg/l]	57	70	111
fatty acids [mg/l]			
C 14:0	0.12	0.16	0.21
C 16:0	2.41	4.27	5.94
C 18:0	0.22	0.42	0.60
C 18:1	1.17	2.42	3.40
C 18:2	2.89	5.53	7.45
C 18:3	<0.25	-	0.50
total fatty acids*	7.83	12.60	15.52
total fatty acids (12 %)*	13.00	21.54	26.70
hydroperoxides [µM/l]			
C 18:2	13.15	41.30	64.37
C 18:3	2.51	7.52	10.19

*without C 18:3

Table 2 Results of the 8-day malts

	8 days germinated		
	min	**mean**	**max**
protein dm [%]	9.2	11.1	13.0
congress wort			
extract dm [%]	59.5	62.2	64.1
apparent attenuation limit [%]	79.9	82.8	88.1
pH	5.8	6.0	6.1
colour [EBC]	3.4	4.2	5.0
boiled wort colour [EBC]	5.2	6.0	7.2
viscosity [mPa·s] 8.6 %	1.501	1.534	1.588
FAN [mg/100 g dm]	103	122	146
soluble nitrogen [mg/100 g dm]	542	614	715
total polyphenols [mg/l]	15	27	41
anthocyanogens [mg/l]	5	10	17
β-glucan [mg/l]	29	44	62
saccharification time [min]	< 10	-	20-25
enzyme activity			
α–amylase [U/g dm]	70	100	152
β-amylase [U/g dm]	68	134	184
Hartong index 65 °C			
viscosity [mPa·s] 8.6 %	1.464	1.522	1.593
β-glucan [mg/l]	53	71	103
fatty acids [mg/l]			
C 14:0	0.12	0.16	0.21
C 16:0	2.75	4.11	5.05
C 18:0	0.31	0.49	0.64
C 18:1	1.50	2.26	3.35
C 18:2	2.90	4.90	7.37
C 18:3	< 0.25	-	0.47
total fatty acids*	7.97	11.92	16.59
total fatty acids (12 %)*	13.78	20.55	29.19
hydroperoxides [µM/l]			
C 18:2	16.83	30.97	50.59
C 18:3	3.50	5.46	7.38

*without C 18:3

Table 3 Comparison of barley and oat malt

	oat malt Duffy/ 7 days	**oat malt Duffy/ 8 days**	**demands barley malt**
protein dm [%]	12.6	12.3	>10.0–11(.5)
extract dm [%]	64.4	63.7	>81.5
apparent attenuation limit [%]	87.1	88.1	>82
colour [EBC]	3.7	3.7	2.5–3.5
boiled wort colour [EBC]	5.9	6.2	5.0–5.5
pH-value	5.9	5.9	5.8–5.9
soluble nitrogen [mg/100 g dm]	681	698	700–750
FAN [mg/100 g dm]	145	145	140–150
Kolbach index [%]	33.8	35.5	38–41
β-glucan VZ 65 °C [mg/l]	63	56	<350
viscosity VZ 65 °C [mPa·s]	1.511	1.535	<1.600

Table 4 Wort analysis of oat malt worts

	brew 1	brew 2	brew 3	brew 4	brew 5
original gravity [% mas]	9.55	9.04	11.49	11.81	16.24
pH	5.62	5.60	5.95	5.89	5.71
colour [EBC]	11.0	10.9	14.5	14.7	39.3
apparent attenuation limit [%]	87.2	85.3	84.2	73.4	67.2
total soluble nitrogen [mg/l]	1075	956	1291	1250	1530
FAN [mg/l]	263	238	322	329	355
coaguable nitrogen [mg/l]	-	-	21	19	53
free DMS [µg/l]	-	-	123	111	116
DMS-P [µg/l]	-	-	292	240	329
β-glucan [mg/l]	-	-	26	30	179
zinc [mg/l]	0.36	0.23	0.30	0.25	0.64
TBI	-	-	34	33	45
Σ Strecker aldehydes [µg/l]	-	-	272	254	276
Σ amino acids [mg/l]	-	-	2666	2675	3114
tryptophan [mg/l]	-	-	69	70	86
pentanal [µg/l]	-	-	3.9	4.0	4.1

Table 5 Results of the analysis of the oat malt beers

	beer 2	beer 3	beer 4	beer 5
original gravity [% mas]	8.99	11.32	11.74	16.22
alcohol [% vol]	3.98	4.86	4.48	5.99
apparent extract [% mas]	1.35	2.13	3.33	5.34
pH-value	4.87	5.03	4.94	4.65
colour [EBC]	7.3	9.3	9.8	17
tannins [mg/l]	61	64	50	80
anthocyanogens [mg/l]	12	13	14	14
TBI	15	20	20	28
foam stability (NIBEM) [s]	196	207	210	195
reducing power [%]	-	32.9	38.3	61.9
apparent attenuation degree [%]	85	81.2	71.6	67.1
Σ ageing indicators [µg/L] (fresh/aged)	-	39/89	40/85	80/160
weighted DLG-score (fresh/aged)*	-	4.44/4.28	4.44/4.03	4.31/4.23
ageing taste score (fresh/aged)**	-	1.0/1.6	1.0/2.0	1.0/1.5
acceptance [%] (fresh/aged)	-	100/82	100/63	99/84

* score 5: very good – score 1 deficiency weighted score: (2*bitterness+2*odour+2*taste+mouthfeel+rezens)/8
** score 1 no staling – score 4 strong stalingweighted score: (2*flavour+2*taste+bitterness)/5

Table 6 Ageing indicators [µg/l] of the oat malt beers

	beer 3		beer 4		beer 5	
	fresh	forced	fresh	forced	fresh	forced
3-methylbutanal	10	11	7.6	10	12	16
2-furfural	traces	37	4.0	33	traces	30
5-methylfurfural	6.3	6.5	6.1	6.9	7.1	8.2
benzaldehyde	0.7	0.7	0.6	0.7	0.8	1.4
2-phenylethanal	7	11	6	11	10	21
diethyl-succinate	traces	traces	traces	traces	2.0	2.1
ethyl-nicotinate	87	88	69	81	189	245
ethyl-phenylacetate	0.6	0.6	0.6	0.7	1.2	1.7
2-acetyl-furan	2.4	3.0	2.2	3.6	19	23
2-propionyl-furan	2.2	3.2	2.5	2.5	non-evaluable	9.5
γ-nonalacton	10	16	10	17	28	47
Σ ageing indicators	39	89	40	85	80	160