A. Forster and A. Gahr

Hopping of Low Alcohol Beers*

In previous tests it could be shown, that aroma hops can partially compensate sensory deficits of low alcohol beers (< 1.2 % ABV) and light beers. In the following trials the main goal was to optimize the quality of low alcohol beers by using stopped fermentation and specific hopping regimes. Beers were produced at two levels of bitterness with 15 and 20 International Bitter Units (IBU) and late hopped with increasing additions (100 to 300 g/hl) of pellets of three aroma varieties (Saphir, Hersbrucker and Hallertau Mittelfrueh).
It is demonstrated to which extent linalool (as a marker for hop aroma compounds) and polyphenols were transferred from aroma hops to beer. Additional sensory results, verified by a panel of 30 untrained participants, are showing that the sensory properties of low alcohol beers at both bitter levels were improved remarkably. This effect covers not only hop aroma but also quality of bitterness and mouthfeel. Low alcohol beers can be produced which show a similar sensoric quality like normal light beers but with 60 % less alcohol.

Descriptors: low alcohol beers, hopping, flavour, bitterness, polyphenols, linalool

1 Introduction

The influence of hop varieties on beer quality is the subject of many scientific papers. In this article the relevant literature on this matter is not reviewed as not to go beyond the scope of this paper. However, the aspect of alcohol-reduced beers has hardly been investigated so far. This article will focus on the aspect that especially in alcohol-reduced beers, hopping plays a decisive part in order to compensate deficits in taste.

In a test series with light and low alcohol beers it could be shown how specific hop additions can compensate for the naturally occurring flavor deficits of these types of beers [1]. Along with an addition of the bittering variety Taurus at the beginning of the boil for base bitterness, the aroma variety Saphir was used both at the end of the boil in an amount of 48 g/hl and additionally at mid boil with 68 g/hl.

The experimental series presented here was limited to low alcohol beers with < 1.2 % alcohol by volume (ABV) and strived to achieve an improved production process with an expansion of the hopping schedule [2].

2 Definition of low alcohol beer

When it comes to light and low alcohol beers there is as of yet no universally valid ruling across the EU countries. As an example the German beer legislation provides a definition of light beers according to table 1 above. In a normal fermentation alcohol content is a predictable function of starting gravity.

Table 1 German Definition of light beer

	Official Range	Common Range
Original Gravity [°P]	7.0–10.9	7.0–8.0
Alcohol by Volume, ABV [%]	2.5–4.5	2.5–3.0

The classification of reduced alcohol beers is guided by food regulation and is valid for many, but not all EU countries. It specifies two levels:

- Alcohol free beer: Alcohol < 0.5 % ABV
- Low alcohol beer: Alcohol 0.5 to 1.2 % ABV

Low alcohol beers have a few aspects that are of interest:

- A discussion about the dangers of alcohol, for example in relation to traffic, would be redundant.
- In the EU only beers that contain < 1.2 % ABV may be promoted based on health related aspects, provided they are justified.
- That could be an indication which limits the EU would view for an advertising ban for alcoholic beverages, in the case that such a ruling looms.
- The production of alcohol free beers, depending on desired quality, is conditioned upon additional dealcoholization processes. This is a difficult challenge for medium sized operations. Low alcohol beers do not require specific investment.

The task at hand is the production of a beer with „light beer character" (approx. 8 degrees Plato starting gravity) using arrested fermentation. The low alcohol beer would contain accordingly about 40 % of the normal alcohol content of a light beer without inferior sensory character. Should this be realistic, the question presents itself: Why are there so few low alcohol beers in the marketplace?

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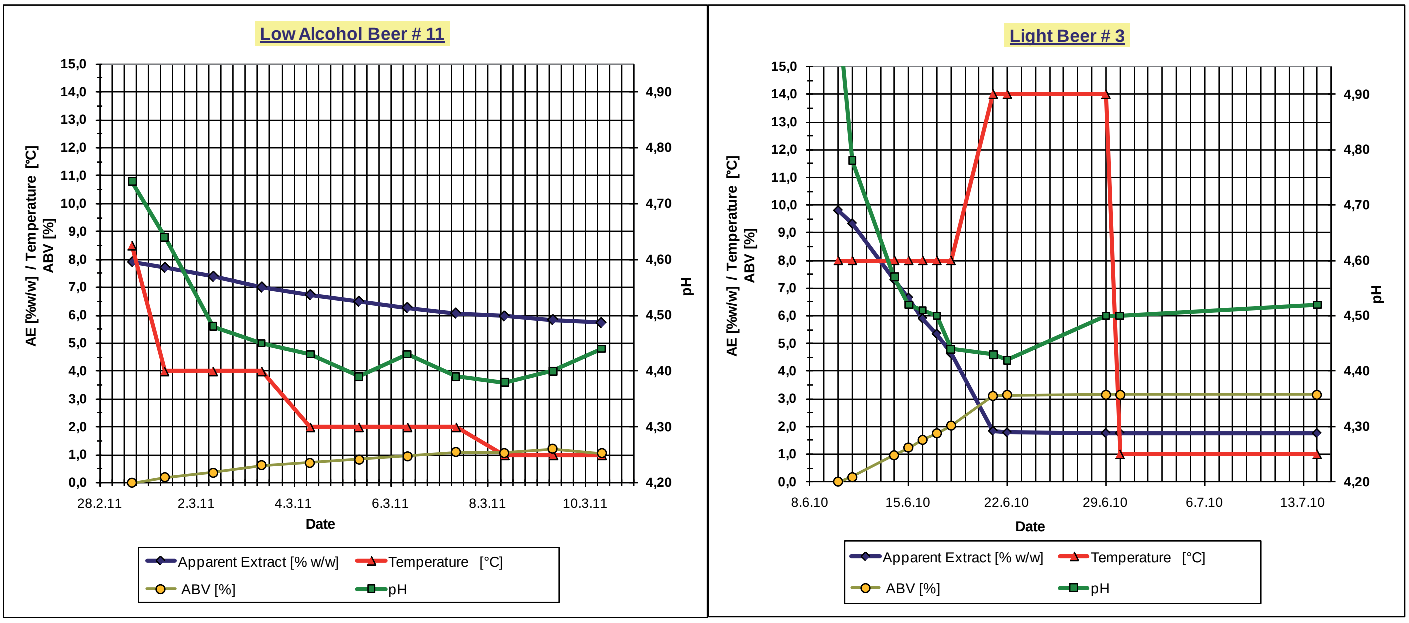

Fig. 1 **Fermentation diagrams of a low alcohol beer in comparison to a normally fermented light beer**

3 Experiment Design

Diverse optimization experiments at the 200 liter Research Brewery in St. Johann resulted in the following process:

- 90 % Pilsner Malt, 10 % Carahell®
- Infusion mash (72/76 °C)
- 70 minutes boiling time in external calandria
- pH correction to 4.7 using lactic acid
- Bottom fermentation with 10 million cells/ml
- Addition of an acetolactate decarboxylase
- Arrested fermentation, cold aging
- Filtration with DE and membranes
- No pasteurization

The addition of an acetolactate decarboxylase was used as an insurance policy. With a suitable choice of yeast this may be avoidable. The relatively tight filtration did not require pasteurization, which however should be checked in individualized cases. Figure 1 compares the fermentation diagram of a low alcohol beer relative to a corresponding light beer. The fermentation temperature has a meaningful impact on the low alcohol beer. It had to be checked with each brew and individually corrected depending on the course of the fermentation.

The hopping of all the beers utilized regular pellets of Hallertau origin. For aroma hops the varieties Hallertauer Mittelfrueh (HHA), Hersbrucker (HHE) and Saphir (HSR) were used. 100 or 200 g pellets per hl were added at boil end (50 % of which to the whirlpool). In two experiments 100 g aroma pellets were also added at the boil midpoint. Taurus (HTU) was used to supplement the bittering units in the first addition at boil begin.

All of the experiments were laid out in two levels of bitterness with 15 and 20 International Bitter Units (IBU). Nothing changed with the aroma additions, simply the addition at the beginning of the boil with different amounts of Taurus pellets to achieve a comparable bitterness within the levels. The hop additions followed an unusual scheme:

- In the middle and final hop additions to convey an obvious hop character
- In the first addition to accomplish the task of providing bitterness

Table 2 **Hopping scheme of the 14 experimental brews; HTU = bittering variety Taurus; HHA/HSR/HHE = aroma varieties Hallertauer Mfr., Saphir and Hersbrucker; values in g/hl**

Beer code		Control	HHA 100	HHA 200	HSR 100	HSR 200	HSR 300	HHE 300
End of boil	15 IBU	–	100	200	100	200	200	200
	20 IBU	–	100	200	100	200	200	200
Middle of boil	15 IBU	–	–	–	–	–	100	100
	20 IBU	–	–	–	–	–	100	100
Begin of boil (HTU)	15 IBU	32,7	28,6	24,5	28,8	24,9	1,5	9,1
	20 IBU	48,6	44,5	40,4	44,7	40,7	17,3	24,9

Table 3 **Analysis data of the four pellets employed**

		HTU	HHA	HSR	HHE
Alpha-acids (HPLC)	% w/w	14,4	5,0	4,1	3,1
Beta : alpha ratio	gβ/gα	0,33	1,26	1,83	2,39
Total polyphenols	% w/w	3,4	4,7	5,0	5,1
Polyphenols : alpha ratio	g/gα	0,24	0,94	1,22	1,65
Linalool	mg/100 g	9	6	9	7
Linalool : alpha ratio	mg/gα	0,63	1,20	2,20	2,26
HSI Hop Storage Index		0,28	0,26	0,29	0,28

Table 4 Analysis results of the seven experimental brews with a level of 15 IBU (MEAN = mean value; SD = standard deviation, CI = confidence interval; student-t-test, α=0,05)

Beer code		Control	HHA 100	HHA 200	HSR 100	HSR 200	HSR 300	HHE 300	MEAN	SD	CI
Original Gravity, OG	% w/w	8,01	7,77	7,90	8,31	8,07	8,04	7,74	7,98	0,20	0,18
Alcohol by volume, ABV	%	1,09	1,19	1,16	1,22	1,15	1,16	1,08	1,15	0,05	0,05
pH		4,47	4,40	4,53	4,43	4,50	4,46	4,44	4,46	0,04	0,04
Bitterness (EBC 9.8)	IBU	15,1	16,0	16,4	15,8	15,8	15,9	16,3	15,9	0,4	0,4
Iso-α-acids (EBC 9.47)	mg/l	12,1	10,4	11,0	10,4	10,0	7,7	9,5			
α-acids (EBC 9.47)	mg/l	1,9	2,3	3,3	2,2	2,6	4,1	3,4			
IBU : Iso-α-acids		1,25	1,54	1,49	1,52	1,58	2,06	1,72			
Total Polyphenols (EBC 9.11)	mg/l	116	132	162	145	163	196	179			
HPLC Polyphenols	mg/l	39,3	48,7	56,8	50,9	62,4	62,6	53,9			
Linalool	µg/l	7	33	66	48	86	95	78			

Table 5 Analysis results of the seven experimental brews with a level of 20 IBU (analogously to Table 4)

Beer code		Control	HHA 100	HHA 200	HSR 100	HSR 200	HSR 300	HHE 300	MEAN	SD	CI
Original Gravity, OG	% w/w	7,92	7,82	8,00	7,89	7,88	8,06	8,06	7,95	0,09	0,09
Alcohol by volume, ABV	%	1,08	1,07	1,15	1,10	1,13	1,18	1,18	1,13	0,05	0,04
pH		4,44	4,49	4,44	4,45	4,53	4,45	4,52	4,47	0,04	0,04
Bitterness (EBC 9.8)	IBU	19,0	20,1	20,4	19,0	19,0	19,3	19,4	19,5	0,6	0,5
Iso-α-acids (EBC 9.47)	mg/l	15,3	16,1	15,6	14,9	12,9	11,9	11,8			
α-acids (EBC 9.47)	mg/l	1,9	2,9	3,5	1,7	2,2	3,6	2,9			
IBU : Iso-α-acids		1,24	1,25	1,31	1,28	1,47	1,62	1,64			
Total Polyphenols (EBC 9.11)	mg/l	116	144	171	145	163	194	186			
HPLC Polyphenols	mg/l	34,0	50,2	57,6	46,6	61,2	71,8	61,1			
Linalool	µg/l	7	39	58	48	74	99	78			

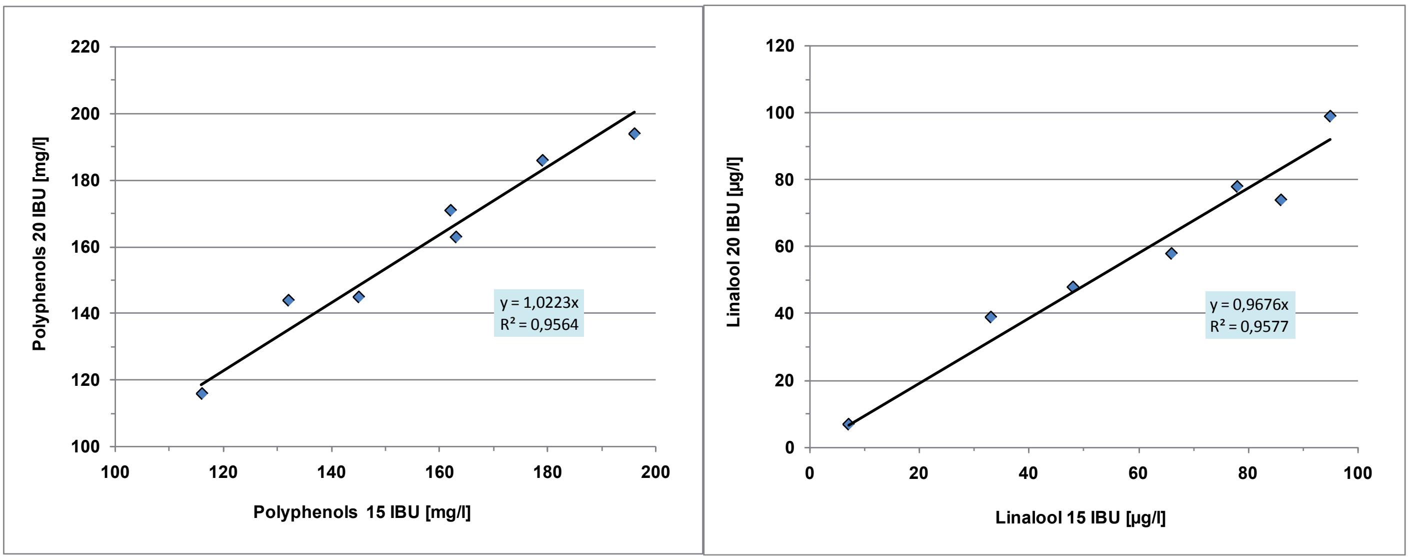

Fig. 2 Polyphenol (left) and linalool (right) values of the 20 IBU series plotted against the 15 IBU series

Table 2 (see page 73) contains the relevant data for the comprehensive program that included 14 beers in total. The abbreviations introduced in table 2 for the test brews are also valid for the rest of the tables and diagrams. The two bitter levels 15 and 20 IBU can also be viewed as double trials for analysis data such as polyphenols or linalool since the middle and final aroma hop additions were identical and only the first bitter hop addition varied slightly.

Table 3 (see page 73) shows some of the key analysis results with ratios, as they are shown in an updated Pocket Guide to German

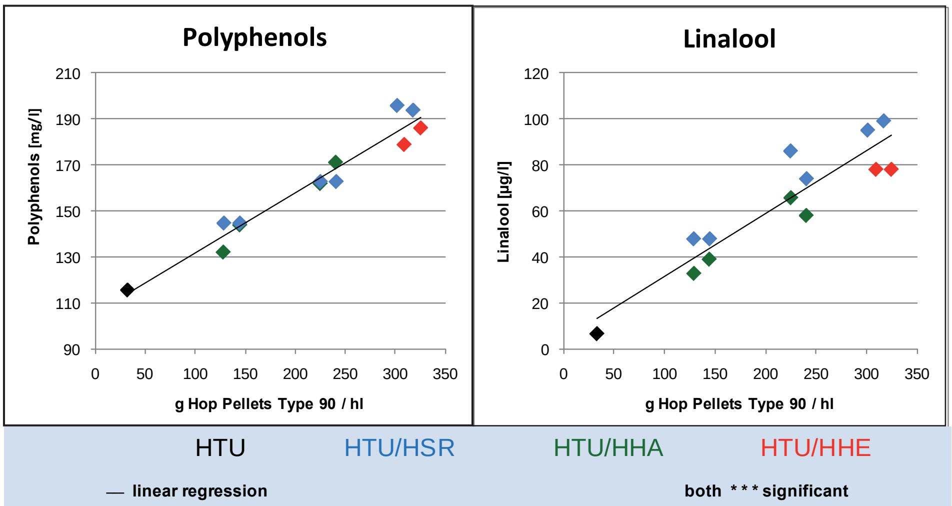

Fig. 3 **Polyphenol (left) and linalool content (right) as a function of pellets added (average of the 15 and 20 IBU series)**

Table 6 **Determination of polyphenol yields through the addition of aroma hops**

Beer code		Control	HHA 100	HHA 200	HSR 100	HSR 200	HSR 300	HHE 300
Hop polyphenols dosed	mg/l	–	47	94	50	100	150	153
Polyphenols in beer [1]	mg/l	116 [2]	138	167	145	163	195	183
Polyphenols in beer minus Control	mg/l	–	22	51	29	47	79	67
Yield	%	–	47	54	58	47	43	44

[1] Average of the two series (15/20 IBU) [2] approx. 10 mg/l hop polyphenols dosed

Hop Varieties [3]. They describe the difference between the bitter and aroma hops, but also within the aroma varieties. The relations of beta-acids, polyphenols and linalool to the respective alpha acid contents demonstrate which amount of these substances can be dosed with the alpha acids. The aging indicator Hop Storage Index shows that all four pellets with an HSI of less than 0.30 can be characterized as totally fresh which is an important precondition for a correct design of experiment.

Table 7 **Contents of selected low molecular polyphenols in four pellet samples; values in mg/100 g**

	Group of substances	HTU	HHA	HSR	HHE	Ø 3 Aroma
Procyanidine C/C/C	P	21	103	106	73	94
Procyanidine B3 C/C	P	31	154	158	127	146
Procyanidine B1 EC/C	P	49	206	185	176	189
Catechine	mF	40	287	219	212	239
Epicatechine	mF	51	53	68	60	60
Coffeeoylquinic acid	HCA	35	95	86	77	86
Feruoylquinic acid	HCA	31	63	58	47	56
Quercetinglucoside	QF	121	158	134	180	157
Quercetinmalonylhexoside	QF	105	310	265	126	234
Kaempferol-3-glucoside	KF	46	75	78	94	82
Kaempferolmalonylhexoside	KF	50	235	244	110	196
Sum		580	1739	1601	1282	1539

C = Catechine; EC = Epicatechine; P = Proanthocyanidine; mF = monomeric flavanols; HCA = Hydroxycinnamic acid; QF = Quercetinflavonoids; KF = Kaempferolflavonoids

4 Analytical Experiment Results

The essential analysis characteristics are shown in tables 4 (15 IBU) and 5 (20 IBU). For parameters, which were intended to be constant like original gravity, alcohol content, pH and bitter units, statistical data are specified additionally to illustrate the good reproducibility. All told, the average starting gravity of the 14 brews is 7.96 % w/w, with a variation of 7.74 to 8.31 % w/w. The alcohol contents vary from 1.07 to 1.22 % ABV, with an average of 1.14 % ABV; only one brew has a slightly higher alcohol content. The series with 15 IBU shows the following averages for bitterness: 15.9 IBU and 10.2 mg/l Iso-alpha acids, respectively. Analogously, the corresponding data in the 20 IBU series are 19.5 IBU and 14.1 mg/l Iso-alpha acids.

The total polyphenol content of both control beers is primarily derived from the malt, as simply only 5 mg/l come from hops. The introduction of polyphenols through the aroma pellets can clearly be recognized.

The control brews show already 7 µg/l linalool in the beers, which can be explained by a resorption from the yeast and that the addition of approximately 25 µg/l from the Taurus addition was not completely evaporated during boiling. The linalool content in the beers increased to 99 µg/l from the aroma hop additions.

Because the additions of aroma pellets weren't different in both the 15 and 20 IBU series, but rather simply showed a set deviated bitterness level due to the bittering pellets, the reproducibility of the experiment can be validated on the basis of the polyphenol and linalool contents also. Figure 2 shows the polyphenol and linalool contents of the 20 IBU series plotted against the 15 IBU series. Strong correlation (and therefore reproducibility) can be seen.

Additionally the polyphenol and linalool yields can be determined. The strong correlation of both series allows for the mean value formation. In table 6 the added hop polyphenols are contrasted against the content in the beers. If the polyphenol content of the control beers is subtracted from these values, the residual amounts in the beer from the corresponding hop additions are arrived at. These divided by the added amounts results in the yields of the additions, which vary between 43 and 58 %.

Parallel to the unspecific total polyphenols, also the low molecular polyphenols, which can be analysed by HPLC, were determined [4]. Only 11 of more than 100 separated substances were selected, which increase

Table 8 Low molecular HPLC polyphenols in seven test brews; values in mg/l

	HTU	HHA		HSR			HHE
		100	200	100	200	300	300
Procyanidine C/C/C	0.5	0.6	0.7	0.5	0.5	0.7	0.4
Procyanidine B3 C/C	2.1	2.3	3.3	2.5	3.5	3.7	3.2
Procyanidine B1 EC/C	0.0	0.3	0.4	0.3	0.4	0.5	0.4
Catechine	2.6	4.1	5.9	4.0	5.9	7.4	7.0
Epicatechine	0.4	1.0	1.3	1.0	1.7	2.2	1.7
Coffeeoylquinic acid	0.2	1.3	2.4	1.3	2.6	3.1	3.0
Feruoylquinic acid	0.2	0.4	0.6	0.4	0.6	0.8	0.8
Quercetinglucoside	0.6	2.1	3.2	2.0	3.4	4.3	4.3
Quercetinmalonylhexoside	0.0	1.7	3.1	1.5	2.9	3.5	2.0
Kaempferol-3-glucoside	0.2	1.0	1.5	1.1	2.0	2.6	2.4
Kaempferolmalonylhexoside	0.0	1.1	2.0	1.1	2.2	2.6	1.4
Sum	6.8	15.9	24.4	13.7	25.7	31.4	26.6

Table 9 Yields of low molecular HPLC polyphenols by the dosage of aroma hops; values in % relative

	HHA		HSR			HHE	Ø
	100	200	100	200	300	300	
Procyanidine C/C/C	9	9	5	9	3	5	7
Procyanidine B3 C/C	15	38	28	42	33	24	30
Procyanidine B1 EC/C	11	9	13	13	5	7	10
Catechine	56	58	71	76	72	61	66
Epicatechine	103	80	93	90	88	75	88
Coffeeoylquinic acid	121	112	124	127	111	110	118
Feruoylquinic acid	56	40	52	43	40	50	47
Quercetinglucoside	102	86	112	112	93	70	96
Quercetinmalonylhexoside	56	49	58	86	58	52	60
Kaempferol-3-glucoside	107	87	115	112	100	76	100
Kaempferolmalonylhexoside	47	42	47	45	36	42	43
Average	62	55	65	69	58	52	

considerably with an aroma hop dosage. Table 7 (see page 75) shows the values in mg/100g hops, which are the basis for the calculation of the dosed amounts added with the hops. In Taurus, the contents of all 11 single components are considerably lower than in the three aroma hops. As an average, 1.539 mg/100 g can be found in aroma hops compared to only 580 mg/100 g in Taurus.

Table 8 shows the values in the corresponding seven test brews as an average of the two bittering levels. The Taurus beer contains only approx. 7 mg/l of the low molecular polyphenols. With the dosage of 100 and 200 g/hl of aroma hops, this amount increases to 15 and 25 mg/l respectively in the beer.

In order to be able to compare the analysed values of the beers with aroma pellets with the dosages, the brews with Taurus are taken as a basis, since the polyphenols primarily originate from malt. In table 9 the yields of the 11 substances are listed. The average yield of all 11 components is between 52 and 69 %. (see numbers in the lowest row of the table). Taking into account the analytical errors, no statements can be made.

Average yields of the individual components of all six tests, however, are more interesting (see right column of table 9). Here, one can see considerable differences:

- Proanthocyanidines show the highest losses. This can be explained with precipitations from wort to final beer
- Catechine seems to be more exposed to precipitations than epicatechine
- There is no explanation for the different yields of feruoylquinic acid (47 %) and coffeoylquinic acid (> 100 %)
- Quercetine- and kaempferolglucosides do not show losses
- In contrast to the above, yields of quercetine- and kaempferolmalonylhexoside (60 % and 43 %, resp.) are considerably lower. For this, there is no explanation at the moment.

The results can only be first indicators of different yields of low molecular polyphenols. Just systematic tests during wort boiling can elucidate the different precipitations of proanthocyanidines and monomeric flavanols. It might be also interesting to investigate the potential of yeast strains for encymatic cleavage of glycosidically bound polyphenols, since both hexosides, but not the glucosides are in decline.

Linalool contents are shown in table 10 (see page 81) . Logically, the average transfer rates of 45% for linalool with a late addition are higher than the 34 % with a supplemental mid boil addition, in which case the linalool is evaporated more intensely.

Figure 3 (see page 75) depicts the polyphenol and linalool contents in connection with the pellet amounts added as an average of both the 15 and 20 IBU series and clearly shows the interdependence.

5 Sensory results

Two different tasting panels were available to evaluate the experimental beers:

- A trained panel with 7–10 participants, which has been in place at the Research Brewery St. Johann for years
- A randomly assembled, untrained panel with 30 participants (breakdown of women to men was 9 to 21), which was put together for the first time for these experiments

As both panels produced similar results, the focus here was intentionally on the random panel. The range of the evaluations of the beers was slightly broader than with the trained panel, but the results of the random panel with a higher number of participants are particularly more informative and valuable.

6 to 7 beers were tasted per session. The following qualities were evaluated using a point scale from 1 (low) to 10 (very pronounced) without half-point scores:

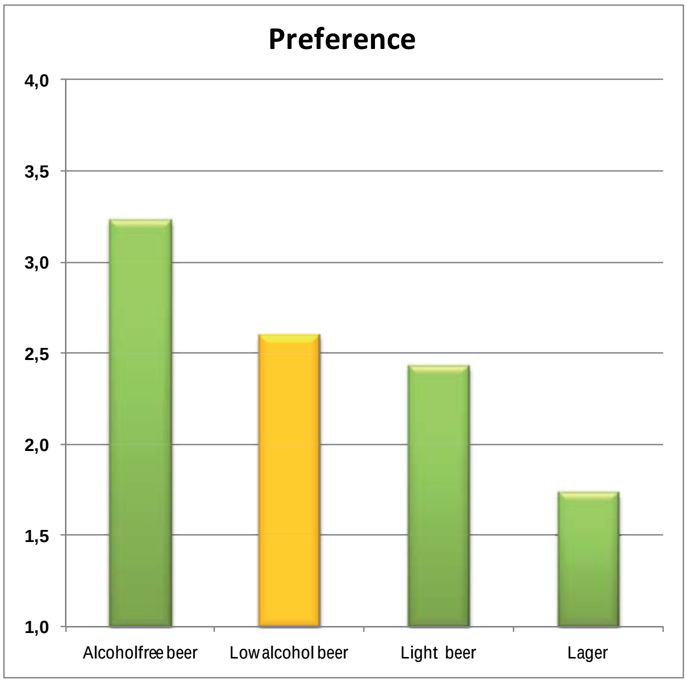

Fig. 4 Preference of 3 commercial beer styles and a low alcohol experimental beer

- Intensity of hop aroma
- Mouthfeel/Palatefullness (refered to in the following as palatefulness)
- Quality/Harmony of bitterness

Additionally the panelists had to rank the beers and they were not allowed to give the same ranking to any two beers (no ties).

In an initial tasting it was of interest whether the randomly assembled panel could differentiate key beer styles. To this end a regular strength, light and alcohol free beer from a well known brewery with respected quality were each compared to a low alcohol test beer without a particularly pronounced hopping (100 g Saphir per hl). Figure 4 shows the average preferences of the four beers and the corresponding deviations. The ranking is as follows:

- Alcohol free beer 3.2
- Low alcohol beer 2.6
- Light beer 2.4
- Lager (regular strength) 1.7

The rank sum test according to Kramer [5] results in 2 star significance of the following rating:

- Regular strength better than light and low alcohol beer
- Light and low alcohol beer better than alcohol free beer

There is no difference between light and low alcohol beer. The random panel could already prove suitability of results in its first tasting.

In the second round the beers with 15 IBUs were tasted, including those with 100 and 200 g/hl of aroma pellets of the varieties Hallertauer Mittelfrueh and Saphir, respectively, in the divided late addition, and the beer that was additionally hopped with 100 g/hl of Saphir pellets at mid boil. The setup of the third tasting was the same as the second, the only difference being that those beers had the higher, base bitterness of 20 IBUs. In the corresponding diagrams the scores of both series are compared with each other for the characteristics hop aroma, palatefullness and quality of bitterness with the 95 % confidence intervals.

The results can be summarized as follows:

- Figure 5 shows a comparison of the intensity of hop aroma for both series. All of the experimental beers with aroma hops clearly rise above the comparison beer, but also higher intensity points can be observed with a higher aroma dosage. Within the aroma hop beers there are also clear differences between the 100 g Saphir in the last addition and the total 300 g Saphir in the mid and final addition.
- The mean value points for palatefullnes of the beers are shown in figure 6 (see page 78). The gap between the beers hopped with aroma pellets and the control beers is similarly pronounced as with the intensity of hop aroma. With Hallertauer Mittelfrueh the difference between 100 und 200 g/hl in the higher bitterness level was moreover outside of the scattering pattern. As was shown earlier, a targeted use of aroma hops can therefore clearly improve the palatefullness of a beer [6].
- The results for quality of bitterness can be seen in figure 7 (see page 78). The intervals between the beers are not as distinct as for the other characteristics. Nevertheless apart from the overall trend to improve the quality of bitterness there are clear sin gular differences. HSR 300 and HHA 100 at 15 IBU, HHA 200 and all three HSR beers at 20 IBU are rated better than the particular control beers.

Comparing the preferences of the panel for the 15 and 20 IBU beers there are significant differences between control beers and all experiments with aroma hops in both cases (Fig. 8, see page 78). Trends could be recognized with the gradations HSR 100 to

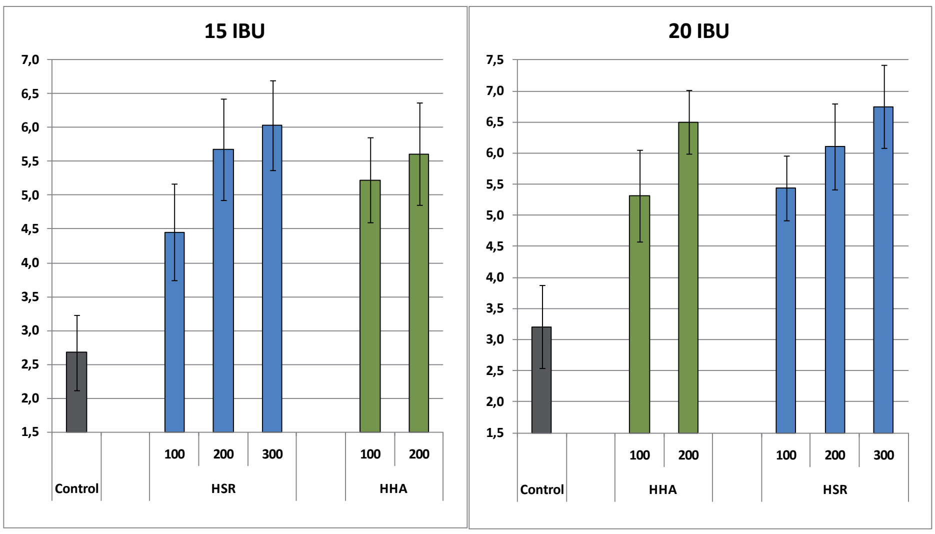

Fig. 5 Intensity of hop aroma with 6 beers at 2 bitterness levels; abbreviations see table 2; data in points from 0 (low) to 10 (very pronounced)

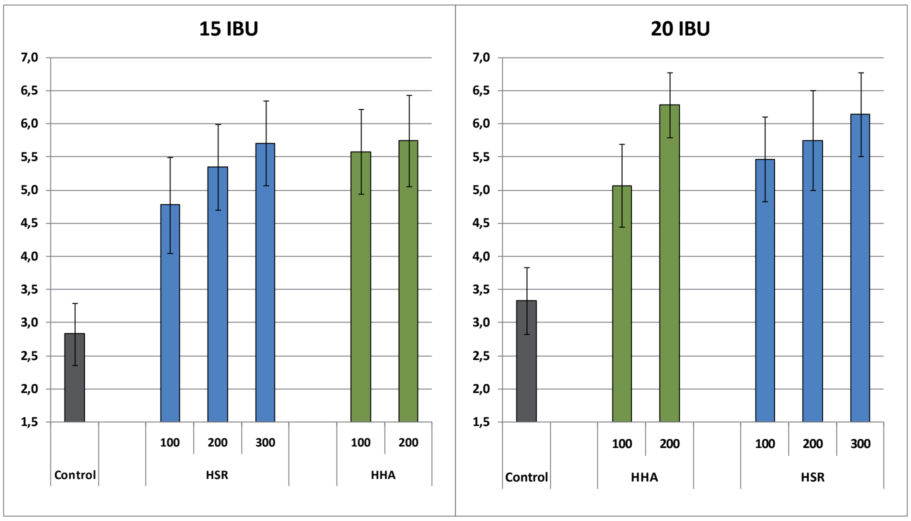

Fig. 6 **Palatefullness with 6 beers at 2 bitterness levels; abbreviations see table 2; data in points from 0 (low) to 10 (very pronounced)**

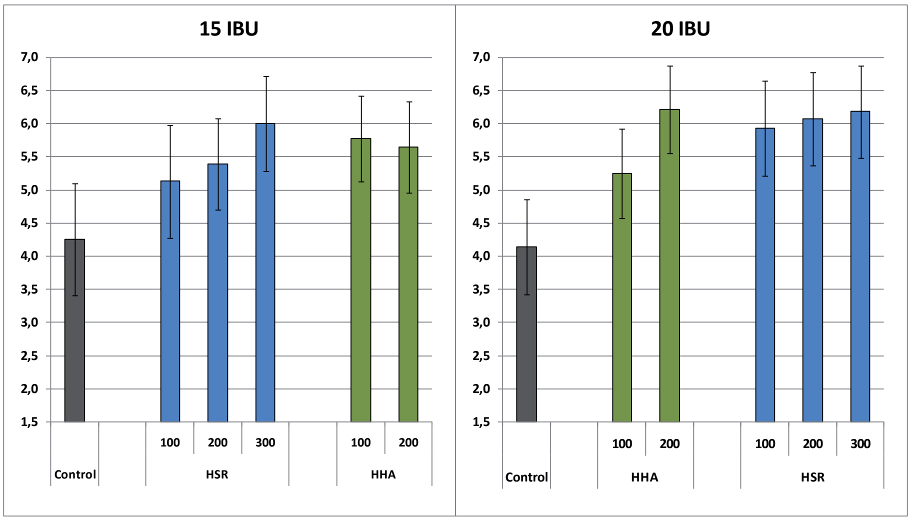

Fig. 7 **Quality of bitterness with 6 beers at 2 bitterness levels; abbreviations see table 2; data in points from 0 (low) to 10 (very pronounced)**

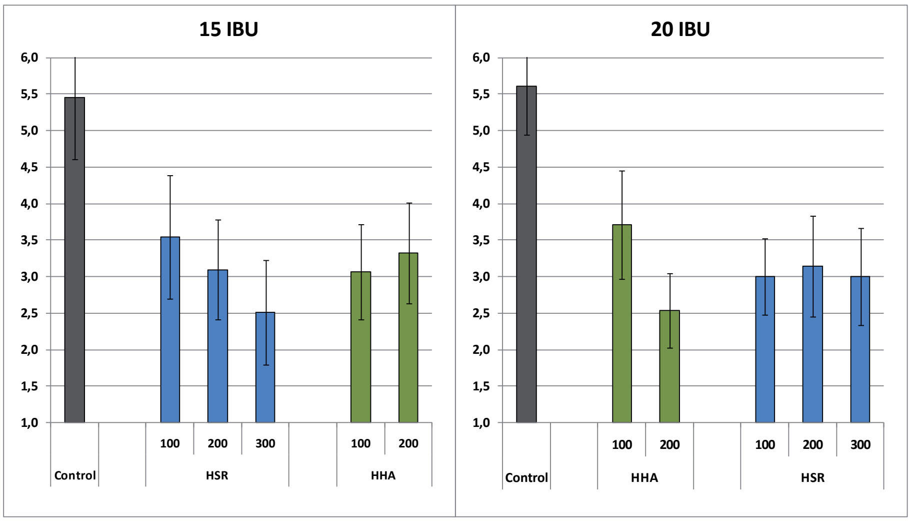

Fig. 8 **Preferences of the experimental beers at the two bitterness levels**

HSR 300 (15 IBU beers) and HHA 100 to HHA 200 (20 IBU beers). In a fourth tasting series the panel had to evaluate seven beers. In addition to the beer that was late hopped with 200 g/hl Hallertauer Mittelfrueh the beers that were given two aroma additions (mid boil and end boil/whirlpool; Saphir and Hersbrucker) were also presented. The two bitterness levels are compared with each other in figures 9–11:

- Intensity of hop aroma (Fig. 9): Also here the control beer came in lower. It's interesting to note however, that the beers with the higher bitterness level received a better rating for hop aroma. The average scores of the 3 beers with 15 IBU were 4.5 compared to 6.0 (3 beers with 20 IBU), while the comparison beer only received 2.1 points. In this case obviously the higher bitterness misleads to a higher grading, which really cannot be explained with an intensified hop aroma.
- A similar phenomenon occurs with the palatefullness of the beers (Fig. 10). The comparison beer clearly came in lower with 2.4 points compared to an average of 4.5 points (15 IBU) and 5.8 points (20 IBU).
- When it came to quality of bitterness (Fig. 11) the control beers still differentiated themselves with 3.2 points from the three 15 IBU beers (5.0 points) and the three 20 IBU beers with average 5.7 points.

The preferences of the seven beers are depicted in figure 12. Only a few panelists put the control beer (average 6.4) better than rank 7 (= worst) so that it came in on the last position far behind of the three 15 IBU beers (4.2) and the three 20 IBU beers (3.0). It may be interesting to note that the higher bitterness level beers receive a better appraisal in all characteristics, even also in preference. That indicates that a random panel does not have to prefer less bitterness if this bitterness is of high quality.

The sensory results can be supplemented with a few observations. In figure 13 (see page 80) the intensity of the hop aroma is plotted against the linalool content of the beers (left with and right without the comparison beers). The correlations result in a 3 star and 1 star significance, respectively. This confirms that linalool can be used as an indicator for the intensity of a hop aroma in beer [7].

The palatefullness of all the experimental beers is applied (Fig. 14, see page 80) in relation to the pellet amounts dosed (left) and the poly-phenol contents of the beers (right). In both cases the regression results in a 2 star significance. An increase of palatefullness can be achieved with the addition of substantial amounts of aroma hops. Coherence with the added hop polyphenols is obvious.

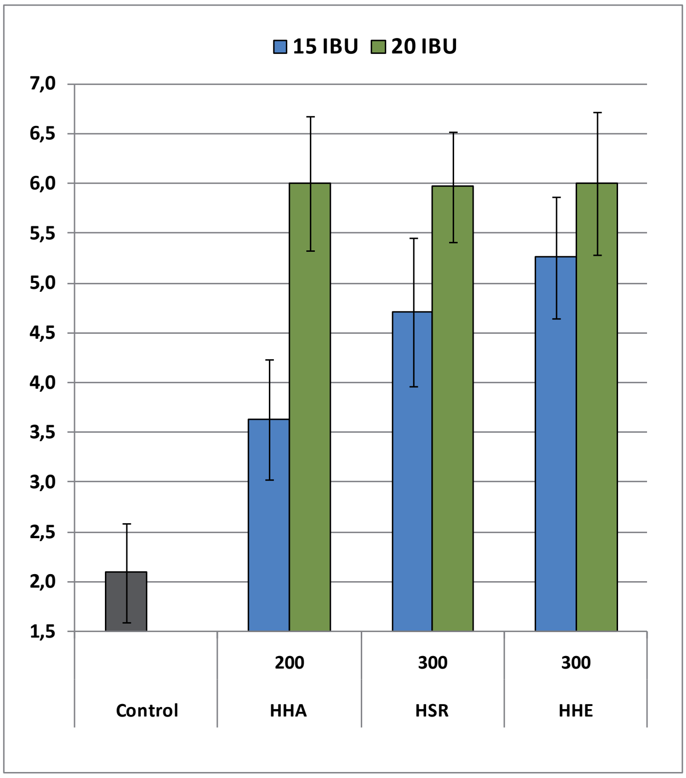

Fig. 9 Intensity of hop aroma with 7 beers; abbreviations see table 2; data in points from 0 (low) to 10 (very pronounced)

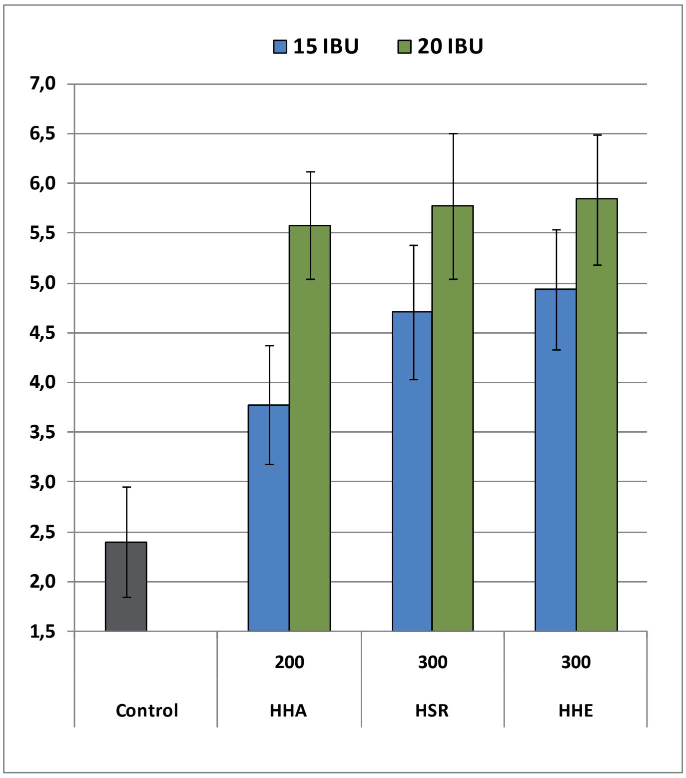

Fig. 10 Palatefullness with 7 beers; abbreviations see table 2; data in points from 0 (low) to 10 (very pronounced)

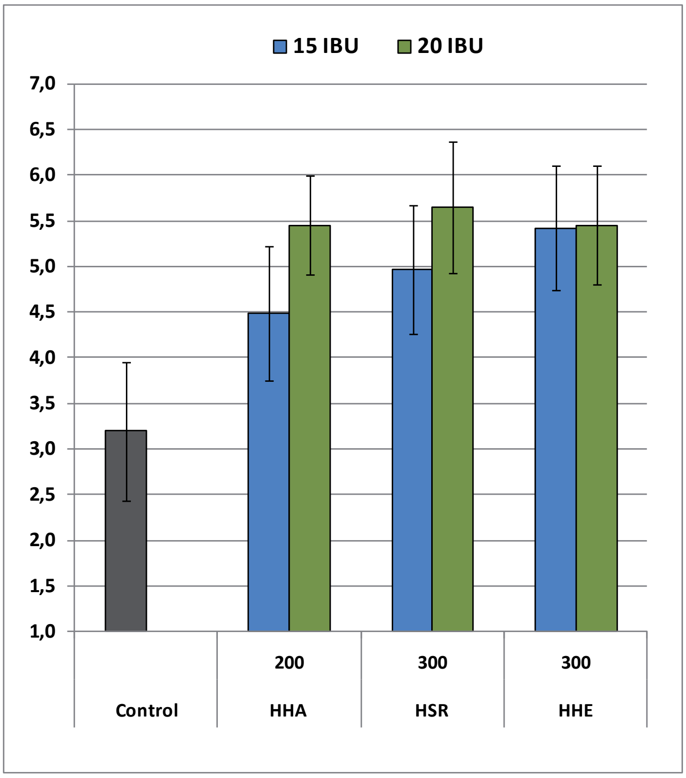

Fig. 11 Quality of bitterness with 7 beers; abbreviations see table 2; data in points from 0 (low) to 10 (very pronounced)

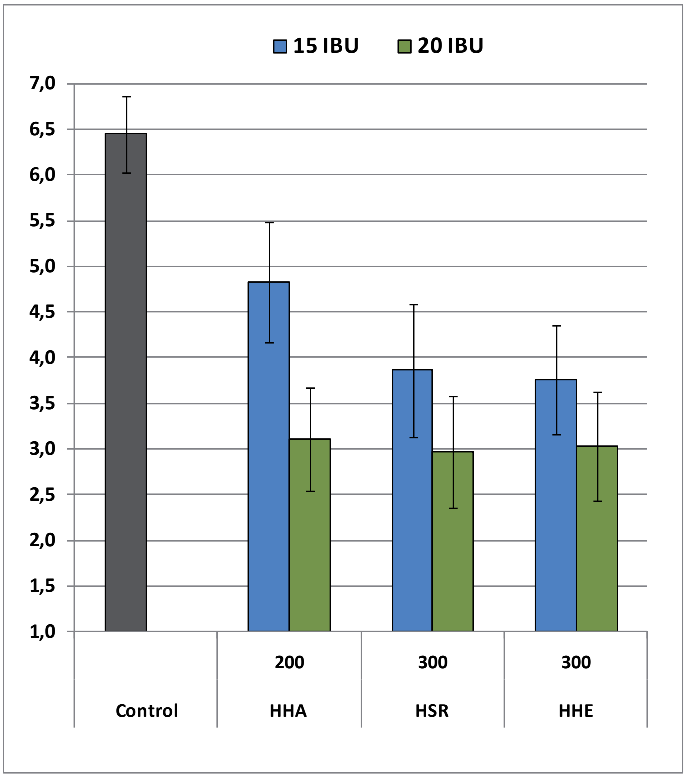

Fig. 12 Preferences of 7 beers

Figure 15 (see page 80) shows the interdependence of the quality of bitterness on polyphenol amounts of the 14 beers, and so with it the amounts of aroma pellets added. Linear regression results in a 2 star significance. The not yet fully revised prejudice of an increased or even negative bitterness impression with increasing polyphenol contents has been refuted in these experiments. Other publications confirm these statements [8, 9].

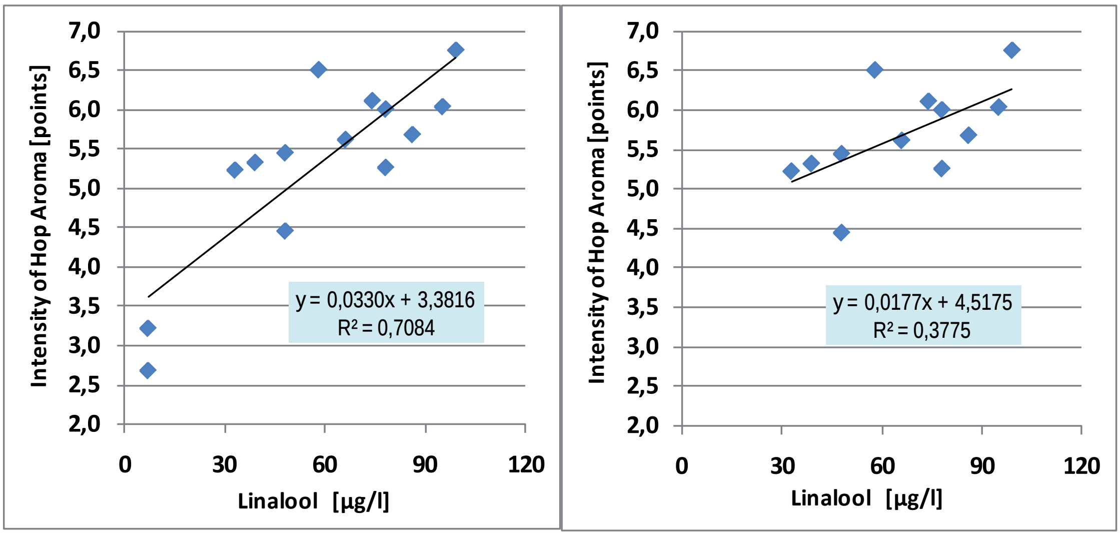

Fig. 13 **Intensity of the hop aroma as a function of the linalool content in the beers; left = all beers; right = aroma hopped beers without controls**

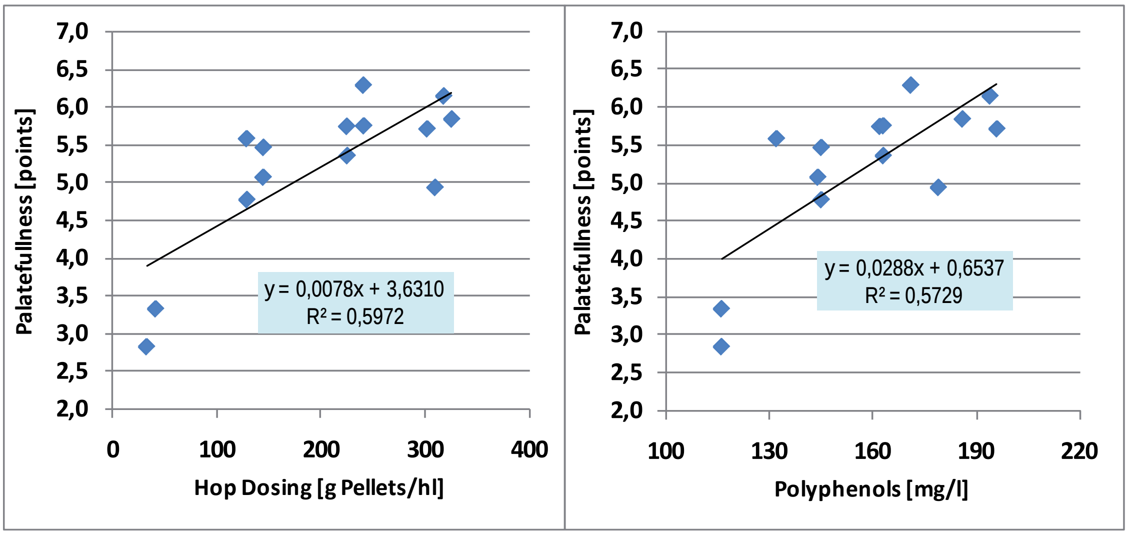

Fig. 14 **Palatefullness of the 14 beers as a function of the amount of pellets added (left) and of the polyphenol contents in the beers (right)**

6 Tasting of Aged Beers

Of the several series reflecting the aging of beers, one representative series was selected. The following beers with 20 IBU were stored for three month at 28 °C:

- Control
- HSR 100
- HSR 200
- HSR 300

Figure 16 shows the results of a tasting session using an enhanced DLG (Deutsche Landwirtschafts-Gesellschaft) tasting scheme in which the focus was laid on smell and taste (higher marks = better rating).

Fig. 17 shows the marks for aging according to Eichhorn.

There are no significant differences to be detected within the beers with various quantities of variety Saphir. It has to be said, however, that the quality of the control beer was considerably lower, which is also evident in the grade of aging. The improvement in flavor stability is obvious already with a dosage of 100 g/hl aroma pellets.

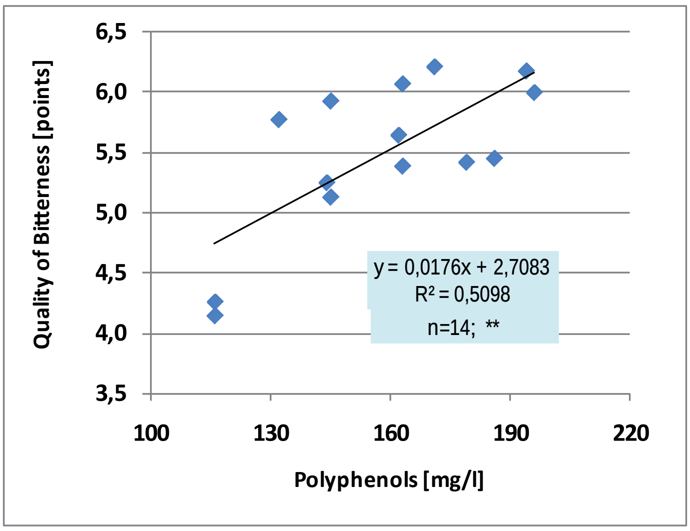

Fig. 15 **Quality of bitterness as a function of polyphenols contents of the 14 beers**

7 Summary

The focus of a test series which included 14 beers was the production of low alcohol beers with a starting gravity of 8 °Plato and an alcohol content of less than 1.2 % ABV. At first, the production process was optimized at the St. Johann research brewery. The only variable was hopping with a target bitterness level of 15 and 20 IBU. In addition to a baseline beer, which was hopped only with Taurus pellets, Hallertauer Mittelfrueh and Saphir were also used in amounts of 100 and 200 g/hl respectively, at the end of the boil and in the whirlpool (1:1). Additionally Saphir and Hersbrucker were dosed in two additions (100 g/hl at mid boil and 200 g/hl at boil end/whirlpool).

An increase of aroma pellets led to increasing polyphenol and linalool contents. In the experimental arrangement, transfer rates

Table 10 Determination of linalool yields through the addition of aroma hops

Beer code		Control	HHA 100	HHA 200	HSR 100	HSR 200	HSR 300	HHE 300
Linalool dosed	µg/l	–	60	120	90	180	270	210
Linalool in beer [1]	µg/l	7 [2]	36	62	48	80	97	78
Linalool in beer minus Control	µg/l	–	29	55	41	73	90	71
Yield	%	–	48	46	46	41	33	34

[1] Average of the two series (15/20 IBU) [2] approx. 27 mg/l Linalool dosed (HTU) at begin of boil

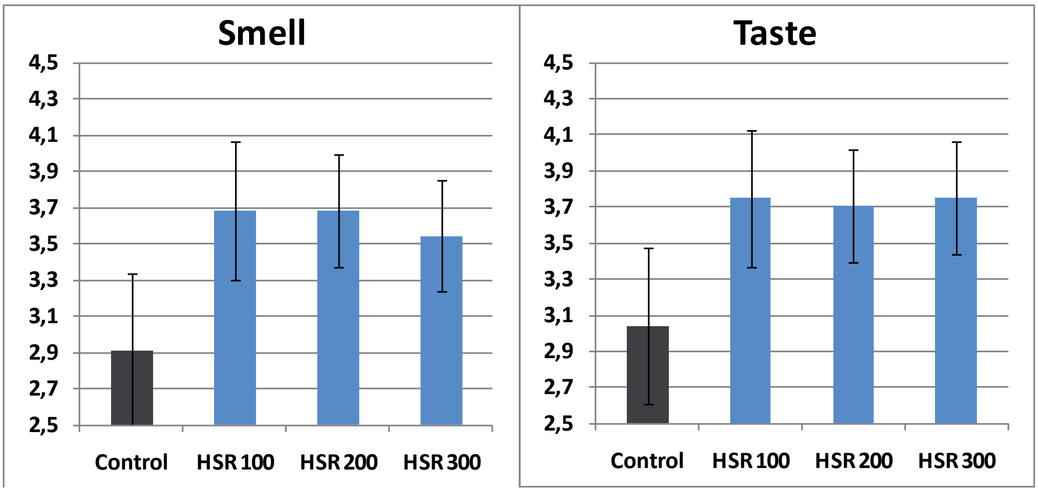

Fig. 16 Rating of smell and taste according to DLG; beers stored for 3 months at 28 °C

were found to be approximately 50 % both for polyphenols dosed at mid and end of boil and linalool dosed at boil end.

The yields of individual low molecular HPLC-polyphenols fluctuates in a wide range. Here, there exists a need for further intensive research.

A random taste panel of 30 participants (similar to a consumer panel) evaluated the beers in a simple rating system ranging from 1 (low) to 10 (very pronounced) on the characteristics of intensity of hop aroma, palatefullness and quality of bitterness. Furthermore, the participants had to state their preferences. The results can be summarized as follows:

- Hop aroma, palatefullness and quality of bitterness of all beers hopped with aroma pellets were rated considerably higher than the beers hopped only with Taurus.
- Even within the beers brewed with aroma hops only, increased dosages showed a positive effect.
- High polyphenol contents from aroma hops improved palatefullness and quality of bitterness, and do not create a negative impression of "tannic substance bitterness."
- The results, particularly those regarding palatefullness, are clearly reflected in the preferences.
- The targeted use of aroma hops can largely mask sensorial deficits of low alcohol beers (arrested fermentation of a light beer).

Consequently, the goal of producing a low alcohol beer which is sensorially equivalent to normal light beers, but contains 60 % less alcohol, could be achieved. Such a beer can be brewed in a medium-sized brewery without additional equipment.

The brewer has to understand and accept, however, that mid or late hop additions (especially with aroma hops) do not have to be linked with the characteristic "bitterness" at all. Instead, he can pursue completely different sensory goals. It must be noted that fresh hops should be used and that merely symbolic additions of a few g/hl have little effect.

There is no explanation why this interesting category of low-alcohol beers has such a low importance in the beer market.

8 References

1. Forster, A. and Gahr, A.: Aromahopfen und die Herstellung von Bieren mit reduziertem Alkoholgehalt, BRAUWELT, no. 8 (2011), pp. 562-566
2. Forster, A. and Gahr, A.: Hopping of Low Alcohol Beers; Presentation at the 33rd EBC Congress, 2011, Glasgow
3. 2010 Pocket Guide to German Hop Varieties, Association of German Hop Growers
4. Forster, A., Beck, B., Schmidt, R., Jansen, C. and Mellenthin, A.: „Über die Zusammensetzung von niedermolekularen Polyphenolen in

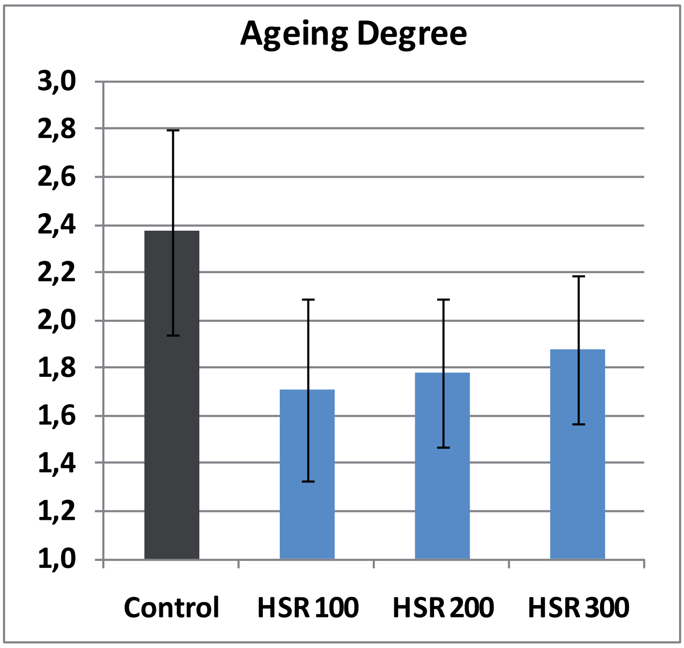

Fig. 17 Tasting session for aged beers according to Eichhorn; beers stored for 3 months at 28 °C, the lower, the better

verschiedenen Hopfensorten und zwei Anbaugebieten“, Monatsschrift für Brauwissenschaft, 5/6, 2002, pp. 98-108

5. Kramer, A.: Chemical Senses and Flavour, **1** (1974), p. 121
6. Forster, A. and Gahr, A.: The influence of Hopping on Beer Quality; BRAUWELT International, no. **1** (2011), pp. 19-23
7. Kaltner, D., Steinhaus, M., Mitter, W., Biendl, M. and Schieberle, P.: (R)-Linalool as key flavour for hop aroma in beer and its behaviour during beer staling, Monatsschrift für Brauwissenschaft **56**, 11/12, 2003, pp. 192-196
8. Aerts, G., DeCooman, L., DeRouck, G. and Goiris, K.: Use of hop polyphenols in beer, United States Patent Application # 20070254063 A1, November 1st 2007
9. Dresel, M. and Hofmann, T.: Revealing the Impact of Hops Hard Resin on the Beers Bitterness; presentation on the 10th International Trends in Brewing, Ghent, 3rd April 2012

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