The influence of dry hopping on three different beer styles

CONTACT TIME – THE DECIDING FACTOR | Dry hopping influences the physico-chemical properties as well as the sensory attributes of beer. The hop aroma and flavor are very different from those present in beers which have been hopped exclusively on the hot side of production (wort boiling and whirlpool). Various factors such as hop variety, the type of hop product, timing of the additions, contact time and the beer matrix appear to affect the resulting flavor and aroma of the finished beer to differing degrees.

FOLLOWING A SYSTEMATIC EXPERIMENTAL APPROACH, a wheat beer, an American pale ale and a bottom-fermented lager beer were dry-hopped with different hop varieties. The beers were then evaluated and analyzed using methods of sensory analysis.

The following varieties of whole leaf hops harvested in 2012 were used in the trials:

- Hallertauer Mittelfrüh (classic landrace);
- Saphir (refined aroma variety; developed in Hüll).

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In addition, three new so-called "flavor" varieties from Hüll have been developed to express characteristic aroma notes:

- Polaris: glacier mint flavor, mint;
- Mandarina Bavaria: mandarin orange, grapefruit;
- breeding variety 93/010/036: citrus notes, grapefruit, aromas reminiscent of wine.

Detailed analysis results for the hop varieties used in the trials are provided in tables 1 and 2 [1, 2].

Experimental trials

The beers were dry-hopped after warm maturation and chilling to 0 °C. The quantity of hops required was determined based on their oil content (wheat beer: 4.5 ml/hl; lager beer: 3.0 ml/hl). The same quantity of hops (85 g/hl) was added to the pale ale brewed in the trials. Once maturation was complete, the unfiltered beer was bottled and was then evaluated sensorially and analyzed.

Experience has shown that the amount of time the hops spend in contact with the beer influences the dry hop character of the beer. Therefore, the contact time was chosen as one of the variables to be tested in the experimental trials. The hops were exposed to the beer for one, two and three weeks.

Analysis results for lager and wheat beer

Compared to the reference samples, an increase in the concentration of alpha acids was observed in the lager and wheat beer samples as a result of dry hopping (see tables 2 and 3). Similarly, an increase in the alpha acid content (71 % for lager beer and 82 % for wheat beer) was measured in the beers exposed to the hops for a longer period (1 - 3 weeks). Also of note is the constant increase in iso-alpha acids throughout the contact time, ranging from 11 percent (Mandarina lager, table 2) to 41 percent (Polaris wheat beer, table 3) compared to the reference samples.

The high quantities of hop oil – up to 4.5 ml/hl are introduced by dry hopping – appeared to have no significant effect on the surface tension of either the lager or the wheat beer (see tables 2 and 3).

A slight increase in pH was measured as a result of dry hopping in both the bottom-fermented lager beer samples as well as in the wheat beers.

In general, it was found that the linalool content was somewhat higher in the dry-hopped beers (wheat beer and lager beer) than in the reference samples which were not dry-hopped. For two weeks of contact time, the linalool yield varied from 6 to 48 percent, depending on the hop variety. The percentages are expressed as purely cold hop yield (see table 4). Of the varieties tested, the highest linalool yields were measured for Hallertauer Mittelfrüh. This is most likely due to the significantly larger hop addition (by mass) of Hallertauer Mittelfrüh. Relative to Polaris, Hallertauer Mittelfrüh is added at a ratio of 5:1, thus pro-

OVERVIEW OF ANALYSIS RESULTS FOR HOP VARIETIES USED IN THE TRIALS

	CV (EBC 7.4)	HPLC (EBC 7.7)			ASBC	EBC 7.10	GC	EBC 9.11
Variety	CV (10 % H_2O) in %	alpha acid content in %	beta acid content in %	cohumulone in %	HSI	total oil in ml/100 g	linalool in mg/100 g	total polyphenols in g/100 g
Polaris	20	19.1	5.4	24.7	0.257	4.6	14.5	2.6
93/010/036	17.2	16.3	6.7	27.5	0.243	3.6	25.5	2.6
Saphir	4.2	3.5	6.4	11.4	0.301	1.9	10.8	4.2
Mandarina Bavaria	9.3	9	5.9	33	0.223	1.3	5.5	2.3
Hallertauer Mittelfrüh	4.4	3.9	4.1	20.4	0.318	0.9	6.2	2.9

Table 1

ANALYSIS RESULTS FOR LAGER BEER

	Ref.	Mandarina, 1 week	Mandarina, 2 weeks	Mandarina, 3 weeks	93/010/036, 2 weeks	Saphir, 2 weeks	Mittelfrüh, 2 weeks	Polaris, 2 weeks
bitterness (EBU)	23.6	25.7	27	26.6	26	25.5	27	25.6
co-iso-alpha acids (mg/l)	7.9	8.5	8.8	10.3	8.4	8.5	8.1	8.2
n + ad-iso-alpha acids (mg/l)	13.5	13.2	13.8	13.5	13.8	14.5	12.7	14
iso-alpha acids (mg/l)	21.4	21.7	22.6	23.8	22.2	23	20.8	22.2
cohumulone (mg/l)	0.8	2	2.9	3.5	1.8	0.9	1.5	2
n- +adhumulone (mg/l)	1.1	2.5	3.7	4.2	3	1.9	3.4	3.9
alpha acids (mg/l)	1.9	4.5	6.6	7.7	4.8	2.8	4.9	5.9
surface tension (mN/m)	44.2	44.4	44.5	43.1	43.6	43.2	43.8	43.6
original gravity (% w/w)	13.5	13.5	13.6	13.6	13.6	13.6	13.6	13.5
alcohol (% by vol.)	5.6	5.7	5.6	5.7	5.6	5.6	5.6	5.6
degree of attenuation (%)	77.3	77.8	76.8	77.3	77.3	77.2	77	77.3
color (EBC)	8.3	8.3	8.4	8.5	8.4	8.4	8.6	8.4
pH	4.4	4.5	4.5	4.5	4.4	4.5	4.5	4.4
nitrate (mg/l)	13	32	33	34	16	24	62	19
foam (sec)	236	207	193	211	219	196	231	230
oxalate (mg/l)	8.5	7.5	7.2	6.2	7.8	7.4	6.2	10.3
linalool (mg/l)	0.006	0.017	0.036	0.042	0.035	0.026	0.096	0.018
total polyphenols (mg/l))	199	207	213	220	202	210	210	205

Table 2

viding a much greater total surface area for contact with the beer.

The values for foam stability were slightly higher for the reference sample compared to the dry-hopped lagers (see table 2). The dry-hopped wheat beers exhibited either no change in foam stability or higher values than the reference samples (see table 3).

As expected, the nitrate content increased in all of the beers as a result of the dry hop additions, some of which were five times higher on the cold side than in the brewhouse. Correspondingly high values were measured for lager beers (62 mg/l) and wheat beers (86 mg/l) dry-hopped with Hallertauer Mittelfrüh. These values exceed the maximum allowable limits (max. 50 mg/l) for nitrate specified in the regulations governing drinking water in Germany.

The total polyphenols increased slightly as a result of dry hopping the lagers and wheat beers. As expected, the total polyphenols did not increase as much in the beers dry-hopped with higher alpha varieties (Polaris and 93/010/036) than they did with aroma varieties, because the latter were added in greater quantities (see tables 2 and 3).

Sensory evaluation

Beer samples from the trials were evaluated by members of three different sensory analysis panels, consisting of eight, 14 and 16

ANALYSIS RESULTS FOR WHEAT BEER

	Ref.	Polaris, 1 week	Polaris, 2 weeks	Polaris, 3 weeks	Saphir, 2 weeks	Mittelfrüh, 2 weeks	93/010/036, 2 weeks	Mandarina, 2 weeks
bitterness (EBU)	12.2	12.9	13.9	14.1	13.1	16.1	13.4	16.3
co-iso-alpha acids (mg/l)	3.5	3.6	4.3	6.0	4.3	4.7	4.5	4.9
n + ad-iso-alpha acids (mg/l)	4.8	4.9	5.1	5.7	4.9	5.1	5.1	5.1
iso-alpha acids (mg/l)	8.3	8.5	9.4	11.7	9.2	9.8	9.6	10.0
cohumulone (mg/l)	0.2	0.9	1.6	1.7	0.3	1.1	1.1	2.3
n- +adhumulone (mg/l)	0.6	1.9	3.1	3.4	1.0	3.1	2.1	3.1
alpha acids (mg/l)	0.8	2.8	4.7	5.1	1.3	4.2	3.2	5.4
surface tension (mN/m)	45.0	44.1	44.5	42.7	45.1	43.6	44.4	43.7
original gravity (% w/w)	12.7	12.7	12.7	12.7	12.8	12.8	12.7	12.8
alcohol (% by vol.)	5.0	5.0	5.0	5.0	5.0	5.1	5.0	5.1
degree of attenuation (%)	73.8	73.6	73.5	73.6	73.8	74.0	73.9	73.8
color (EBC)	8.5	8.5	8.5	8.6	8.6	8.9	8.7	8.9
pH	4.1	4.2	4.2	4.2	4.2	4.3	4.2	4.3
foam (sec)	247.0	255.0	246.0	248.0	237.0	257.0	246.0	259.0
nitrate (mg/l)	12.0	19.0	20.0	19.0	28.0	86.0	16.0	42.0
oxalate (mg/l)	9.7	8.2	7.5	7.6	7.9	6.3	7.9	6.4
linalool (mg/l)	0.003	0.009	0.016	0.008	0.015	0.085	0.032	0.031
total polyphenols (mg/l)	91.0	92.0	93.0	98.0	108.0	114.0	96.0	114.0

Table 3

LINALOOL CONCENTRATION IN HOPS AND BEER

Breeding line/ variety	linalool dosage µg/l, wheat beer	linalool µg/l, wheat beer	linalool yield in %, wheat beer	linalool dosage µg/l, lager beer	linalool µg/l, lager beer	linalool yield in %, lager beer
Polaris	141	16	11 %	94	27	29 %
93/010/036	321	32	10 %	214	35	16 %
Saphir	263	15	6 %	175	26	15 %
Mandarina Bavaria	190	31	16 %	127	36	28 %
Hallertauer Mfr.	300	85	28 %	200	96	48 %

Table 4

people. Prior to the evaluation, each of the teams received a training on how to use the specific sensory evaluation rubric especially developed as an aid for tasting and evaluating hoppy beers.

The distinguishing characteristics like

- intensity of the hop aroma,
- intensity of the hop flavor,
- intensity of the bitterness,
- quality of the bitterness,
- and the overall impression of the beer

were ranked on a scale from 0 to 10 on the evaluation sheet (intensity: 0 = not perceptible, 10 = very intense; quality and overall impression: 0 = not balanced, 10 = very balanced/harmonious).

The panelists were also given the option of marking a list of different aroma impressions, which were divided into the groups vegetal, citrus, fruity, spicy and floral.

The weighted averages of the results from all three sensory analysis teams are summarized in figures 1 - 6. The lager beer dry-hopped with Mandarina Bavaria possessed a clearly perceptible citrus note. Floral and fruity notes were evident in the beer with a two-week contact time (see fig. 1).

The sensory impression of Hallertauer Mittelfrüh was accentuated by citrus and fruity notes, which could at least in part be attributable to the high concentration of linalool in the beer samples. At 96 µg/l, it was the highest in this series of trials. Saphir imparted a distinct vegetal note to the lager beer samples (see fig. 2).

The sensory characteristics of beer (see fig. 3) dry-hopped with Polaris constantly changed over the period that the hops were in contact with the beer (cold side). In the trials with Polaris, the intense sulfur note that developed over the two-week contact time caused the beer to receive a low score, confirming previous reports about dry hopping with this variety. The hop aromas were completely masked by the sulfur note and were not perceptible. However, contact times of one week and three weeks did produce interesting spicy, fruity and citrus notes, which were detectable in the beer. Unique sensory differences were achieved

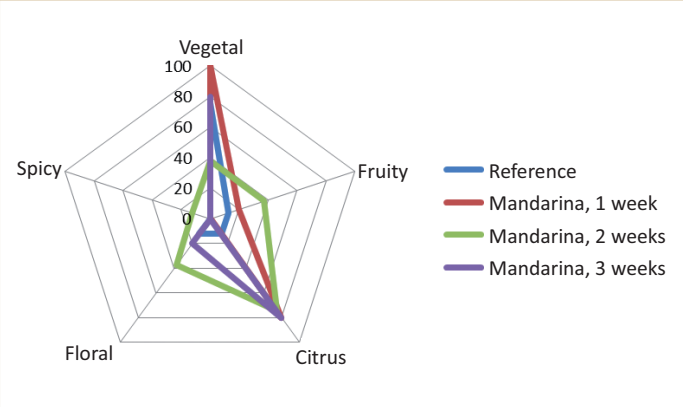

Fig. 1 Aroma impressions in lager beer, expressed in % – Mandarina Bavaria with different contact times, compared to reference sample

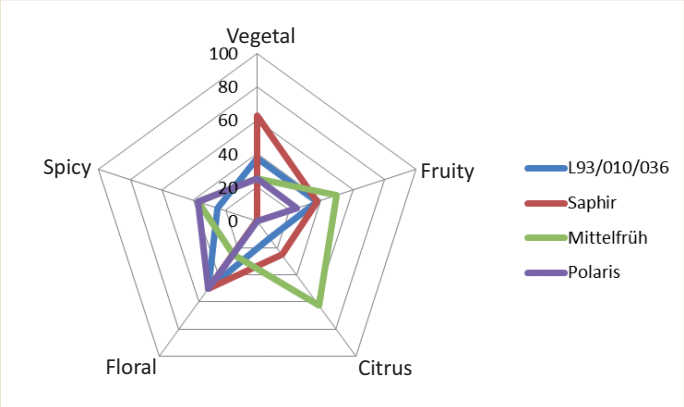

Fig. 2 Aroma impressions in lager beer, expressed in % – dry-hopped with Saphir, Hallertauer Mittelfrüh and Polaris

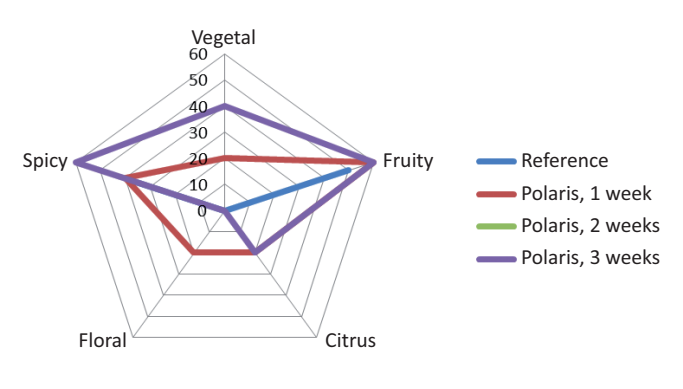

Fig. 3 Aroma impressions in wheat beer, expressed in % – Polaris with different contact times, compared to reference sample

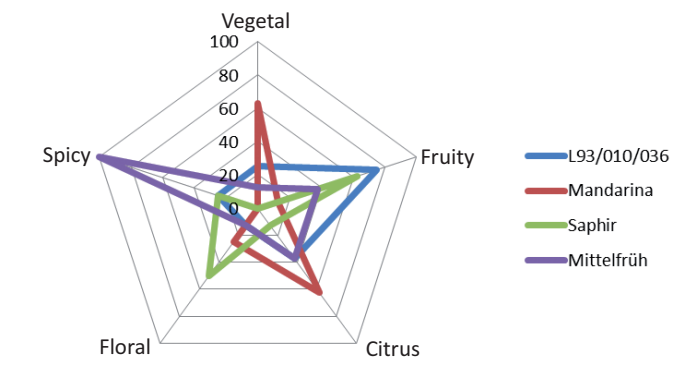

Fig. 4 Aroma impressions in wheat beer, expressed in % – dry-hopped with 93/010/036, Mandarina Bavaria, Saphir and Hallertauer Mittelfrüh

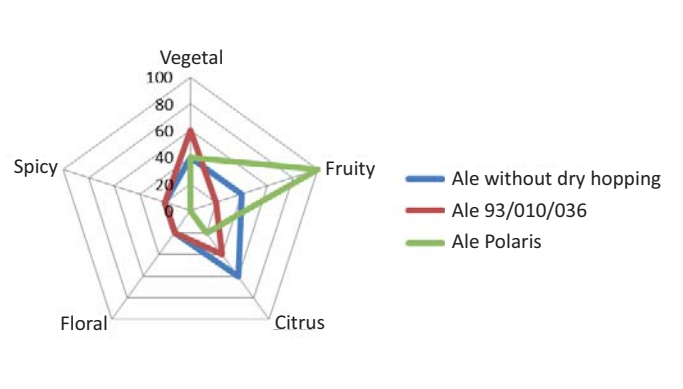

Fig. 5 Aroma impressions in pale ale, expressed in % – 93/010/036 with different contact times, compared to reference sample

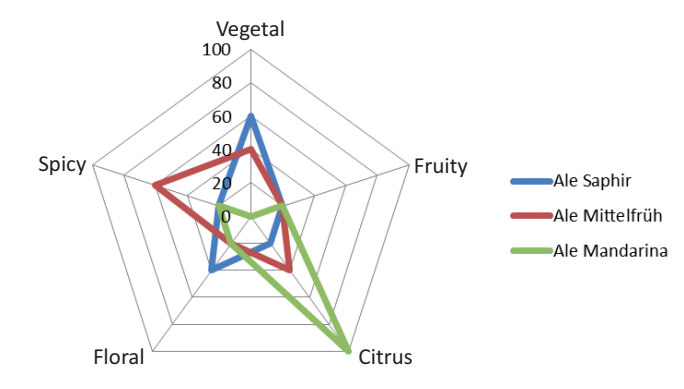

Fig. 6 Aroma impressions in pale ale, expressed in % – dry-hopped with Saphir, Hallertauer Mittelfrüh and Mandarina Bavaria

by varying the dry hops used in the wheat beer. Hallertauer Mittelfrüh stood out with a characteristic spicy note. The beer hopped with breeding variety 93/010/036 had a distinct and pleasant fruitiness, while Mandarina Bavaria exhibited pronounced citrus and vegetal notes. The beer dry-hopped with Saphir possessed stronger fruit and floral notes (see fig. 4).

The pale ale dry-hopped with Polaris for two weeks had very strong fruity notes along with clearly perceptible cheesy elements to its aroma (see fig. 5). The beer hopped with the breeding variety 93/010/036 was characterized by vegetal, fruity, spicy and citrus impressions. In pale ale, Saphir emerged with more distinct aroma notes in the direction of vegetal and floral. With this beer style, stronger citrus notes were associated with Mandarina Bavaria, while Hallertauer Mittelfrüh imparted spicy impressions accompanied by a light citrus note.

Comprehensive sensory evaluation

Polaris and Mandarina Bavaria were each added as dry hops to lager and wheat beer and stored for one, two and three week periods. As expected, significant differences in the overall sensory impressions were observed. The sensory scores for beer dry-hopped with Polaris confirmed previous reports, that a contact time of two weeks results in an unpleasant overall impression. However, shorter (one week or less) and longer (three weeks or more) contact times for dry hopping with Polaris yield higher scores in the sensory evaluation. Mandarina Bavaria did very well in the sensory evaluation, which indicated that contact times between one and two weeks

are generally recommended for this variety.

The overall evaluation results and the most frequently evoked aroma impressions in the three beer styles are listed below.

Lager beer – ranking and sensory impressions

- No. 1: Lager beer dry-hopped with Mandarina Bavaria (contact time: 2 weeks), sensory impressions: mandarin orange, citrus, orange, vegetal;
- no. 2: Lager beer reference sample with no dry hopping, sensory impressions: more neutral, no significant hop notes;
- no. 3: Lager beer dry-hopped with Hallertauer Mittelfrüh (contact time: 2 weeks), sensory impressions: spicy, citrus, fruity.

Wheat beer – ranking and sensory impressions

- No. 1: Wheat beer reference sample with no dry hopping;
- no. 2: Wheat beer dry-hopped with Mandarina Bavaria (contact time: 2 weeks), sensory impressions: mandarin orange, citrus;
- no. 3: Wheat beer dry-hopped with Saphir (contact time: 2 weeks), sensory impression: citrus.

Pale ale – ranking and sensory impressions

- No. 1: Pale ale dry-hopped with Mandarina Bavaria (contact time: 2 weeks), sensory impressions: mandarin orange, citrus, floral;
- no. 2: Pale ale reference sample with no dry hopping, sensory impressions: spicy, vegetal, citrus, fruity;
- no. 3: Pale ale dry-hopped with Saphir (contact time: 2 weeks), sensory impressions: citrus, vegetal, floral;
- no. 4: Pale ale dry-hopped with 93/010/036 (contact time: 2 weeks), sensory impressions: citrus, vegetal, floral.

Summary

It was demonstrated that it is possible to use selected hop varieties to enhance the aroma and flavor profile of beer, even among different beer styles. The key findings from the sensory evaluation and analysis results may be summarized as follows:

- Alpha acid concentrations of up to 7.7 mg/l were measured in beer. Through dry hopping, up to 4 mg/l can be added to the beer;
- an increase in iso-alpha acids of up to 2 mg/l may occur while the beer is in contact with the hops;
- dry hopping did not influence the surface tension of the beers tested in these trials;
- the pH value of the beer increases slightly;
- the concentration of linalool in beer increases by 5 to 90 µg/l. The linalool yield from dry hopping ranges from 6 to 48 percent, depending on the hop variety and the contact time;
- dry hopping has a minor effect on the stability of the beer foam;
- the nitrate concentration is influenced by dry hopping. Very high dosages can exceed the maximum allowable concentration of 50 mg/l;
- the total polyphenols in beer may increase a small amount depending on the hop dosage and the duration of contact;
- the contact time is a key factor influencing the hop aroma brought about by dry hopping beer on the cold side of the production process. The hop variety Polaris requires longer contact periods, up to three weeks or more. By contrast, Mandarina Bavaria, as a flavor hop variety with pleasant sensory characteristics, has proven to be suitable for use in many applications;
- Mandarina Bavaria received the highest overall score for all of the beer styles tested as part of these experimental trials. The mandarin orange note from the hops is reflected in beer dry-hopped with this variety, which was considered to be a positive sensory attribute. ■

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