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Influence of hop seeds on the analytical properties and sensory quality of beer

The EU certification system distinguishes between seedless and seeded hops. The vast majority of hops produced within the EU belong to the category of hops without seeds, which allows a maximum seed content of 2 % (w/w). However, with increasingly restrictive herbicide regulations and the resulting growing difficulty of controlling male plants, compliance with this limit may become challenging in the future. Hop seeds are generally regarded as undesirable in brewing because of their high fat content, which promotes oxidative degradation and may impair beer foam stability. Previous studies on the influence of hop seeds on beer quality have produced contradictory results. In this work, the impact of hop seeds on beer quality was assessed through brewing trials. Lager beers were produced with additions of 50 and 70 g/hl hop seeds during wort boiling and after primary fermentation. The addition of hop seeds showed no measurable effects on foam stability or sensory properties. Even in long-term storage tests (6 months at 30 °C), no differences in quality were detected between beers brewed with and without seeds. The only noticeable change was a slightly increased alcohol content, likely resulting from amylolytic enzyme activity in the seeds. Seed proportions above the EU limit of 2 % therefore do not appear to negatively affect beer quality. Nevertheless, hop seeds do not contain relevant amounts of bitter compounds and thus offer no technological value in brewing. Instead, they merely contribute additional weight, increasing costs for harvest and subsequent processing steps such as pellet production. Moreover, seed formation raises the plant's nutrient demand during cultivation. Taken together, a high seed content is incompatible with economically and environmentally sustainable hop production.

Descriptors: Hop seeds, beer quality, foam stability, enzymatic activity, hop creep, fatty acid composition

1 Introduction

The prevailing opinion is that hop seeds have a negative impact on beer quality, mainly due to their comparatively high fat content [1]. Accordingly, the EU certification procedure for hops sets an upper limit of 2 % by weight for seeds [2]. It is striking, however, that relevant textbooks make only brief or no statements on the subject. Narziß, for example, merely refers to "undesirable fertilization of the female flowers" [3]. The EBC Manual of Good Practice cautiously states: "There are different opinions concerning the brewing impact of hop seeds. It is a common view that oxidation of the seed's fat can give rancid flavors in beer, while others argue that brewing beers with seeded hops does not have a detrimental impact on flavor." [4]. In another standard work, the topic is not even mentioned [5].

Historically, the cultivation of seeded hops was widespread in England until the 1970s, as it results in higher yields. There is no record of any fundamental rejection by breweries. It is possible that the typical, aroma-intensive ale beers played a role, as they were less sensitive to seed content than continental lager and pilsner beers. Hartley [6], however, doubted the usefulness of fertilization. He discovered that seed-bearing hops are poorer in bitter acids and hop oil and recommended that only unfertilized hops be cultivated in England.

Janicki et al. demonstrated higher enzymatic activity in seeded hops [6]. More recent systematic studies confirm this observation [7]. At the same time, the authors found no quality defects in beers brewed with seeded hops.

The literature on the question of impairment of beer quality presents a heterogeneous picture:

- No negative effects: Seven publications report that beers brewed with hops containing up to 10 % seeds by weight showed no reduction in quality [8–14].
- Negative effects: Five studies, on the other hand, describe quality losses when using seeded hops [15–19].

There is no evidence of a sensory preference for beers brewed with seeded hops.

Compliance with the EU limit of 2 % by weight of seeds requires the consistent removal of male hop plants in the vicinity of hop gardens. This can be done either manually or through the targeted use of herbicides such as glyphosate. As the approval and use of such active substances is becoming increasingly restricted and their

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social acceptance is declining, the chemical elimination of male plants is becoming more and more difficult. This increases the risk that at least moderate exceedances of the 2 % limit will be almost impossible to avoid in the future. In view of this development and the inconsistent study results, the currently established limit regulation appears to be worthy of discussion. In addition, the official method for determining seed content [20] is overcomplicated, very time-consuming and often replaced in practice by error-prone visual estimates.

Fig. 1 Hop Seed Manual Separation

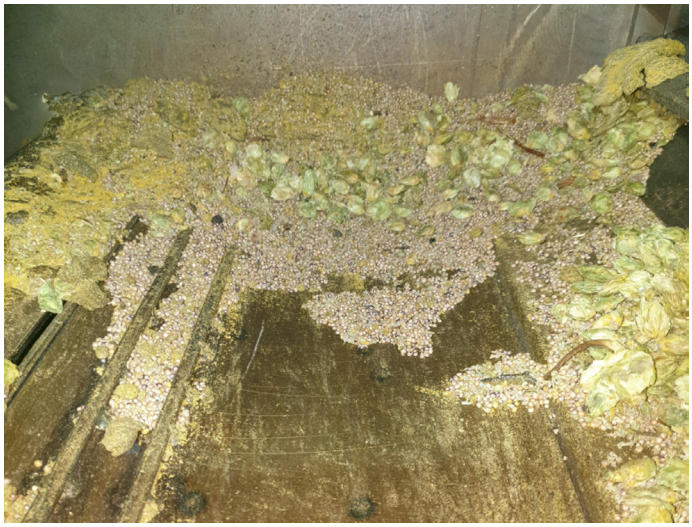

Fig. 2 Hop Seeds in a part of the hammer mill

The aim of this study is to examine the influence of hop seeds on beer quality and to question the relevance of the regulatory upper limit of 2.0 % by weight.

2. Materials and methods

2.1 Characterization of hop seeds

To characterize hop seeds, seeds were taken from hop cones, weighed and analyzed as following:

- Carbohydrates and proteins acc. MEBAK [21]
- Bitter compounds: HPLC analysis according to EBC Analytica 7.7 [22].
- Fat and fatty acids: Total fat determination and gas chromatographic analysis of individual fatty acids [23].

The seeds were obtained in two ways:

1. Manual separation: Seeds (see fig. 1) were removed from cones of a defined variety using tweezers.

2. Technical separation: During hop processing, larger quantities of seeds were obtained from the cavities of a mill. After removal, these were simply cleaned of leaf parts (see fig. 2).

2.2 Beer production

Test brews were carried out in the 2-hl St. Johann research brewery, whose suitability for experimental brewing trials has been documented [24]. A bottom-fermented lager beer with approx. 12 % original wort and 15 to18 mg/l iso-α-acids served as the basis.

Series 1

The basic bittering was carried out with type 90 pellets of the Polaris variety. One beer was brewed as a comparison without seed addition (= control), another received an addition of 50 g seeds/hl at the end of boiling (= seeds late, SL). After primary fermentation, both brews were divided into two tanks and treated as follows:

- C: Control without further addition
- SL: Seeds late, without further addition
- C + seeds dry: Control, plus 50 g seeds/hl after fermentation
- SL + seeds dry: seeds late, plus 50 g seeds/hl after fermentation

The hop seeds were ground before dosing in order to force the transfer of substances similar to pellets.

Series 2

In this series, the seed quantities were increased and a total of six beers were produced in three brews. All beers had the following in common:

- A bitter substance addition at the start of boiling with 4.5 g α-acids/hl (pellets type 90, variety Herkules)
- An aroma hop addition of 200 g pellets/hl of a breeding strain (HVG04) at the end of boil

The experiments in this series were structured as follows:

Brew 1:

- Wort boiling without seeds (control)
- Division after primary fermentation into:
  - Control
  - Control + dry seeds (70 g seeds/hl after fermentation = young beer)

Brew 2:

- Addition of 70 g seeds/hl at the beginning of boiling (BoB)
- Division after main fermentation into:
  - BoB (seeds at beginning of boiling)
  - BoB + dry seeds (additional 70 g seeds/hl after fermentation)

Brew 3:

- Addition of 70 g seeds/hl at the end of boiling (EoB)
- Division after main fermentation into:
  - EoB (seeds at the end of boiling)
  - EoB + dry seeds (additional 70 g seeds/hl after fermentation)
  - EoB + dry seeds + dry hopping (additional 70 g seeds/hl after fermentation) + dry hopping of 200 g aroma hops/hl).

This beer was produced to determine the extent to which additional dry hopping can trigger fermentation activity.

The experimental setup allowed for the targeted investigation of two additional questions:

1. Influence of the holding time (seed addition at the start of boiling vs. at the end of boiling)

2. Influence of seed addition after main fermentation without thermal stress (dry seeds).

3. Results and discussion

3.1 Hop seeds

The hop seeds of various varieties examined had diameters of between 1 and 2 mm. The individual weight varied depending on the variety. For two batches of the Perle variety, for example, mean values of 41 mg (SD ± 3 mg) and 35 mg (SD ± 4 mg) were determined. The seeds collected at the pelletizing plant, which could not be assigned to a specific variety, showed a significantly wider spread with individual values between 23 and 71 mg (fig. 3).

The material composition of non-specific seeds yielded the following values:

- Protein: 25 – 29 %
- Carbohydrates: 12 – 14 %
- Fat: 22 – 29 %

Bitter substance content

Determining the bitter substances proved problematic, as sticky hop resins adhere to the seed coat and distort the results. After carefully rubbing the seed surface with ethanol-soaked cloths, the following values for α- plus β-acids (in % by weight) were obtained according to EBC 7.7 [22]: uncleaned 5.5 %, cleaned 0.9 %. A hop oil analysis (EBC 7.10) of the cleaned seeds yielded a content of 0.05 ml/100 g. It is therefore unlikely that neither bitter substances nor hop aroma components are stored in hop seeds in a noticeable amount. There is consequently no benefit in terms of brewing technology. Rather, the seed content leads to a relative dilution of the valuable lupulin, which reduces the proportion of α- and β-acids and hop oils in relation to the cone mass. This dilution reduces the material and economic efficiency of the hops. In addition, seed formation causes additional biomass, which is associated with a higher demand for soil nutrients, energy, and processing costs (drying, packaging, transport, storage). Overall, a high seed content is therefore contrary to resource-efficient and sustainable hop production.

Table 1 Fat content and fatty acid composition of two hop seed samples, data given as % relative to total fat

Groups of fatty acids	Unit	Sample 1	Sample 2	Main representatives
Total fat	% w/w	26.4	21.4	
Saturated	% rel.	9.2	9.1	palmitic and stearic acid
Mono-unsaturated	% rel.	15.1	12.1	oleic acid
Double unsaturated	% rel.	52.7	56.0	linoleic acid isomers
Triple unsaturated	% rel.	21.7	22.4	α- and γ-linolenic acid
Quadruple unsaturated	% rel.	1.4	0.5	stearidonic acid

Fat content and fatty acid profile

As with other plant seeds, the lipids in hop seeds primarily serve as energy stores. References report total fat contents of between 18 and 28 % by weight, but detailed information on the distribution of the individual fatty acids is not yet available. The analyses carried out show that of a total of 36 fatty acids analyzed, 20 were below the detection limit. The detectable fatty acids can be assigned to five main groups, each characterized by typical representatives (see table 1). All figures are given as relative proportions of the total fat content. Approximately 14 % of the unsaturated fatty acids can be classified as omega-3 fatty acids. Polyunsaturated fatty acids with five or six double bonds could not be detected.

In comparison, barley and wheat contain around 2 % fat [25]. With a malt dosage of 15 kg/hl wort, this corresponds to approximately 3 g fat/l. To achieve the same fat content with hop seeds alone, approximately 12 g seeds/l would be required. Even with a high seed content of 20 % [7], the dosage would then be approximately 60 g hops/l. This comparison illustrates that seed fat play only a minor role, if any, in normal wort dosages. There are currently no references in the literature regarding possible effects during dry hopping.

3.2 Test Beers – Series 1

Wort and fermentation parameters

The results of the standard beer analyses, including selected bitter substances, can be found in table 2. The standard deviations of the triplicate determinations are also given and serve to estimate whether differences are relevant. No influence of the seed addition on original wort, pH value, or color could be detected. The fermentation processes were also identical in all brews, regardless of the seed addition. The slightly increased bitterness values (IBU, α-acids and humulinones) in the dry seeded variants can be explained by bitter substances adhering to the seed husks.

It is noticeable that the beers with seed addition in the young beer (seeds dry) had slightly higher alcohol contents than the control without seeds.

Foam stability

The results of the foam tests are summarized in table 3. Foam retention was carried out acc. NIBEM [26] and optical adhesion test acc. DLG [27]. When comparing control and seeds added late, the control beer achieved slightly better values. However, it is questionable whether these insignificant differences are relevant. Interestingly, the seeds added after the main fermentation (seeds dry) did not lead to any measurable reduction in the foam properties.

One possible explanation for this is that α- acids adhering to the seeds can have a foam-stabilizing effect [5, pp. 262] Theoretically, when dosed in the cold range, they could have a compensatory effect on foam-negative fatty acids.

The differences between Control + dry seeds and late seeds + dry seeds were marginal.

Aging indicators

Of these indicators, furfural, the sum of 2-acetylfuran and 2-propionylfuran, and the sum of all aging indicators are relevant. The results in the fresh state and after forced aging tests [28] are listed in table 4. The slight deviations indicate that the addition of seeds has no significant influence, at least in fresh beers. The slight differences in the oxygen indicators confirms a reproducible, low-oxygen bottling.

Sensory

The sensory tests included triangle tastings with the following comparisons:

- Control vs. seeds late:
  13 correct answers from 25 tasters → * significant, but without clear preference
- Control + seeds dry vs. seeds late + seeds dry:
  10 correct out of 24 tasters → not significant
- Control vs. late seeds + dry seeds:
  12 correct answers out of 24 tasters → not significant

The results do not indicate any clear sensory influence of the hop seeds.

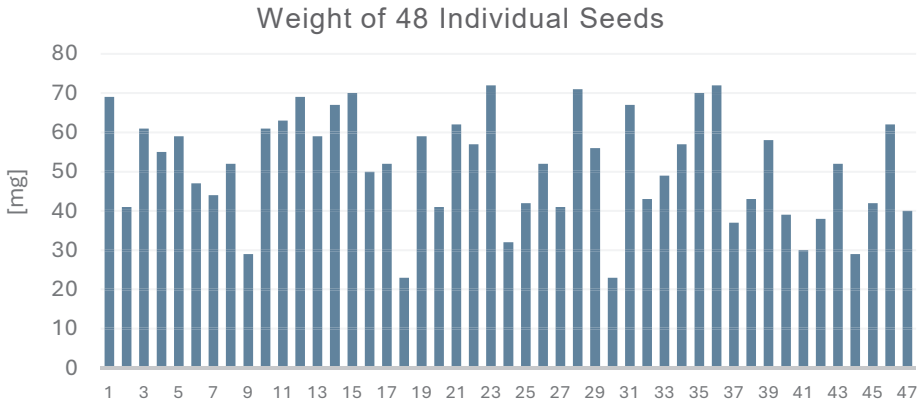

Fig. 3 Weight of 48 individual seeds

Table 2 Beer analyses (series 1)

Analysis	Unit	Control	Seeds late	Control + Seeds Dry	Seeds late + Seeds Dry	SD
Original Gravity	% w/w	12.4	12.5	12.4	12.4	0.1
Alcohol	% vol	5.5	5.4	5.8	5.7	0.1
pH		4.40	4.46	4.34	4.32	0.03
Colour	EBC	7.9	7.4	7.4	7.5	0.2
Bitterness	IBU	14.4	14.5	15.6	16.0	0.4
Iso-α-acids	mg/l	13.6	13.5	13.8	12.9	0.5
α-acids	mg/l	1.1	1.7	2.7	2.8	0.2
Humulinones	mg/l	0.5	0.9	1.1	1.3	0.2

Table 3 Foam analyses according to NIBEM ; foam adhesion in points according to DLG; 1st series

Foam assessment	Unit	Control	Seeds late	Control + Seeds Dry	Seeds late + Seeds Dry	SD
NIBEM	s	236	221	225	229	8
Foam Adhesion	points	4.5	4.2	4.3	4.3	0.3

Additional tastings according to DLG [27] and CMA [29] (see table 5) showed only slightly poorer results for beers with seeds added in the cold range. This is especially true when the relatively high standard deviation of the results of the 24 tasters is taken into account. The Control and Seeds late variants, on the other hand, were rated equally.

3.3 Test Beers – Series 2

Since the results of the first series did not show any clear influences of hop seeds, a second series of tests was carried out with higher seed doses (70 g/hl at the begin of boiling (BoB) or end of boiling (EoB), each combined with 70 g/hl after primary fermentation = seeds dry).

Fermentation and wort parameters

The fermentation processes were comparable in all beers. The key

Table 4 Aging indicators fresh and after forced aging, 1st series

Aging indicators	Condition	Control	Seeds late	Control + Seeds Dry	Seeds late + Seeds Dry
2-Furfural	fresh	6	10	6	< 5
	forced aged	79	76	69	77
Σ Acetyl-Furan and Propionyl-Furan	fresh	< 10	12	25	35
	forced aged	< 10	11	23	35
Oxygen indicators	fresh	35	23	35	41
	forced aged	37	48	37	46
Aging indicators	fresh	196	245	199	210
	forced aged	270	305	256	287

Table 5 Tasting results of the first series

Tasting method	Control	Seeds late	Control + Seeds Dry	Seeds late + Seeds Dry	SD
DLG Average	4.17	4.14	4.01	4.07	0.18
CMA Bitterness Quality	7.7	7.6	7.4	7.3	0.4
CMA Overall Aroma Quality	6.0	5.9	5.7	5.8	0.3

Table 6 Beer analyses (series 2)

Analysis	Unit	Control	Control + Seeds dry	Seeds BoB	Seeds BoB + Seeds dry	Seeds EoB	Seeds EoB + Seeds dry	SD
Original Gravity	% w/w	12.3	12.4	12.6	12.4	12.6	12.7	0.1
Alcohol	% vol	5.3	5.9	5.7	6.0	5.5	6.0	0.1
Final Attenuation	%	82.4	90.1	84.6	91.1	82.5	89.6	0.3
pH		4.62	4.58	4.61	4.57	4.71	4.60	0,03
Colour	EBC	6.6	6.5	5.9	5.6	7.3	6.7	0.2
Bitterness	IBU	17	18	13	12	18	18	0.4
Iso-α-acids	mg/l	13.5	14.5	13.0	13.2	12.8	14.4	0.5
α-acids	mg/l	3.7	3.4	1.1	0.9	4.7	2.9	0.2
Humulinones	mg/l	1.5	1.9	0.5	0.8	1.7	2.0	0.2
Linalool	µg/l	65	76	< 2	6	88	76	4
Foam NIBEM	s	203	221	197	184	216	209	7
Foam Adhesion	points	3.9	4.1	4.1	3.9	3.9	4.2	0,3

beer analyses are shown in table 6 (SD see table 2 and 3) and allow the following conclusions to be drawn:

- Original wort: Differences were marginal.
- Alcohol content: The beers with additional seed plugs (70 g/hl after primary fermentation) achieved an average of 6.0 % vol. and were thus significantly higher than the beers without seed plugs (5.5 % vol.).
- Degree of fermentation: Consequently, the average increases from 83.2 % (without dry seeds) to 90.3 % (with dry seeds).
- pH value: Slight decrease (4.65 vs. 4.58 with seed dry).
- Color: Slight reduction (6.6 vs. 6.3 EBC).

These results indicate that the seeds introduce a relevant potential of carbohydrate-degrading enzymes into the wort, which triggers further fermentation, as already reported in [6, 7]. The phenomenon is reminiscent of the "hop creep" described in the literature [30], according to which dry hopping induces additional fermentation activity.

To clarify whether seeds alone or additional hops also cause increased secondary fermentation, the three brews were divided into three tanks after primary fermentation:

- without additives,

Table 7 Comparison of the average tasting results for beers with and without seeds added in the cold part, 2nd series

Tasting method	without : with Seeds dry	SD
DLG Average	4.21 : 4.26	0.18
DLG Bitterness Quality	4.00 : 3.93	0.21
CMA Average Aroma Intensity Points	3.42 : 3.45	0.3
CMA Bitterness Quality	7.77 : 7.67	0.4

- with 70 g seeds/hl,
- with 70 g seeds/hl + 200 g hops/hl

The alcohol content rose from 5.5 % (without additives) to 6.0 % (seeds) and 6.1 % (seeds + hops). This means that the additional fermentation is mainly due to the addition of seeds, which raises the question of whether even small amounts of seeds in commercially available hops can already cause additional enzyme activity.

Bitter compounds, aroma, and foam

The analyses of bitter substances and linalool content showed no trends which can be attributed to the hop seed dosing. The foam analysis also showed no dependence on the addition of seeds. The differences are most likely due to the divergent bitter substance composition (sum of alpha acids, humulinones, and iso-alpha acids). The foam properties also remained unaffected: on average, the three beers without added seeds after primary fermentation (Control, Seeds BoB, Seeds EoB) achieved 205 s according to NIBEM. The corresponding beers with dry seeds showed an identical NIBEM average of 205 s. The DLG evaluation of foam adhesion confirmed the results. The average values were similar at 4.0 points without and 4.1 points with dry seeds.

Sensory

The results of the tastings with 25 participants showed no tendencies according to either the DLG or CMA evaluations. In particular, there were no sensory differences between the beers to which seeds were added at the start or end of boiling. The holding time therefore had no influence on the sensory result. A comparison of the three beers without seeds after primary fermentation with the corresponding variants with seeds also showed no negative effects on the sensory properties of the beers (see table 7, incl. SD of 25 panelists).

Aging and stability

Indicators of aging behavior are shown in table 8. No differences between beers with and without seed addition were apparent either in the fresh state or after forced aging. Only 2-furfural and nicotinic acid ethyl ester increased as expected after forced storage, but independently of the seed dosage.

After six months of storage at 30 °C, the beers were re-evaluated sensorily (see table 9). In addition to DLG and CMA, the aging score was assessed according to Eichhorn/Lustig [28]. This was assigned in half-point increments from 1 to 4 (1 = hardly aged, 4 = heavily aged) and was based on a weighting of the characteristics of smell, taste, and bitterness. In addition, the test subjects rated the acceptability of the beers in percent (0 % = undrinkable, 100 % = fully acceptable).

The comparison of beers with and without added seeds after primary fermentation showed only marginal differences. Neither

Table 8 Aging indicators fresh and after forced aging, 2nd series

Aging indiators	Condition	Control	Control + Seeds dry	Seeds BoB	Seeds BoB + Seeds dry	Seeds EoB	Seeds EoB + Seeds dry
2-and 3-Methylbutanal	fresh	28	25	39	25	39	36
	forced aged	31	26	28	31	39	44
2-Furfural	fresh	97	115	86	93	82	92
	forced aged	151	177	158	151	139	157
Benzalaldehyde	fresh	10	10	< 5	< 5	10	9
	forced aged	9	9	< 5	< 5	10	8
Ethyl nicotinate	fresh	7	8	5	6	6	6
	forced aged	15	17	15	16	16	16
2-Acetylfuran	fresh	80	84	< 5	5	82	72
	forced aged	76	74	< 5	6	78	61
2-Propionylfuran	fresh	41	38	< 5	8	44	30
	forced aged	36	35	< 5	8	42	29
y-Nonalactone	fresh	14	16	11	13	10	14
	forced aged	17	17	14	14	15	16

Table 9 **Sensory evaluation of the beers (series 2) after aging for 6 months at 30 °C; comparison of the average ratngs of the beers without vs. with seeds added in the cold part**

Tasting method	without : with seeds dry	SD
DLG Average	3.64 : 3.69	0.18
DLG Bitterness Quality	3.53 : 3.50	0.21
Aging grade	2.33 : 2.33	0.32
Acceptance [%]	52 : 51	7.33

in the fresh nor in the aged samples could any influence of the seeds on the sensory properties of the beers be detected at the selected dosage.

4. Summary

In the hop trade, predominantly unfertilized female cones are marketed. An EU regulation limits the seed content for seedless hops to a maximum of 2 % by weight, requiring hop growers to remove male plants near hop gardens to prevent fertilization, often with herbicides.

The literature on the influence of hop seeds on beer quality is inconsistent. More than a half of the publications report no adverse effects, while others describe negative impacts, mainly attributed to the high fat content of the seeds, which could accelerate aging and have negative effects on the foam stability.

In this study, hop seeds were characterized and evaluated in brewing trials. Bottom-fermented beers were produced with additions of 50 and 70 g seeds/hl during wort boiling and a further 50 and 70 g/hl after primary fermentation. Based on hops containing 10 % seeds, these dosages correspond to 1.0 and 1.4 kg hops/hl, which is considerably higher than commercial practice.

Key findings:

→ Seed additions after primary fermentation increased alcohol content, most likely attributable to amylolytic enzyme activity in the seeds. The effect resembles the "hop creep" phenomenon known from dry hopping.

→ No deterioration in foam stability was observed in both series. NIBEM and visual assessments confirmed nearly identical results.

→ Aging indicators (furfural, 2-acetylfuran) showed no differences between beers with and without seeds, either after accelerated testing or long-term storage (6 months at 30 °C).

→ Triangular tastings did not yield a conclusive picture. Even in the case of the only significant difference, no clear preference could be established. Supplementary evaluations according to the DLG and CMA schemes confirmed the equivalence of the beers. Tasting after six months of aging at 30 °C showed no differences between beers with and without added seeds.

Within the tested range, seed additions had no adverse effects on foam stability, sensory properties, or overall beer stability. These findings, however, do not justify uncontrolled fertilization of female hop plants, since seeds conferred no technological benefit. They add mass without contributing to the brewing process and should therefore be controlled. Nevertheless, a seed content in the range of approximately 5 to 8 % may be regarded as technologically acceptable. Overall, the results support a re-evaluation of the current regulatory limit of 2 % seed content.

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