

V. Nesvadba, J. Olšovská, J. Charvátová, S. Trnková and G. Fritschová

New Czech fine aroma hop varieties (*Humulus lupulus* L.) – Saaz Brilliant, Saaz Comfort and Saaz Shine – have found extensive use in hop growing and beer brewing

The renowned Saaz hop variety is primarily used for the production of lager beers. Saaz is the genetic basis for the new Saaz Brilliant, Saaz Comfort and Saaz Shine breeding lines. The present study evaluated the stability and stability trends of the new hop varieties over a period of twenty years based on the content of alpha and beta acids and their ratio. The study also included a comparison between lager beers hopped with the new hop varieties and those hopped with Saaz. The results of long-term monitoring show that the content of alpha acids of the new aroma hops in the Saaz Brilliant, Saaz Comfort and Saaz Shine breeding lines ranges between 2.16 and 5.36 % w/w, 3.39 and 8.73 % w/w and 2.07 and 7.22 % w/w, respectively. Saaz Brilliant has the highest variability in the content of alpha acids. In contrast, Saaz Shine has the lowest variability and demonstrates an increasing trend in the content of alpha acids. All three hop varieties fall within the category of fine aroma hops, which provide beer with a fine bitterness and a hoppy aroma. Saaz Shine has a lower intensity of bitterness with a fine character and is more suitable for lighter lager beers. In contrast, Saaz Comfort with its higher intensity of bitterness and a longer aftertaste is more fitting for the „Premium Lager” category. The new hop varieties also demonstrate a very good drought tolerance. Their unique qualities are attracting growing interest, leading to an increase in their cultivation area in the Czech Republic.

Descriptors: Fine aroma hops; Saaz; Saaz Brilliant; Saaz Comfort; Saaz Shine; lager

1 Introduction

Saaz is the most renowned and most popular Czech hop variety for the production of lager beers. The first clonal selection in the original Saaz population was performed in Auscha in 1853 by Kryštof Semš from Vrbice near Roudnice, who carried out a positive selection in his own hop vegetation. Karel Osvald was the founder of modern methods of hop breeding based on a selecting in indigenous regional vegetations. His long-term efforts brought three clones to Czech hop growing. They were named after the breeder (Osvald's clone 31, Osvald's clone 72 and Osvald's clone 114) [1] and they currently take up 90 % of the Czech Republic's total hop acreage. In the 1960s, hop hybridization or cross-breeding was introduced to hop breeding [2].

<https://doi.org/10.23763/BrSc24-11nesvadba>

Authors

Vladimír Nesvadba (ORCID ID: 0009-0004-2682-9287), Jitka Charvátová, Sabina Trnková, Hop Research Institute, Žatec, Czech Republic; Gabriela Fritschová (ORCID ID: 0009-0005-1137-773X), Hop Research Institute, Žatec, Czech Republic, Department of Biotechnology, Faculty of Food and Biochemical Technology, University of Chemistry and Technology, Prague, Czech Republic; Jana Olšovská (ORCID ID: 0000-0003-4938-3666), Research Institute of Brewing and Malting, Prague, Czech Republic; corresponding author: olsovska@beerresearch.cz

In the Czech Republic, the breeding of new hop varieties is almost exclusively in the hands of the Hop Research Institute in Žatec, which has registered a total of 26 hop varieties. Bor and Sládek were registered in 1994 as the first Czech hop varieties resulting from hybridization. Premiant was registered in 1996 as a new variety with better performance parameters and was aimed at replacing Bor. In 2001, the registration of the first Czech bitter hop variety (Agnus) with a content of alpha acids above 10 % followed [3]. From 2004 to 2017, an additional eight hop varieties were registered, namely Harmonie, Rubín, Vital, Kazbek, Bohemie, Saaz Late, Gaia and Boomerang [4,5]. Vital was developed for biomedical applications [6]. In 2019, new aroma hop varieties were registered as Saaz Brilliant, Saaz Comfort, Saaz Shine and Mimosa [7]. Mention should also be made of the breeding of hops for low trellises and the registration of the first low-trellis hops (Country, Jazz and Blues) in 2018 and 2019 [8]. The last registered hop varieties are Juno, Ceres, Saturn, Jupiter, Eris and Pluto, which fall into the category of “aroma hops”. These varieties have a distinctive non-hoppy flavor, such as citrusy, fruity, etc. [9].

Hop breeding in the Czech Republic primarily focuses on aroma hops, which include the fine aroma hop variety Saaz, with balanced alpha/beta ratio, and most importantly the fine hoppy aroma. In 1995, a new breeding program was launched, specializing in aroma hops based on Saaz. The program resulted in the registration of three new hop varieties: Saaz Brilliant, Saaz Comfort and Saaz Shine. They show many characteristics identical with those of Saaz. Since

2017, these new hop varieties have been grown in piloting conditions. In addition, brewing tests have been performed, followed by verification brews in brewery operations [10, 11]. Currently, the new hop varieties are grown on several hop-growing farms. In 2024, the harvest acreage of Saaz Brilliant is 0.7 ha. Saaz Comfort is grown on 1.4 ha and Saaz Shine on 5.6 ha [12]. Saaz Shine is gaining in popularity, which is evident from its increasing acreage.

The results of brewing tests show that all three hop varieties provide Pilsner lagers with a fine bitterness and a delicate aftertaste. Beers hopped with Saaz Comfort have a higher intensity of bitterness than those hopped with Saaz Brilliant and Saaz Shine [10]. According to the latest study, Pilsner lagers hopped with these hop varieties have a fine hoppy aroma with an herbal and floral scent and differ in small details. Saaz Comfort has a more intensive hoppy aroma in beer whereas Saaz Shine has a fruity scent and traces of citrus in its aroma. All beers made with these varieties are characterized by a high concentration of farnesol, which is an oxidized form of farnesene. [11]. The high concentration is typical for hop varieties in the Saaz family [13]. Farnesol, similarly to other oxidized forms of sesquiterpenes (caryophyllene epoxide, humulene epoxide I, humulene epoxide II and humulenol II), creates the typical herbal and spicy aromas that are part of the “fine hoppy” or “noble” aroma of beer [14].

The aim of our research was to evaluate the stability and stability trends of the new Saaz Brilliant, Saaz Comfort and Saaz Shine breeding lines over a period of 20 years based on the content of alpha and beta acids and their ratio. The aforementioned parameters were evaluated in hops grown in both breeding nurseries and growers' hop fields on a regular basis. The study also included brewing tests necessary in order to use the new hop varieties in the production of lager beers. The evaluation focused on the popularity of beer as well as on the character and intensity of its bitterness. The results of the research will be relevant for both hop growing and beer brewing.

2 Materials and methods

2.1 Characterization of evaluated hop varieties

All of the evaluated hops were registered in 2019. The original Saaz variety was selected as a benchmark variety [13].

Saaz (SAZ) was gained from a clonal selection in the original vegetation of the Žatec (Saaz) and Úštěk (Auscha) regions. The plant has a medium size and a regular cylindrical shape. Bines have a green-red color and a thickness of 9 – 11 mm. Stems with hops are of short or medium length, growing at a low level of the plant. Hop cones are egg-shaped (medium or long) and have a high density. The average weight of 100 hop cones is between 13 – 17 grams. Its fine hoppy aroma is composed of herbal and flowery scents and is fruity and grassy in the background. The scent is of low intensity. The yield of this hop variety amounts to 1.0 – 1.6 t/ha⁻¹.

Saaz Brilliant (SAI) was gained from a selection of descendents resulting from the inbreeding of the Saaz variety. The plant has a massive size and a cylindrical shape. Bines have a red color and a

thickness of 10 – 13 mm. Stems with hops are of medium length, growing at a medium level of the plant. Hop cones are egg-shaped (medium or long) and have a high density. The average weight of 100 hop cones is between 17 – 20 grams. Its fine hoppy aroma is composed of herbal and flowery scents and is grassy in the background. The scent is of lower intensity. The yield of this hop variety amounts to 1.0 – 1.6 t/ha⁻¹.

Saaz Comfort (SAC) was gained from a selection of descendents of Dubský zeleňák (Dauba hops) and a Saaz male plant (found in a hop field in Liběšice near Žatec). The plant has a massive size and a cylindrical shape. Bines are green-red with a thickness of 11 – 14 mm. Stems with hops have a medium length, growing at a medium or low level of the plant. Egg-shaped hop cones (medium or long) have a high density. The average weight of 100 hop cones is between 17 – 20 grams. Its fine hoppy aroma is composed of herbal and grassy scents and is woody in the background. The yield of this hop variety amounts to 1.0 – 1.6 t/ha⁻¹.

Saaz Shine (SAH) was gained from a selection of descendents of a Sládek female plant and a Saaz male plant (an identical father with Saaz Brilliant). The plant has a very massive size and a cylindrical shape. Bines are green-red with a thickness of 10 – 13 mm. Stems with hops have a medium length, growing at a very low level of the plant. Hop cones are egg-shaped (medium) and have a very high density. The average weight of 100 hop cones is between 15 – 19 grams. Its fine hoppy aroma is composed of herbal and fruity scents and is citrusy in the background. The scent is of medium intensity. The yield of this hop variety amounts to 1.0 – 1.6 t/ha⁻¹.

2.2 Location of hops evaluation

1. Ohře river basin – Rybňany (GPS: 50.331146, 13.595462) and Stekník (GPS: 50.329988, 13.618508). Alluvial soils, hop fields with irrigation.
2. Rakovník region – Nesuchyně (GPS: 50.187038, 13.687232) and Chrášťany (GPS: 50.155447, 13.672450). Brown soils, rather dry, hop fields without irrigation.
3. Údolí zlatého potoka (“Golden Creek Valley”) – Očihov (GPS: 50.191522, 13.477852). Permian red soils near the Blšanka creek, hop fields without irrigation.
4. Úštěk (Auscha) region – Radovesice (GPS: 50.405983, 14.075183). Brown soils of alluvial type, hop fields without irrigation.

The results were obtained from the above-mentioned field trials. In the locations Rybňany, Stekník, and Chrášťany, each variety was grown with a minimum of 150 plants, while in other locations, the minimum was 70 plants. All plants were cultivated within commercial hop fields.

2.3 Chemical parameters of evaluated hops

The content and composition of hop resins was evaluated on the basis of the EBC 7.7 method in each hop variety [15]. Every plant was harvested separately. A Volf experimental picking machine was used to pick hop plants. Subsequently, samples were dried

at a temperature of 55 °C and submitted for chemical analyses.

2.4 Brewing test

The beer samples were prepared in a 70 l experimental brewhouse (Brewtec, Czech Republic). 11.7 kg of Pilsner malt was used for each brew (Benešov, Czech Republic). The single-decoction mashing method was applied at a mash-in temperature of 64 °C and a mash-out temperature of 72 °C. Single kettle hopping with 100 % of the tested hop variety was carried out in three doses: 33.3 % at the beginning, 33.3 % in the 30th minute and 33.3 % 10 minutes before the end of the 75-minute wort boiling. All beer samples were fermented with W34/70 yeast in a fermentation cellar at a temperature of 11 °C over a period of 6 days. The maturation took place at 2 ± 0.5 °C over 21 days. The samples were filtered on a plate with S10N filter plates (Hobra Školník, Broumov, Czech Republic) and filled into 0.33 l bottles 3 days prior to the beer tasting. The beer samples were stored at a temperature of 2 °C. Original gravity of the beer ranged between 11.1 % and 11.3 %. Bitterness amounted to 39 – 43 IBU.

2.5 Sensory analysis of beer

The tasted beer samples had a temperature of 7 – 9 °C. The beer was evaluated by 36 trained beer tasters, who were asked to evaluate 3 parameters: (i) the overall liking of bitterness on a scale from 1 to 4, with 1 being the best evaluation and 4 the worst, (ii) the character of bitterness on a scale from 1 to 4, with 1 being the finest bitterness and 4 the harshest and (iii) the profile of bitterness intensity on a scale from 0 to 20.

2.6 Statistical analysis

The following basic statistics were prepared: mean (M), median (Med) and standard deviation (SD). Relative amount of variability is used to compare a set with different levels. Resulting variability amounts are dimensionless numbers (usually in %). This makes it possible to compare the variability of statistical characteristics differing in measure units. Coefficient of variation (CV), showing the extent of variability in %, was used for data processing. A paired t-test was applied to determine the significance of difference between hop varieties. The difference of sets was determined on the basis of significance level (α), which shows the probability of difference of the tested sets [16].

3 Results and discussion

The first objective of the present study was to evaluate the stability and stability trend of the new SAI, SAC, and SAH breeding line over a period of 20 years. Table 1 shows the statistical parameters of the content of alpha acids in the period from 2005 to 2024. According to the table, the highest average content of alpha acids was established in SAC (5.55 % w/w). However, the t-test demonstrated that the difference between the varieties is not statisti-

Table 1 Statistical parameters of alpha acids content in the period from 2005 to 2024

Parameter	SAI	SAC	SAH	SAZ
M	3.77	5.55	3.79	3.21
Med	3.69	5.51	3.50	3.31
SD	0.789	1.134	1.112	0.857
CV (%)	20.95	20.43	28.32	26.70
min	2.16	3.39	2.07	1.87
max	5.36	8.73	7.22	4.97

(M) mean, (Med) median, (SD) standard deviation, (CV) coefficient of variation, (min) minimum value, (max) maximum value

Table 2 Trend of dependence (y) and dependence tightness with respect to the alpha acids content evaluated for the hop varieties in the years 2005 – 2024

Hop variety	y	P-value	r	r2
Saaz Brilliant	- 0,0219x + 47,844	0,62	0,12	0,0148
Saaz Comfort	- 0,0493x + 104,910	0,46	0,19	0,0345
Saaz Shine	0,0078x + 11,996	0,52	0,03	0,0009
Saaz	- 0,0411x + 85,955	0,84	0,25	0,0625

cally significant. The other hop varieties have an almost identical average content of alpha acids. SAH has the highest difference between average and median values. SAI and SAC have a lower variability (CV %) than SAZ and SAH. Only SAZ has an alpha acids content below 2 % w/w, specifically in 2012, 2017 and 2023. At the same time, its content of alpha acids never exceeded 5.00 % w/w. A similar range of the alpha acids content was established in SAI (2.16 – 5.36 % w/w). The highest variability as well as a broad range of the content values was determined in SAH (the lowest content of alpha acids was measured in 2022 and the highest in 2021). SAC has the best parameters in terms of alpha acids content and the variability of alpha acids content: the highest alpha acids content and the lowest variability.

According to a study evaluating alpha acids content in SAZ in the period from 2010 to 2019, the average alpha acids content amounts

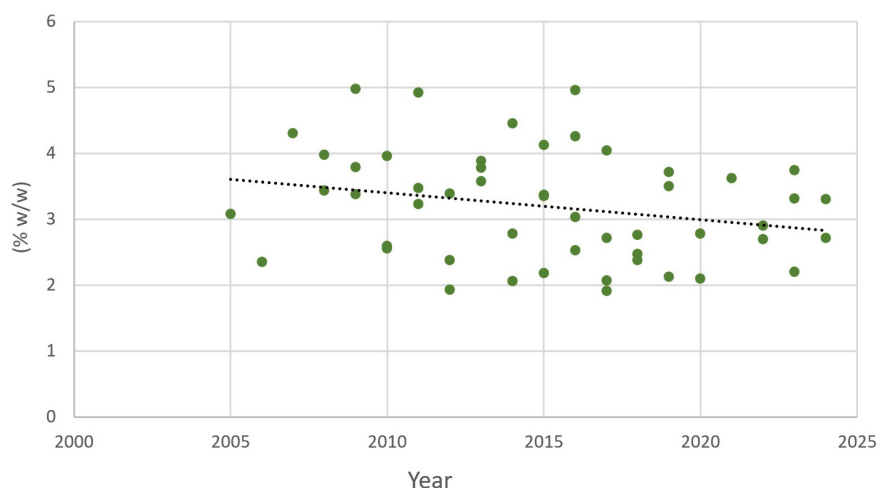


Fig. 1 Trend of alpha acids content in SAZ in the years 2005 – 2024

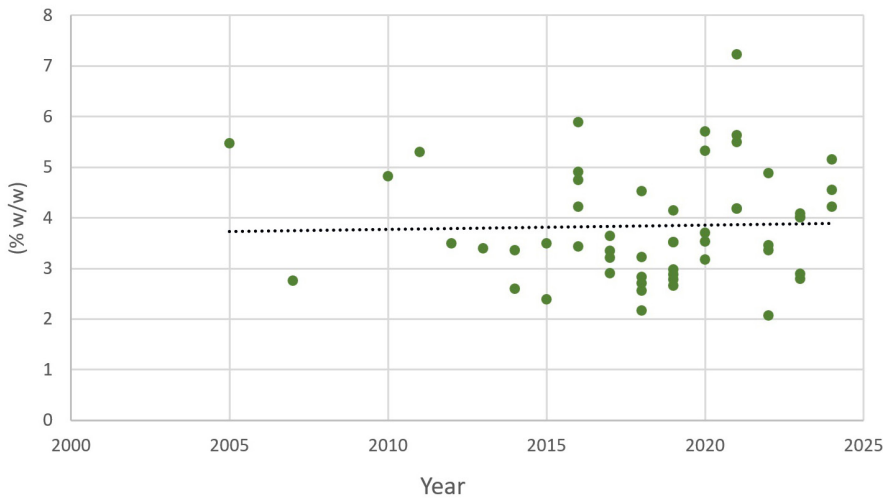


Fig. 2 Trend of alpha acid content in SAH in the years 2005 - 2024

to 2.87 % w/w and its variability is 25.38 % [17]. The concentration value is lower compared to our data collected in the period from 2005 to 2024, while its variability is almost at the same level. This is most likely due to the fact that the study was carried out in one location only [17] and the present study in 4 locations with a different composition of soils and irrigation possibilities. In 2024, Forster et al. published the results of an evaluation of Hersbrucker Spät, a German fine aroma variety, which started in 2015. This study also established a low average content of alpha acids, i.e. 1.9 % w/w [18].

Table 2 shows trends in the content of alpha acids in the period from 2005 to 2024. SAZ, SAI and SAC have a decreasing trend in the content of alpha acids over a period of 20 years. The greatest decrease was recorded in SAZ (Fig. 1). The decreasing trend corresponds to 0.041 % of alpha acids, which means a decrease in alpha acids of 0.82 % w/w over a period of 20 years. SAZ shows the highest tightness of dependence ($r^2 = 0.0625$), which means that 6.25 % of the decrease is explained by the time series. For comparison, the Hersbrucker Spät fine aroma variety also demonstrates a decrease in the content of alpha acids and its average content amounts to 1.9 % w/w [18]. It is very likely that old landraces such as SAZ and Hersbrucker Spät are more sensitive to climate change. All evaluated hop varieties have a low coefficient of determination. This is also in line with the results of a study evaluating the trend of alpha acids in 21 European hop varieties in a time series from 2009 to 2023, in which none shows an increasing trend in the alpha acids content [19]. SAH is the only hop variety showing an increasing trend in the alpha acids content (see Table 2 and Fig. 2). This trend may be influenced by numerous factors such as the selection of suitable growing locations, the correct harvest time and a higher stability of the alpha acids content in older plants. Another important factor is that SAH demonstrates a higher tolerance to drought compared to SAZ [13].

The highest average beta acids content was established in SAC and the lowest in SAI (see Table 3). However, differences between the hop varieties are not statistically significant. The greatest difference between the average and median values was determined in SAZ (the difference amounts to 0.22 % w/w). All hop varieties have an almost identical variability of the beta acids content, with

the lowest beta acids content recorded in SAH in 2007. In 2015, 2018 and 2020, SAH had a beta acids content below 2 %. Beta acids content below 2 % w/w was also determined in SAI in the years 2015, 2020 and 2022. The highest maximum beta acids content was measured in SAC. This hop variety shows a content of beta acids above 7.00 % w/w in the years 2014 and 2016. The original variety SAZ has a beta acids content ranging from 2.41 to 6.79 % w/w.

The alpha/beta ratio is extremely important for fine aroma hops. It should be around 1.0 [20].

The results achieved show that the lowest average alpha/beta ratio is that of SAZ (0.85). In contrast, SAI has the highest alpha/beta ratio (1.43). All of the hop varieties show a fairly broad range of the alpha/beta ratio values, and therefore no statistical significance of difference between the hop varieties could be established. The lowest variability of the alpha/beta ratio was determined in SAI (17.96 %) and the highest in SAZ (32.84 %).

Table 3 Statistical parameters of beta acids content in the years 2005 - 2024

Parameter	SAI	SAC	SAH	SAZ
M	2.69	5.28	2.93	4.09
Med	2.66	5.24	2.92	3.87
SD	0.563	1.378	0.703	1.067
CV (%)	20.94	26.10	24.02	26.11
min	1.54	2.44	1.15	2.41
max	4.03	8.57	4.29	6.79

(M) mean, (Med) median, (SD) standard deviation, (CV) coefficient of variation, (min) minimum value, (max) maximum value

Table 4 Statistical parameters of the alpha/beta ratio in the period from 2005 to 2024

Parameter	SAI	SAC	SAH	SAZ
M	1.43	1.10	1.31	0.85
Med	1.40	1.10	1.24	0.80
SD	0.256	0.272	0.282	0.280
CV (%)	17.96	24.68	21.47	32.84
min	0.97	0.50	0.88	0.35
max	2.22	1.75	2.39	1.69

(M) mean, (Med) median, (SD) standard deviation, (CV) coefficient of variation, (min) minimum value, (max) maximum value

Table 5 Trend of dependence (y) and dependence tightness with respect to the alpha/beta ratio evaluated in hop varieties in the years 2005 - 2024

Hop variety	y	P-value	r	r ²
Saaz Brilliant	0,0026x + 3,8694	0,35	0,04	0,0020
Saaz Comfort	0,0117x + 22,531	0,72	0,21	0,0439
Saaz Shine	- 0,0165x + 34,870	0,64	0,14	0,0191
Saaz	0,0069x + 13,006	0,81	0,13	0,0157

Table 6 Statistical parameters of the cohumulone share in the years 2005 – 2024

Parameter	SAI	SAC	SAH	SAZ
M	24.23	17.96	23.85	23.10
Med	24.30	17.90	24.20	23.10
SD	2.316	1.976	1.980	1.946
CV (%)	9.56	11.00	8.30	8.42
min	17.10	14.80	19.40	19.70
max	31.30	26.20	27.50	30.50

(M) mean, (Med) median, (SD) standard deviation, (CV) coefficient of variation, (min) minimum value, (max) maximum value

Table 7 Content and composition of bitter acids in Czech hop varieties (Atlas of Czech Hop Varieties, Nesvadba et al., 2022)

HOP RESINS	SAI	SAC	SAH	SAZ
alpha acids (% w/w)	3.0 – 4.5	4.0 – 7.0	2.0 – 5.0	2.0 – 5.0
beta acids (% w/w)	2.0 – 3.0	3.5 – 5.5	2.0 – 4.0	3.5 – 5.0
alpha/beta ratio	0.8 – 1.1	0.9 – 1.4	0.9 – 1.3	0.6 – 1.0
cohumulone (% rel.)	22 – 26	15 – 20	21 – 27	22 – 26

Table 8 Results of evaluated beers made from the tested hop varieties

Hop variety	Popularity (liking)		Character of bitterness	
	Average score	Ranking	Average score	Ranking
SAZ	2.46	2	2.41	2
SAI	2.53	3	2.56	3
SAH	2.24	1	2.06	1
SAC	2.68	4	2.71	4

Table 9 Significance of difference in the evaluation of popularity of the beer samples based on the t-test

Hop variety	SAH		SAZ	SAI
	SAH	SAI		
SAZ	-	-	-	-
SAI	-	-	-	-
SAC	0.1	-	-	-

Table 10 Significance of difference in the evaluation of bitterness character of the beer samples based on the t-test

Hop variety	SAH		SAZ	SAI
	SAH	SAI		
SAZ	-	-	-	-
SAI	0.1	-	-	-
SAC	0.05	-	-	-

Table 5 shows trends in the alpha/beta ratio in the period from 2005 to 2024. It was determined that only SAH has a decreasing trend of the alpha/beta ratio. Other hop varieties demonstrate an increasing trend in the alpha/beta ratio. The dependence tightness is not significant and the highest was established in SAC. The results are not statistically significant; however, it is positive that SAH does not have an increasing alpha/beta ratio. The alpha/beta ratio of this variety should not go up. Overall, it can be concluded that all of the hop varieties under review show a very good stability of the

alpha/beta ratio. However, this does not apply to all hop varieties grown in the Czech Republic. For example, Agnus, Herkules and Hallertauer Tradition do not achieve such stability under the Czech Republic's growing conditions [19].

Table 6 shows statistical parameters of cohumulone. The lowest share of cohumulone was established in SAC (17.96 % rel.). Other hop varieties were nearly at the same level. As for the very low variability of between 8.30% (SAH) and 11.00% (SAC), it is very likely that this characteristic is not substantially influenced by the particular location or length of cultivation. A broader gap between minimum and maximum values of the cohumulone content is impacted by the specific year and selected harvest time. For example, SAI shows

a share of cohumulone above 30 % rel. only in 2021 and SAZ in 2022, when this value was established in a single sample.

The overview of the content and composition of bitter acids of Czech hop varieties in table 7 originates from the Atlas of Czech Hop Varieties [21]. Compared to these data, our results show a higher variability and a broader range of values.

For example, SAI has a content of alpha acids between 2.16 and 5.36 % w/w (see Table 1), whereas the Atlas specifies a range from 3.0 to 4.5 % w/w (see Table 7). Out of 82 analyses, 15 samples are below the bottom limit of 3.0 % w/w and 16 samples above the top limit of 4.5 % w/w. This means that only 51 samples (i.e. 62 % of data) are within the limits specified in the Atlas. Therefore, it can be assumed that SAI can have a higher range for different years than shown in the Atlas. As for SAC the data in the Atlas and our study correspond to each other much more. Out of 68 samples, only 3 samples are below 4.0 % w/w and 6 samples above 7.0 % w/w. That means that 87 % of the values were within the limits specified in the Atlas. SAH, of which 54 samples were evaluated, never had an alpha acids content below 2.0 % and only 3 samples were below 2.5 % w/w. 9 samples in our study had values above 5.0 % w/w, which means that 85 % of our results are within the limits specified in the Atlas of Czech Hop Varieties. Based on our new results, we can assume that the content of alpha acids in SAH will range between 2.5 and 6.0 % w/w. The content of beta acids, the alpha/beta ratio and the cohumulone share can be assessed in a similar manner.

Aroma is an important part of the evaluation of hop varieties. Figure 3 shows the long-term evaluation of scents of the hop varieties under review. The original SAZ variety is a traditional fine aroma hop variety having a typical fine hoppy aroma with a pronounced herbal scent and fruity, spicy, citrusy and floral tones in the background. SAI has a characteristic fine hoppy aroma with a pronounced herbal scent and light spicy, fruity and citrusy tones in the background. SAC has a characteristic fine hoppy aroma with a pronounced spicy and herbal scent and light fruity tones in the background. SAH has a rich, yet fine hoppy aroma with a pronounced fruity and citrusy scent, complemented by a balanced herbal, floral, and spicy scent in the background.

The second objective of the study was to carry out a sensory evaluation of single hopped beers made from SAZ, SAI, SAC and SAH.

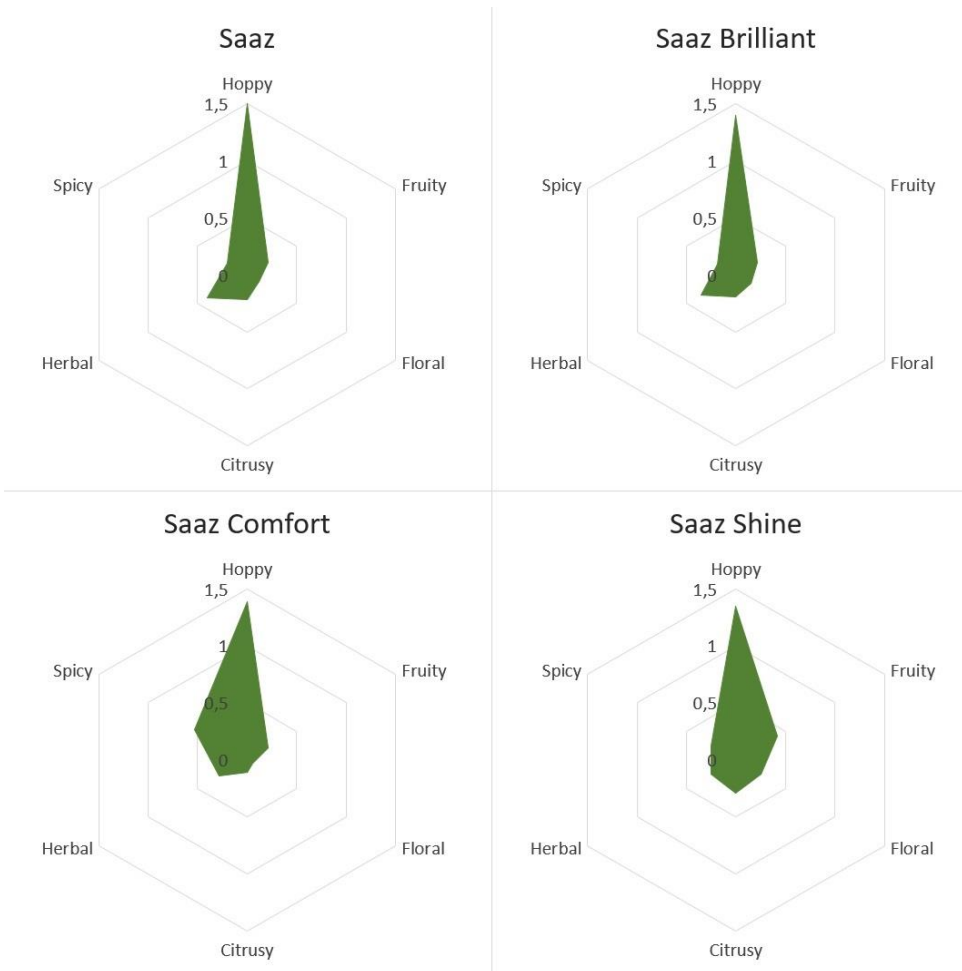


Fig. 3 Aroma profile of SAZ, SAI, SAC and SAH

Popularity (liking) and bitterness character were evaluated on a scale from 1 to 5, with 1 being the best score. Table 8 shows the results of the sensory evaluation. The highest popularity was achieved by the beer hopped with SAH, followed by SAZ, SAI and SAC.

The t-test was used to determine the statistical significance of difference between the hop varieties (see Table 9). With a probability of 95 %, SAH has a significantly higher popularity than SAC. The statistical significance of difference between other hop varieties was not determined. In addition, no statistically significant difference was established between the popularity of the new varieties and that of the original SAZ variety. This is in line with a recently published study, which compared these hop varieties in lagers using a sensory method referred to as “Projective Mapping”. In the study, no statistically significant difference was determined with respect to beers hopped with the original SAZ variety [11].

Table 8 shows the results of the evaluation of bitterness character. The best evaluation was received by SAH (2.06 points), which shows a significant difference compared to SAC and SAI (Table 10). However, none of these hop varieties

shows a statistically significant difference compared to SAZ.

The evaluation also focused on the development of the intensity profile of bitterness over time. Figure 4 shows that the beers slightly differ when it comes to the development of the bitterness perception after swallowing. Beer hopped with SAC had the fastest onset of bitterness and the maximum intensity value was achieved after 12 seconds, in SAI after 14 seconds and in both SAZ and SAH after 16 seconds. The highest bitterness intensity was established in SAC (20 points). In contrast, SAH has the lowest intensity (12.6 points). Perception of bitterness in the benchmark variety SAZ starts after 5 seconds and achieves the maximum value (15 points) after 15 seconds. The curve of the bitterness profile is fairly symmetrical up to the 22nd second. Then, the aftertaste is softer up to the 34th second. SAI has a very similar development of intensity. The only difference is that bitterness starts after 6 seconds, the maximum bitterness is slightly stronger (16.3 points) but the bitterness aftertaste is 5 seconds shorter. The greatest difference in the bitterness profile was determined between SAC and SAH. In beer hopped with SAC, perception of bitterness starts after 3

seconds, the maximum intensity (20 points) is achieved after 12 seconds and the aftertaste is softer up until the 48th second. The onset and maximum bitterness intensity in SAH is very similar to those in SAZ. However, SAH is different in terms of its culmination

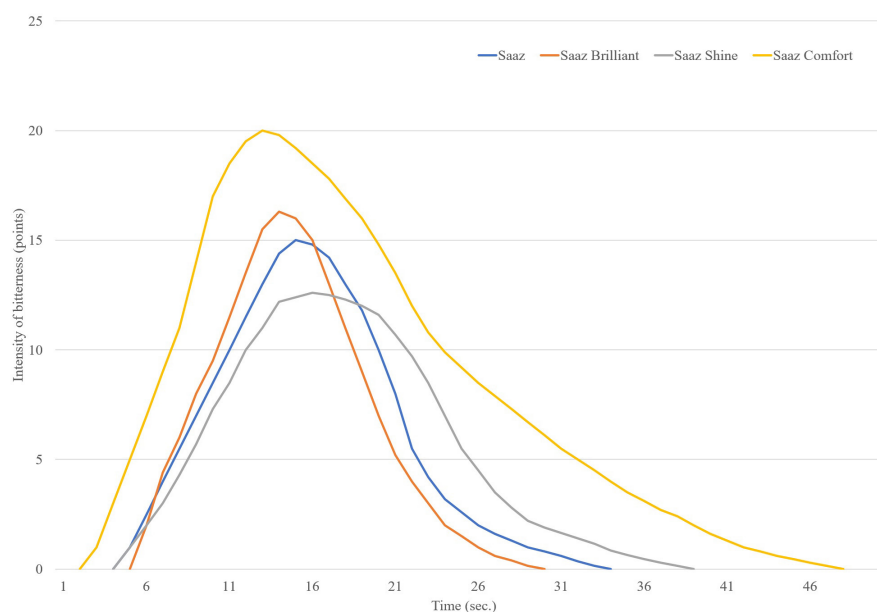


Fig. 4 Profile of bitterness intensity over time

period (about 8 seconds) as well as its slower and longer after-taste. All other hop varieties have a culmination period of about 4 seconds. The difference in bitterness profiles between SAC and SAH probably influenced the evaluation of beers in Table 8. SAH shows a fine, less intensive bitterness whereas SAC has a more intensive bitterness with a harsher character, with a longer and partly lingering aftertaste.

In 2021, a similar study was carried out. In addition to the Saaz family varieties under review, the Agnus bitter variety was added and accounted for 44 % of hopping. The resulting beer had a similar bitterness (39-42 IBU) but a higher original gravity (11.9 – 12.3 % w/w). Similar differences were established in the bitterness character and intensity across the hop varieties. However, beer hopped with SAC had a better evaluation than SAH [10]. The reason behind the different results can be a heterogeneous group of beer tasters during the experiment in the years 2021 and 2024. Nonetheless, it is more likely that it was due to the fact that technology used for the production of experimental beers was not identical. In the study of 2021, the single-hopping method was not used. Instead, the Agnus bitter variety was added to the brews (44 %) in addition to the hop varieties under review. Another (and in our opinion the most important) reason is a different original gravity. SAH, which shows a lower bitterness intensity with a fine character, receives a better evaluation in lager with a lower original gravity (10 – 11 % w/w) whereas SAC, which has a higher bitterness intensity and a longer aftertaste, is more suitable for the Premium Lager category with an original gravity above 11 %. Over the last five years, this phenomenon has been confirmed by breweries based on their own experience.

SAH and SAC differ slightly. However, none of the studies carried out so far could determine a statistically significant difference between either of them and SAZ. Thanks to the similarity, they can be regarded as two possible alternatives for the production of Pils lagers. It needs to be mentioned that SAC and SAH demonstrate a very good tolerance to drought. Therefore, they can be grown in areas where irrigation is not possible [13]. To popularize them and to raise awareness among beer brewers, they were included in the new “Czech Beer Vision” competition in 2023. In a special category dedicated to beers hopped with these hop varieties, 10 Czech breweries participated in 2023 and 26 in 2024 (<https://beer-research.cz/vyhlaseni-souteze-ceska-pivni-vize-2024>).

4 Conclusion

Results from long-term monitoring indicate that SAI exhibits greater variability in alpha acids content, while SAH shows the least variability. Furthermore, SAH is the only variety among these hops to demonstrate an increasing trend in alpha acids content. This is most likely due to the fact that SAH is currently grown on nearly 6 hectares (compared to 0.7 ha of SAI and 1.4 ha of SAC), and therefore hop growers already have more experience with the cultivation of this variety. Selecting the correct harvest time is crucial in order to achieve the optimal content of alpha and beta acids and to avoid an increasing alpha/beta ratio. SAC is also gaining in popularity and its growing area is expanding. Therefore, it can be expected that the content and composition of hop resins in this hop variety will also

stabilize, which is crucial from breweries’ perspective in order to ensure the same quality and composition in annual hop supplies.

Another equally important aspect is the taste profile, which places these varieties in the category of fine aroma hops, giving beer a fine bitterness and hoppy aroma.

Last but not least positive characteristic of SAH and SAC is their very good tolerance to drought. They can be grown in dry areas where irrigation is not possible. Breweries are becoming more and more interested in these hop varieties, and therefore SAI and SAC are now being propagated and prepared for the planting in new hop fields. Strong interest in these hop varieties is expressed not only by craft breweries but also by large industrial breweries. For example, Plzeňský Prazdroj used SAH for its special limited edition “Volba sládků” (“Brewers Choice”). The new hop varieties have also been popularized by the new brewing competition “Česká pivní vize” (“Czech Beer Vision”). Thanks to the competition both breweries and end customers learned about the high quality of the new fine aroma hops and the excellent taste of beer brewed from them.

Acknowledgments

This research was funded by the Ministry of Agriculture of the Czech Republic within the project QK21010136 entitled “Application of new hop varieties and genotypes resistant to drought in hop growing and beer brewing”.

Conflict of interest

The authors declare that there are no conflicts of interest.

5 References

1. Fric, V.: Odrůdová skladba a ozdravovací proces chmele v ČSFR (in Czech), *Chmelařství*, (1992), pp. 85-86.
2. Rígr, A.; Beránek, F. and Nesvadba, V.: Phenotype variability of the main characteristics of hop varieties as a source for hop hybridisation process, *Rostlinná výroba*, **43** (1997), no. 7, pp. 315-318.
3. Nesvadba, V. and Krofta, K.: New hop variety Agnus as the result of breeding process innovation in the Czech Republic. *Rostlinná výroba*, **48** (2002), no. 11, pp. 513-517.
4. Nesvadba, V., Brynda, M., Henychová, A., Ježek, J., Kořen, J., Krofta, K., Malířová, I., Patzak, J., Polončíková, Z., Svoboda, P., Valeš, V. and Vostřel, J.: Development and tradition of Czech hop varieties, *Chmelařský institut s.r.o. Žatec*, 2013, ISBN 978-80-86576-61-9.
5. Nesvadba, V., Charvátová J. and Stefanová, L.: Hop Breeding in the Czech Republic, *Proceedings of the Scientific-Technical Commission of the International Hop Growers’ Convention*, 2017, pp. 7-10.
6. Krofta, K., Patzak, J., Nesvadba, V., Mikyška, A., Slabý, M. and Čejka, P.: Vital – The Czech Hop Hybrid Variety – Part I, **59** (2012), no. 1, pp. 2-13.
7. Nesvadba, V. and Charvátová, J.: New fine aroma varieties of hops (*Humulus lupulus* L.) Saaz Brilliant, Saaz Comfort, Saaz Shine and Mimosa. *Kvasny Prumysl*, **66** (2020), no. 4, pp. 320-330.
8. Nesvadba, V.: Breeding Process Aimed at Dwarf Hops. *Kvasny Prumysl*, **62** (2016), no. 6, pp. 166-172.
9. Nesvadba, V., Olšovská, J., Straková, L. and Hervert, J.: Impairment

- of spicy, fruity and herbal aromas from the Czech hop varieties of Ceres, Pluto and Saturn to beer, *Kvasny Prumysl*, **69** (2023), no. 6, pp. 831-838.
10. Nesvadba, V., Hervert, J., Krofta, K. and Charvatová, J.: Evaluation of Czech hop varieties in beer, *Kvasny Prumysl*, **67** (2021), no. 6, pp. 529-536.
 11. Olšovská, J., Straková, L., Nesvadba, V., Vrzal, T. and Přikryl, J.: The comparison and brewing value of Saaz hop pedigree, *Beverages*, **10** (2024), no. 4, p. 101.
 12. Kršková, L.: Aktuální plochy chmelnic v České republice (in Czech), *Chmelařství 4-5* (2024), pp. 48-51.
 13. Olšovská, J., Straková, L., Nesvadba, V., Vrzal, T., Malečková, M., Patzak, J. and Donner, P.: SAAZ – fine aroma hop pedigree. A review of current knowledge, *Beverages*, **10** (2024), no. 3, p. 90.
 14. Goiris, K., De Ridder, M., De Rouck, G., Boeykens, A., Van Opstaele, F., Aerts, G. and De Keukeleire, D.: The oxygenated sesqu-iterpenoid fraction of hops in relation to the spicy hop character of beer, *Journal of the Institute of Brewing*, **108** (2002), no. 1, pp. 86-93.
 15. Analytica EBC. 7.7 – α - and β -Acids in Hops and Hop Products by HPLC. Available online: <https://brewup.eu/ebc-analytica/hops-and-hop-products/and-acids-in-hops-and-hop-products-by-hplc7/7.7> (accessed on 21 September 2024).
 16. Meloun, M. and Militký, J.: Statistické zpracování experimentálních dat (in Czech). Plus Praha, 1994.
 17. Nesvadba, V., Charvátová, J., Vostřel, J. and Werschallová, M.: Evaluation of Czech hop cultivars since 2010 till 2019, *Plant, Soil and Environment*, **66** (2020), no. 12, pp. 658-663.
 18. Forster, A., Gahr, A., Schüll, F.: Hopfenrsorgung unter dem Druck des Klimawandels, *Hopfen-Rundschau, International 2023/2024*, pp. 34-42.
 19. Nesvadba, V., Charvátová, J., Olšovská, J. and Trnková, S.: Evaluation of variability in alpha and beta acid content in European hop varieties (*Humulus lupulus* L.), *Kvasny Prumysl*, **70** (2024), no. 4, pp. 919-926.
 20. Forster, A., Gahr, A., Schüll, F. and Lehmail, E.: Distinguishing hop varieties as either aroma or bitter hops – is this still relevant? Proceedings of the Scientific-Technical Commission of the International Hop Growers' Convention, 2022, pp. 88-91.
 21. Nesvadba, V., Krofta, K. and Patzak, J.: Atlas českých odrůd chmele (Atlas of Czech hop varieties, in Czech), *Chmelařský institut, Žatec*, pp. 36. ISBN 978-80-86836-60-7; available on http://www.chizatec.cz/atlas_chmele/cz/ChiZatec_Atlas_CZ.html

Received 30 September 2024, accepted 20 November 2024