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New fine aroma varieties of hops (*Humulus lupulus* L.) Saaz Brilliant, Saaz Comfort, Saaz Shine and Mimosa

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Abstract

Four new aroma hop varieties – Saaz Brilliant, Saaz Comfort, Saaz Shine and Mimosa – were registered in the Czech Republic in 2019. All of the new hop varieties have significantly higher yields than the traditional Saaz aroma variety. Saaz Comfort has the significantly highest content of alpha acids (5.59%) whereas Mimosa has the significantly lowest content of alpha acids (1.90%). The Saaz Comfort and Saaz Brilliant varieties show a variability of alpha acid content below 20%. The other hop varieties, Saaz Shine and Mimosa, as well as Saaz, have a variability of alpha acid content above 25%. Mimosa has the significantly highest content of beta acids (6.07%). Mimosa shows the highest average cohumulone content (29.29% rel.) whereas Saaz Comfort has the lowest cohumulone content (18.04% rel.). Saaz Comfort and Saaz Shine have the highest average contents of hop essential oils (0.84% w. and 0.75% w., respectively). The Saaz, Saaz Shine and Saaz Brilliant varieties show the significantly highest farnesene contents (13.47% rel., 12.50% rel. and 12.38% rel., respectively), which are higher than those of Saaz Comfort and Mimosa.

Key words: hop, *Humulus lupulus* L., yield, essential oils, resins, variability

1 Introduction

Currently, the Hop Research Institute in Žatec has 20 hop varieties registered. The first clonal selection dates back to 1853. It was done in the Auscha population by Kryštof Semš from Vrbice near Roudnice, who performed the first positive selection in his vegetation. Associate professor Karel Osvald was the founder of modern methods of hop breeding based on clonal selection in the original regional vegetations. He started applying clonal selection in 1927. His longtime efforts in Czech hop growing resulted in three clones (Fric, 1992), which were named after him (Osvald's clone 31, Osvald's clone 72 and Osvald's clone 114). These clones currently take up 90% of the total hop growing area in the Czech Republic. In the 1960s, hop hybridisation (i.e. crossbreeding) was introduced to hop breeding. In 1994, Bor and Sládek were the first registered Czech varieties resulting from hybridisation. In 1996, the new Premiant variety was registered. Thanks to its better performance parameters, it replaced the Bor variety. In 2001, the first Czech bittering hop variety (Agnus) was registered. It shows an alpha acid content of 10% (Nesvadba et al., 2002). In the years 2004 to 2017, the Hop Research Institute in Žatec registered an additional 8 hop varieties (Nesvadba et al., 2013; Nesvadba et al., 2017), namely Harmonie, Rubín, Vital (developed for biomedical applications as well) (Krofta et al, 2013), Kazbek, Bohemie, Saaz Late, Gaia and Boomerang. In 2019, the Saaz Brilliant, Saaz Comfort, Saaz Shine and Mimosa aroma hop varieties were registered (Nesvadba et al., 2019). Last but not least, the breeding of hops for low-trellis production (Nesvadba, 2016) and the registration of the first Czech varieties of hops for low-trellis production (Country, Jazz and Blues) in the years 2018 and 2019 need to be mentioned. In the past, breeding was aimed at first at productivity, typical aroma and higher alpha acid contents and tolerance to diseases (Wirowskij, 1980). Many important characteristics are based on a polygenic way (Nesvadba at al., 1999). Only several characteristics are monogenic, e.g. dwarfness, which is used for breeding process aimed at

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hop varieties suitable for low trellises (Darby, 2001). Hop is a dioecious plant and just female plants bear cones. It is the reason why male plants enter the breeding process as an unknown pollinator (Neve, 1981). Therefore, it is very important to test also males (Krofta, 2005). It is important to test breeding because it brings knowledge about characteristics given to progeny by male plants. Chemical analyses aimed at contents of hop resins and essential oils help to enrich this knowledge as well (Krofta and Nesvadba, 2005). Hop varieties can be divided into aroma, bitter and others (IHGC hop variety list, 2018). As hop plants are grown at the same place for ten years at least, emphasis is put on the stability of yield and content of alpha acids. Maintenance of breeding is followed in all the registered hop varieties, where stability and uniformity are assessed.

Hop breeding in the Czech Republic mostly focuses on aroma hops. The Saaz fine aroma variety is the best-known Czech hop variety around the world. The breeding of aroma hops dates back at least 160 years. It gives preference to aroma features, including the aroma of hop cones, the balanced ratio of alpha/beta acids and the positive impact on beer quality. The breeding of aroma hops is based on the Saaz variety. In recent years, foreign varieties or even wild hops have been used as well (Nesvadba et al., 2018). In 1995, a new program for breeding of aroma hop varieties with Saaz in their origin was launched. This resulted in the registration of three new varieties (Saaz Brilliant, Saaz Comfort and Saaz Shine) that show numerous features identical with Saaz. Another registered variety from this program is Mimosa, which is different. All new varieties are currently being grown in pilot conditions. Brewing tests and test brews are under way in brewery operations (Nesvadba et al., 2020).

Performance stability is a very important parameter for hop growing and beer brewing. Therefore, it is necessary to test the new hop varieties over a longer period of time and in different locations. Profitability of hop growing for at least 15 years is important for hop growers. Stability of the content and composition of hop essential oils and resins are key for breweries. New varieties are being tested in different hop growing locations.

2 Material and methods

Creation of hop varieties is based on the hybridisation method. Seeds from suitable parent components are sown in a greenhouse and young plants are tested in terms of their resistance to *Pseudoperonospora humuli* and *Sphaerotheca humuli*. Resistant and tolerant plants are planted in a breeding hop field. In the second year of cultivation, the best genotypes are selected for the second breeding stage. Upon a five-year evaluation, the best genotypes are propagated and planted three times in a testing nursery and later on as part of field and zoning experiments. At that stage, features important for hop growing and beer brewing are evaluated in greater detail. The best genotypes are submitted for registration experiments. New hop varieties are evaluated in breeding nurseries, field experiments and piloting areas. Mother plants are always original. Therefore, the performance of some hop varieties can be lower than that of virus-free plants (Nesvadba, 1999). At the moment, each variety is being monitored in a maintenance breeding program including a minimum of 40 plants. Every year, 10 mother plants are evaluated. Each mother plant is evaluated in terms of morphological features with regard being paid to any deviations from the uniformity of the particular hop variety.

The following parameters are evaluated for each variety: hop yield, content and composition of hop resins (EBC 7.4; Krofta K., 2008), content and composition of hop essential oils (based on liquid chromatography). Each plant is harvested separately. An experimental Volf picking machine is used for hop picking. Yield is shown in kg of fresh hops per plant (hereinafter: kg/plant). The conversion of hop yield is based on the number of plants per hectare, which amounts to 2,900 plants at a spacing of 1.14 × 3.00 m. The coefficient of dry matter in fresh hops and dry hops is 4. The following statistics were prepared: average (A), median (Med) and standard deviation (S). Relative amount of variability is used to compare a set with different levels. Resulting variability amounts are dimensionless numbers (mostly in %). This allows to compare the variability of statistical features differing in measure units. Coefficient of variation (CV), showing the extent of variability in %, was used for data processing. The t-test was applied to determine and prove the 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 (Meloun and Militký, 1994). For example, if the significance level is determined as $\alpha = 0.01$, it means there is a 99% probability that the sets under review are different.

Our evaluation was performed in the following locations:

1. The Ohře river basin – Rybňany and Stekník. There are alluvial soils in this location. Hop fields are irrigated.
2. The Rakovník region – Nesuchyně and Chrášťany. There are brown soils in this location. It is a rather dry area with no irrigation.
3. Údolí zlatého potoka (“Golden Creek Valley”) – Očihov. There are permian red soils at the Blšanka creek and no irrigation.
4. The Auscha region – Radovesice. This area has alluvial brown soils.

3 Results and discussion

Table 1 shows that the Saaz Shine and Saaz Comfort varieties have the highest average yields (2.16 t/ha and 2.11 t/ha respectively). The Saaz benchmark variety has the lowest yield (1.65 t/ha). Based on the t-test, Saaz Shine, Saaz Comfort, Mimosa and Saaz Brilliant have higher yields than Saaz with a probability of 99%. No statistical difference was determined between other varieties in terms of hop yield. Saaz Comfort has the lowest variability of hop yield (33.39%), whereas Saaz Shine has the highest (43.94%). The values of minimum and maximum yields have a broad range, which is due to the conversion of harvested plants per hectare. However, the results suggest that the new varieties can generate very high yields in good conditions.

Table 1 *Statistical parameters of hop yield (from 2005 to 2019)*

Parameter	Saaz Brilliant	Saaz Comfort	Saaz Shine	Mimosa	Saaz
A (t/ha)	1.91	2.11	2.16	1.93	1.65
Med (t/ha)	1.84	2.02	1.89	2.02	1.02
S	0.80	0.71	0.98	0.79	0.48
CV (%)	41.89	33.39	43.94	41.11	41.81
Min (t/ha)	0.85	1.04	1.18	0.70	0.59
Max (t/ha)	3.55	3.39	4.51	3.00	2.78

A – average; Med – median; S – standard deviation; CV - coefficient of variation; Min – minimal yield; Max – maximal yield.

The **Saaz Brilliant** variety has an average content of alpha acids of 3.77% with a variability of 18.95% (Table 2). The variability suggests that year and location contribute nearly 20% to the content of alpha acids. The median is 3.69%. The highest content of alpha acids was determined in 2017 in Chrášťany (Rakovník district) and amounted to 5.36%. A content of alpha acids exceeding 5% was determined in four additional locations in Očihov in 2014 (5.14% w.) and in Rybňany in 2009 and 2010 (5.09% w. and 5.10% w., respectively). In contrast, the lowest content of alpha acids (2.38% w.) was found in 2015 in Nesuchyně (Rakovník district). Out of 64 samples, 7 samples had an alpha acid content below 3% w. in Rybňany in the years 2013 to 2017 and one sample in Nesuchyně in 2015. The average content of beta acids is 2.75% w. and the median is 2.80% w. Variability is almost at the same level as that of alpha acid content, amounting to 19.26%. The lowest content of beta acids (1.60% w.) was determined in Nesuchyně in 2015 and the highest content of beta acids (4.03%) in Očihov in 2014. The average and median values of the alpha/beta ratio are almost identical, amounting to 1.39 and 1.38, respectively. Variability is 17.53%. The lowest alpha/beta acid ratio was found in Očihov in 2014 (0.97) and the highest in Očihov in 2015 (2.22). Such a high ratio was exceptional since the second highest alpha/beta acid ratio was 1.87 and was determined in Rybňany in 2015. The alpha/beta acid ratio is influenced by the year because in 2015 the average alpha/beta ratio was 1.67 (11 samples) and in 2014 it amounted to 0.98 (12 samples). The average content of cohumulone is 24.64% rel. and the median is 24.40% rel., with avariability of 9.09%. The lowest cohumulone content was determined in Rybňany in

Table 2 *Statistical parameters of hop resin content and composition, xanthohumol and DMX content in the Saaz Brilliant variety in the years 2005 to 2019*

Parameter	Alpha acids (% w.)	Beta acids (% w.)	Alpha/beta ratio	Cohumulone (% rel.)	Colupulone (% rel.)	X (% w.)	DMX (% w.)
A	3.77	2.75	1.39	24.64	44.50	0.21	0.04
Med	3.69	2.80	1.38	24.40	44.40	0.21	0.04
S	0.71	0.53	0.24	2.24	2.76	0.04	0.02
CV (%)	18.95	19.26	17.53	9.09	6.20	19.29	49.81
Min	2.38	1.60	0.97	20.80	39.50	0.13	0.02
Max	5.36	4.03	2.22	31.30	50.80	0.32	0.14

A – average; Med – median; S – standard deviation; CV – coefficient of variation; Min – minimal content; Max – maximal content; X – xanthohumol; DMX – desmethylxanthohumol.

2015 (20.80% rel.). A cohumulone content above 30% was determined only in 2011 during two sample-taking occasions in Rybňany. The low variability suggests that the cohumulone content has a genetic basis. However, it is likely that the cohumulone content can be influenced by the year. The average cohumulone content in 2011 amounted to 29.85% rel. (4 samples). In 2015, the average cohumulone content was as low as 22.75% rel. (11 samples). The average colupulone content is 44.50% rel. and the median is 44.40% rel., with a variability of only 6.20%. The lowest and highest colupulone contents were determined in the same samples as the corresponding cohumulone contents. The average and median values of xanthohumol content are identical, amounting to 0.21%, with a variability of 19.29%. Similarly, the average and median of of desmethylxanthohumol (DMX) content content are identical, namely 0.04%, with a high variability of 49.81%.

The **Saaz Comfort** variety has an average content of alpha acids of 5.59% w. and the median is 5.51% w. Content variability amounts to 18.19% (Table 3). The lowest content was determined in Rybňany in 2018 (3.39% w.). Out of 53 samples, 1 sample was below 4.00% w. The highest contents were found in Rybňany in the years 2010 (7.90% w.), 2009 (7.85% w.) and 2005 (7.80% hm.). Additional 12 samples have a content above 6.00% w. Unfortunately, in the years 2017 to 2019 the highest content of alpha acids was 5.44% w. and the average in the years 2017 to 2019 was only 4.56%, which is 1.03% w. less than the average since 2005. The average content of alpha acids is likely to be at 4.5% in the hop growing practice. The average content of beta acids is 5.67% w. and the median amounts to 5.51% w. Variability of the beta acid content is 22.64%. The lowest content of beta acids of 3.14% w. was determined in the same sample as the lowest content of alpha acids (in Rybňany in 2018) and amounted to 3.14% w. The highest content of beta acids of 8.57% w. was in 2014 (Očihov). This sample shows the lowest content of alpha acids (4.50% w.), and therefore the alpha/beta ratio is as low as 0.5. The average and median of the alpha/beta ratio are nearly at the same level (1.02 and 1.05, respectively). Variability is 22.64%. The lowest alpha/beta ratio was determined in Očihov in 2014 (0.50). In contrast, the highest ratio was in Rybňany in 2011 (1.58). The variety is characterized by a balanced alpha/beta ratio. The year influences the alpha/beta ratio of the Saaz Comfort variety as well. In 2014, the average alpha/beta ratio was 0.73. In 2015, it amounted to 1.24. The average content of cohumulone is 18.04% rel. and the median is 17.90% rel., with a variability of 11.09. The highest cohumulone content was determined in 2015 (26.20% rel.) and the lowest in 2018 (14.80% rel.) in Rybňany. The variability of the cohumulone content is 11.02%. Compared to the Saaz Brilliant variety, there are no substantial differences in average cohumulone contents between the individual years. The lowest cohumulone content was determined in 2012 and amounted to 15.80% rel. The highest cohumulone content was 19.08% rel. in 2015. The average colupulone content is 37.17% rel. and median is 36.50% rel., with a variability of 7.54%. In the same samples that were used to measure cohumulone content in Rybňany, the lowest cohumulone content was determined in 2014 (32.70% rel.) and the highest in 2015 (51.20% rel.). The average content of xanthohumol is 0.34, the median is 0.33 and content variability is 19.40%. The highest content of xanthohumol (0.64% w.) was found in Rybňany in 2015. Such a content is unique because the other samples do not exceed 0.50% w. The average and median of DMX content are identical and amount to 0.14%, with a variability of 42.69%. The highest content of DMX (0.34% w.) was determined in Rybňany in 2014.

Table 4 shows that the **Saaz Shine** variety has an average content of alpha acids of 3.56% w. The median is 3.37% w. and the variability of the content of alpha acids is 27.12%. The highest content of alpha acids was determined in Rybňany in the years 2016 (5.75% w.), 2015 (5.47% w.) and 2011 (5.30% w.). In

Table 3 *Statistical parameters of hop resin content and composition, xanthohumol and DMX content in the Saaz Comfort variety in the years 2005 to 2019*

Parameter	Alpha acids (% hm.)	Beta acids (% w.)	Alpha/beta ratio	Cohumulone (% rel.)	Colupulone (% rel.)	X (% w.)	DMX (% w.)
A	5.59	5.67	1.02	18.04	37.17	0.34	0.14
Med	5.51	5.51	1.05	17.90	36.50	0.33	0.14
S	1.01	1.22	0.23	2.00	2.80	0.07	0.06
CV (%)	18.19	21.57	22.64	11.09	7.54	19.40	42.69
Min	3.39	3.14	0.50	14.80	32.70	0.21	0.05
Max	7.90	8.57	1.58	26.20	51.20	0.64	0.34

A – average; Med – median; S – standard deviation; CV - coefficient of variation; Min – minimal content; Max – maximal content; X – xanthohumol; DMX – desmethylxanthohumol.

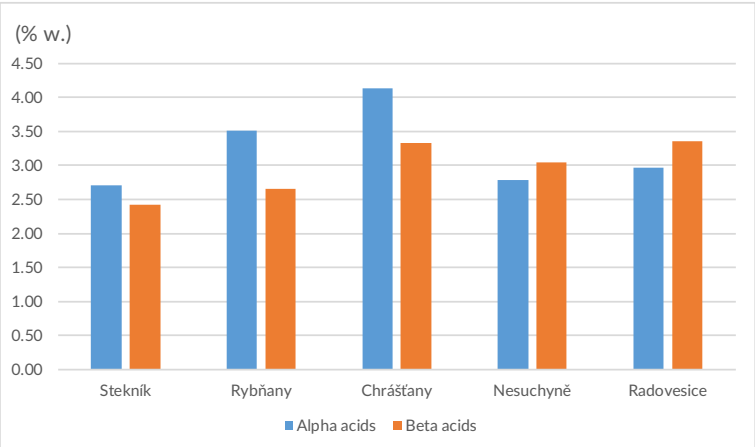
Table 4 *Statistical parameters of hop resin content and composition, xanthohumol and DMX content in the Saaz Shine variety in the years 2005 to 2019*

Parameter	Alpha acids (% hm.)	Beta acids (% w.)	Alpha/beta ratio	Cohumulone (% rel.)	Colupulone (% rel.)	X (% w.)	DMX (% w.)
A	3.56	2.95	1.23	24.30	45.13	0.36	0.04
Med	3.37	2.99	1.20	24.25	44.90	0.38	0.04
S	0.96	0.73	0.28	1.69	3.43	0.06	0.01
CV (%)	27.12	24.65	22.51	6.94	7.60	16.56	31.20
Min	2.17	1.15	0.88	20.30	38.80	0.24	0.02
Max	5.89	4.26	2.39	27.50	51.60	0.46	0.07

A – average; Med – median; S – standard deviation; CV - coefficient of variation; Min – minimal content; Max – maximal content; X – xanthohumol; DMX – desmethylxanthohumol.

contrast, the lowest content was determined in Rybňany in 2018 and it amounted to 2.17% w. A content of beta acid below 2% w. was determined in Rybňany in the years 2007 (1.15% w.) and 2018 (1.98% w.). A content of beta acids above 4% was found in Rybňany in 2016 (4.26% w.) and in Chrášťany in 2018 (4.04% w.). Figure 1 shows the content of alpha and beta acids in 2019 on five sites. The highest content of alpha acids was in Chrášťany (4.14% w.) and the highest content of beta acids was in Radovesice (3.36% w.). The lowest content of both alpha and beta acids was in Stekník (2.71% w. and 2.42% w., respectively). Even results from one year show the variability of the content of hop resins between the individual locations. The average content of alpha/beta acids is 1.23 and the median is almost identical (1.20), with a variability of 22.51%. The highest ratio was determined in a sample from Rybňany in 2007 (2.39). It was the only sample having an alpha/beta ratio above 2. The lowest alpha/beta ratio was determined in Radovesice in 2019 and amounted to 0.88. The average content of cohumulone is 24.30% rel., the median is 24.25% rel. and the variability of cohumulone content is 6.94%. The highest cohumulone content was in Nesuchyně in 2019, namely 27.50% rel. Additional 10 samples (out of a total of 33 analyses) have a cohumulone content above 25% rel. The lowest cohumulone content was determined in Stekník in 2019 (20.30% rel.). The average colupulone content is 45.13% rel., the median is 44.90% rel. and variability 7.60%. The highest cohumulone content was in Nesuchyně in 2019 (51.60% rel.) and the lowest in Rybňany in 2018 (38.50% rel.). The average content of xanthohumol is 0.36% w. and the median is 0.38% w. Variability is as low as 16.56%. The lowest content of xanthohumol was found in Stekník in 2018 (0.21% w.) and the highest in Chrášťany in 2019 (0.46% w.). The average content and the median of DMX are identical (0.04% w.) Variability amounts to 31.20%. The lowest content of DMX was in Rybňany in 2018 (0.02% w.) and the highest in Chrášťany in 2018 (0.07% w.). It is interesting that the variety shows the highest contents of xanthohumol (0.41% w. and 0.46% w., respectively) and DMX (0.07% w. and 0.06% w. respectively) in Chrášťany in the years 2018 and 2019.

Figure 1 *Content of alpha and beta acids in the Saaz Shine variety in 2019*



The **Mimosa** variety has an average content of alpha acids of 1.90% w. The median amounts to 1.75% w. Content variability is 42.41% (Table 5). The highest content of alpha acids was determined at the beginning of the breeding process, i.e. upon a selection from descendants after hybridisation. A high content of alpha acids was found in the years 2008 (3.80% w.), 2009 (4.84% w.) and 2010 (4.80% w.). After 2011, the highest content of alpha acids was determined in Rybňany in 2015 and amounted to 2.74%. It was probably due to a virus or viroid infection, which will be the subject of further research. After

Table 5 *Statistical parameters of hop resin content and composition, xanthohumol and DMX content in the Mimosa variety in the years 2008 to 2019*

Parameter	Alpha acids (% w.)	Beta acids (% w.)	Alpha/beta ratio	Cohumulone (% rel.)	Colupulone (% rel.)	X (% w.)	DMX (% w.)
A	1.90	6.07	0.31	29.29	55.98	0.34	0.06
Med	1.75	6.12	0.28	29.40	56.20	0.33	0.06
S	0.81	1.08	0.12	2.10	1.98	0.06	0.03
CV (%)	42.41	17.76	39.10	7.15	3.54	16.71	41.50
Min	0.82	4.34	0.18	21.20	50.10	0.24	0.03
Max	4.84	8.44	0.80	34.20	59.40	0.53	0.12

A – average; Med – median; S – standard deviation; CV – coefficient of variation; Min – minimal content; Max – maximal content; X – xanthohumol; DMX – desmethylxanthohumol.

2011, the average content of alpha acids was 1.74% w., thus reducing the variability to 28.38%. The Mimosa variety is characterized by a low content of alpha acids. Out of 47 samples, 13 samples have an alpha acid content below 1% w. The lowest content of alpha acids (0.82% w.) was determined in Rybňany in 2018. The average content of alpha acids is 6.07 and the median is higher, namely 6.12% w. The content of beta acids has a low variability (17.76%). The content of beta acids is not influenced by the age of the plant in the same way as the content of alpha acids since the content of beta acids was 5.79–7.82% w. in the years 2008 to 2010. The highest content of beta acids was found in Rybňany in 2015 (8.44% w.). In contrast, the lowest content of beta acids was determined in Rybňany in 2019 (4.34% w.). Mimosa is characterized by a low alpha/beta ratio. The average is 0.31, the median is 0.28 and variability 39.10%. The highest ratio (0.8) was found in samples from the years 2009 and 2010, which have a high content of alpha acids and beta acids (5.76% w. and 5.80% w., respectively). Samples with an alpha/beta ratio below 0.2 also have a high content of beta acids, namely 4.34–6.33% w. The average content of cohumulone is 29.29% rel., the median is 29.40 and variability is 7.15%. The lowest content of cohumulone of 21.20% rel. determined in Rybňany in 2014 was exceptional because other samples have a cohumulone content above 25% rel. The highest content was found in Rybňany in 2017, namely 34.20% rel. The average colupulone content is 55.98% rel., the median is 56.20% rel. and variability is very low (3.54%). The lowest colupulone content was found in a sample from Rybňany in 2018 (50.10% rel.) and the highest colupulone content was in a sample from Rybňany in 2010 (59.40% rel.). The average and median of the xanthohumol content are almost identical (0.34% w. and 0.33% w., respectively) and those of DMX content are identical (0.06% hm.). Content variability is very different. With respect to xanthohumol content it amounts to 16.71% and for DMX content it is 41.50%. The highest contents of xanthohumol (0.53% w.) and DMX (0.12% w.) were determined in Rybňany in 2015. The lowest contents of xanthohumol (0.24% w.) and DMX (0.03% w.) were found in 2018.

Figure 2 *Average contents of alpha and beta acids in the new aroma varieties and the Saaz benchmark variety*

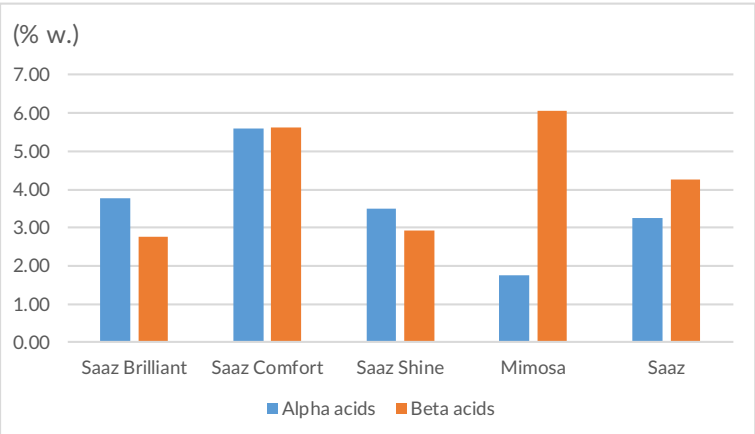


Figure 2 shows average contents of **alpha and beta acids** of the hop varieties under review compared to the standard variety Saaz. With a probability of 99%, the Saaz Comfort variety has a higher content of alpha acids (5.59% w.) than the other varieties. In contrast, with a probability of 99%, the Mimosa variety has a significantly lower content of alpha acids (1.90% w.). No statistical difference could be determined between the Saaz Brilliant, Saaz Shine and Saaz varieties. The Mimosa variety has a significantly higher content of beta acids compared to the Saaz Comfort variety with a 90% probability and compared to the Saaz, Saaz Shine and

Saaz Brilliant varieties with a 99% probability. The Saaz Comfort variety has a significantly higher content of beta acids than Saaz, Saaz Shine and Saaz Brilliant with a 99% probability. Saaz has a significantly higher content of beta acids than Saaz Shine and Saaz Brilliant with a 99% probability. No statistically significant difference in the content of beta acids was determined between Saaz Shine and Saaz Briliant. Average alpha/beta ratios of Saaz Brilliant (1.39), Saaz Shine (1.23), Saaz Comfort (1.02), Saaz (0.84) and Mimosa (0.31) are significantly different with a 99% probability. A variability of the alpha acid content below 20% was found with respect to the Saaz Comfort and Saaz Brilliant varieties. The other varieties – Saaz Shine, Mimosa and Saaz – have a variability of the content of alpha acids above 25% (Figure 3). The variability of the content of beta acids is the lowest in Mimosa (17.76%) and the highest in Saaz Shine (24.65%).

Figure 3 *Average variability of the content of alpha and beta acids in the new aroma varieties and the Saaz benchmark variety*

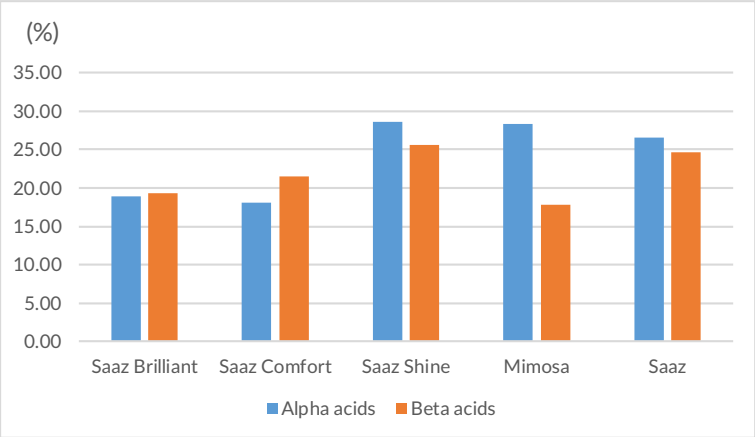


Figure 4 *Average content of cohumulone and its variability in the new aroma varieties and the Saaz benchmark variety*

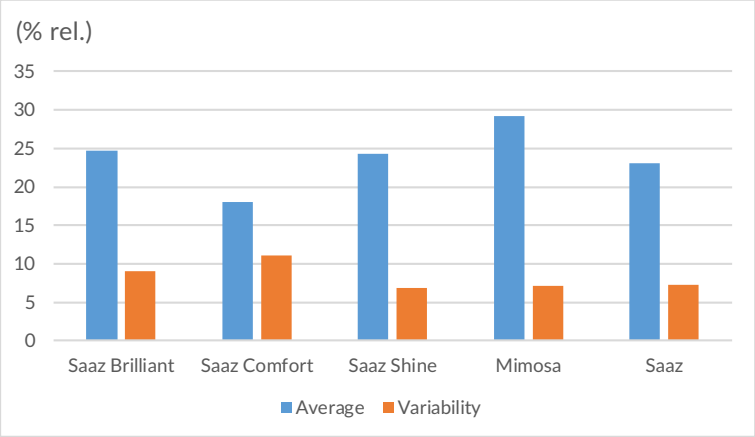


Figure 5 *Average content of xanthohumol and DMX in the new aroma varieties and the Saaz benchmark variety*

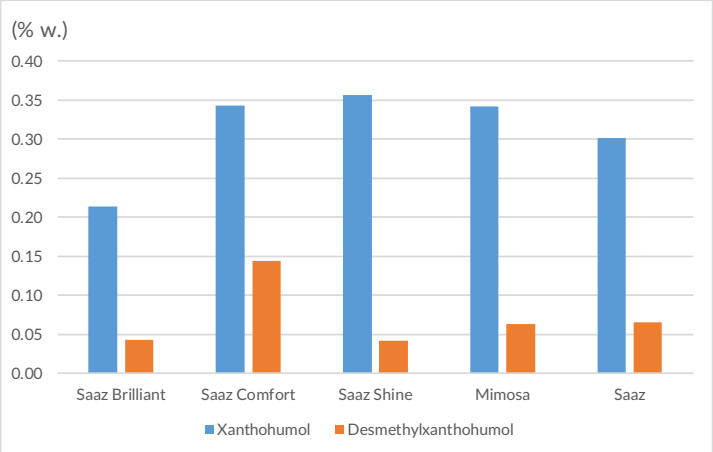


Figure 4 shows that Mimosa has the highest average content of **cohumolone** (29.29% rel.) and Saaz Comfort the lowest content of cohumulone (18.04% rel.). For all the varieties, except for Saaz Brilliant and Saaz Shine, a significant difference in cohumulone was determined compared to Saaz with a 99% probability. The lowest variability of the cohumulone content was determined in Saaz Shine (6.84%), Mimosa (7.15%) and Saaz (7.25%). Only Saaz Comfort has a variability of the cohumulone content above 10%.

The Saaz Brilliant variety has the significantly lowest content of **xanthohumol** compared to the other varieties (Figure 5) with a 99% probability. Saaz has a significantly lower xanthohumol content with respect to Saaz Shine with a 99% probability and with respect to Saaz Comfort and Mimosa with a 98% probability. No statistical significance of the difference in the xanthohumol content was determined between the Saaz Shine, Saaz Comfort and Mimosa varieties. With a probability of 99%, Saaz Comfort has the significantly highest DMX content compared to the other varieties. No significant difference in the DMX content was established between Saaz and Mimosa. However, both varieties have a significantly higher DMX content than Saaz Brilliant and Saaz Shine with a probability of 99%. No significant difference

was established between Saaz Brilliant and Saaz Shine. The xanthohumol/alpha ratio is very interesting. The ratio of xanthohumol and alpha acid content is also crucial. It states how many grams of xanthohumol are contained in 100 g of alpha acids. Breweries hop beer according to the content of alpha acids. Mimosa has the highest xanthohumol/alpha ratio, namely 19.6 (Figure 6). When 100 g of alpha acids are used per 1000 l of beer for hopping, this variety contains 12 g of xanthohumol. Almost identical xanthohumol/alpha ratios were found in Saaz Shine (10.2) and Saaz (9.2). The lowest xanthohumol/alpha ratios were determined in Saaz Comfort (6.1) and Saaz Brilliant (5.7).

Figure 7 shows that the highest average content of **hop essential oils** was determined in Saaz Comfort (0.84% w.) and Saaz Shine (0.75% w.). No significant difference in the content of hop essential oils was found between these two varieties. With a probability of 99%, Mimosa has a lower content of hop essential oils than Saaz Comfort. No statistical significance of the difference in hop essential oil content was determined for Saaz Shine. With a probability of 99%, the significantly lowest content of hop essential oils was determined for Saaz Brilliant (0.52% w.) and Saaz (0.51% w.) compared to the other varieties. There is no significant difference in the content of hop essential oils between Saaz Brilliant and Saaz.

The highest **myrcene** content was found in Mimosa (30.46% rel.). It shows a significant difference compared to Saaz Shine and Saaz Brilliant with a probability of 90% and compared to Saaz with a probability of 99%. Saaz Comfort has an average myrcene content of 28.05% rel. However, only compared to Saaz, there is a significant difference in the myrcene content with a probability of 99%. The lowest contents were found in Saaz (22.04% rel.), Saaz Brilliant (24.99% rel.) and Saaz Shine (25.11% rel.). No significant difference was determined between the varieties. The significantly highest **caryophyllene** content was found in Saaz Shine (10.30% rel.), compared to Saaz, Saaz Comfort and Mimosa with a 99% probability. In contrast, the lowest caryophyllene content was determined in Mimosa (6.05% rel.) with a probability of 99%. There is no statistical difference in the average contents of Saaz Brilliant (9.07% rel.), Saaz (8.40% rel.) and Saaz Comfort (8.23% rel.). With a 99% probability, the significantly highest average content of **farnesene** was found in Saaz (13.47% rel.), Saaz Shine (12.50% rel.) and Saaz Brilliant (12.38% rel.), compared to Saaz Comfort and Mimosa. With a 99% probability, Saaz Comfort has a significantly higher farnesene content (4.70% rel.) than Mimosa (0.84% rel.). The average content of **humulene** in Saaz Shine (28.81% rel.) is significantly higher compared to Saaz with a 95% probability and compared to Saaz Brilliant, Saaz Comfort and Mimosa with a 99% probability. There is no statistical difference in the average content of humulene between Saaz (25.00% rel.) and Saaz Brilliant (23.98% rel.). In Saaz Comfort the average content of humulene (16.68% rel.) is significantly lower than that in Saaz Shine, Saaz and Saaz Brilliant with a 99% probability. In Mimosa the average content of humulene (3.39% rel.) is significantly lower than that in other varieties under review with a 99% probability. The average con-

Figure 6 *Average ratios of xanthohumol/alpha acids in the new aroma varieties and the Saaz benchmark variety*

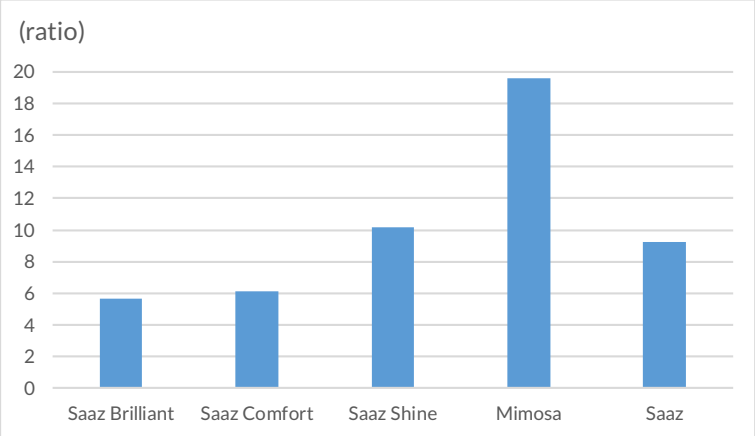
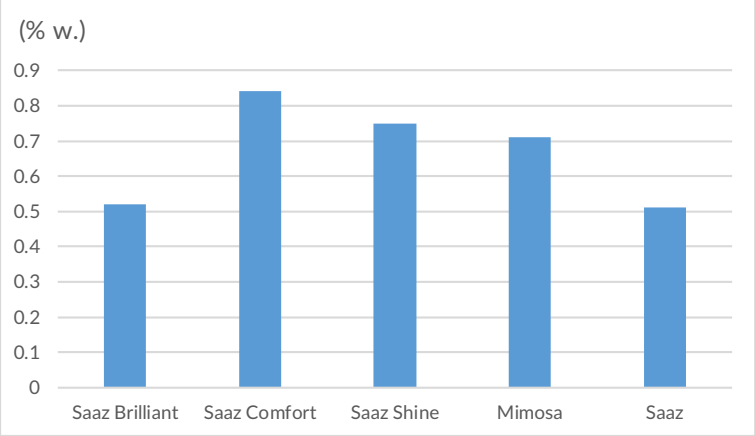


Figure 7 *Average content of hop essential oils in the new aroma varieties and the Saaz benchmark variety*



tent of **selinenes** in Mimosa (32.98% rel.) is significantly higher than that of the other varieties with a 99% probability. Saaz Comfort has a significantly higher content of selinenes (16.91% rel.) than Saaz Brilliant, Saaz and Saaz Shine with a probability of 99%. Saaz Brilliant has a significantly higher content of selinenes (4.06% rel.) than Saaz and Saaz Shine with a 98% probability. There is no statistical difference in the average contents of selinenes in Saaz (2.34% rel.) and Saaz Shine (2.13% rel.).

Table 6 shows the ranges of hop essential oil content and composition. The Saaz Shine, Mimosa and Saaz Comfort varieties show contents of hop essential oils above 1% w. The ranges of myrcene content make it clear that all varieties can have a myrcene content above 30% rel. Mimosa exceeded 40% rel. in Rybňany in 2015. In contrast, Mimosa did not exceed 10% rel. with respect to caryophyllene compared to the other varieties. All varieties (except for Mimosa) have a farnesene content above 10%. In 2018, only Saaz Shine in Chrášťany and Saaz in Rybňany exceeded 20% rel. The selinene contents vary greatly. Mimosa has a selinene content of 22–44% rel., Saaz Comfort 11–26% rel. and the other varieties have a selinene content below 10% rel.

Figure 8 *Composition of hop essential oils in the new aroma hop varieties and the Saaz benchmark variety*

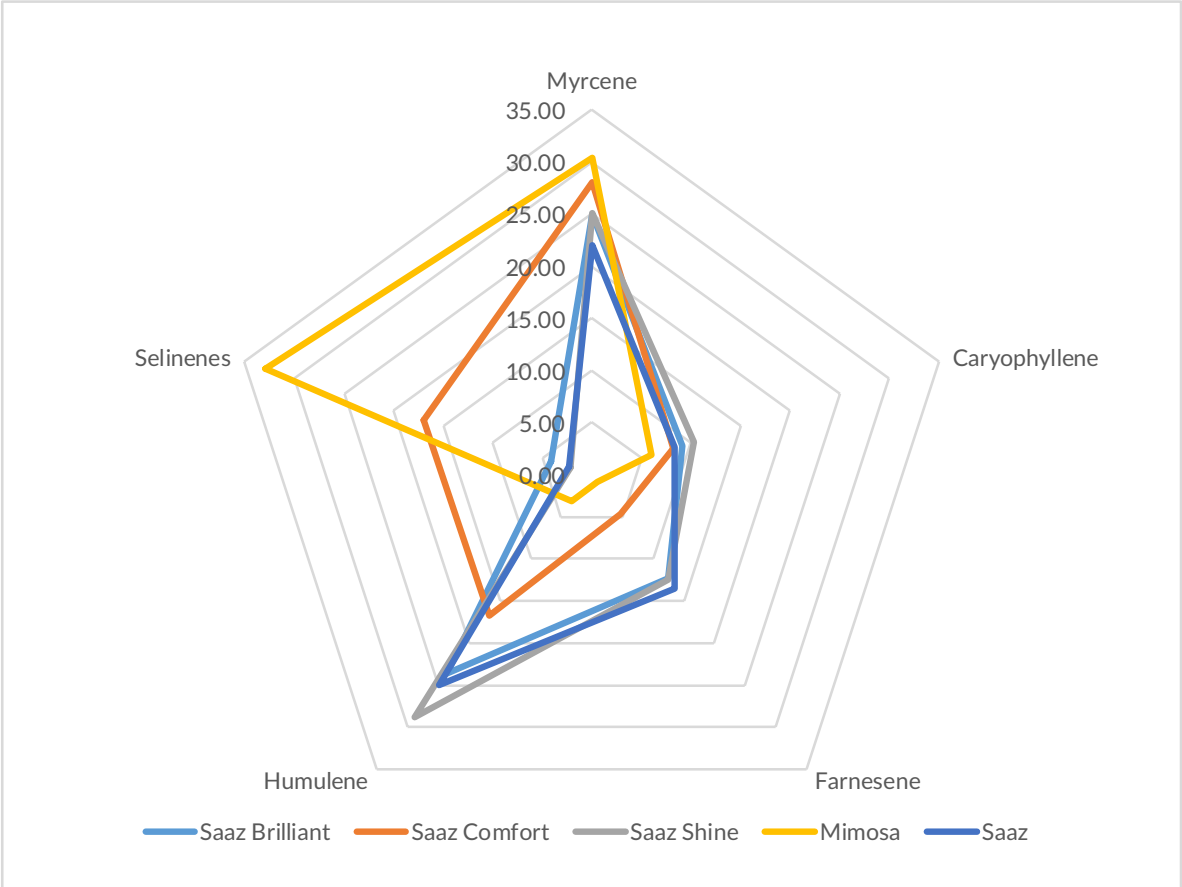


Table 6 *Content and composition of hop essential oils in the new aroma varieties compared to Saaz in the years 2005 to 2019.*

Parameter	Saaz Brilliant	Saaz Comfort	Saaz Shine	Mimosa	Saaz
Content (% w.)	0.3–0.8	0.4–1,1	0.5–1.3	0.5–1.2	0.3 –0.9
Myrcene (% rel.)	11–34	14–36	12–35	16–42	11–32
Caryophyllene (% rel.)	7–14	6–12	7–15	5–8	5–12
Farnesene (% rel.)	7–17	2–14	7–20	below 3.5	8–20
Humulene (% rel.)	14–33	10–20	22–39	below 12	15–43
Selinenes (% rel.)	1–9	11–26	below 3	22–44	1–6

4 Conclusion

The results show quantitative and qualitative parameters of new hop varieties. The results can be compared to the Saaz variety on the basis of statistical significance. Table 7 shows a higher or lower significance of the difference between the aroma hop varieties under review and the benchmark variety (Saaz). Saaz Brilliant has identical parameters as Saaz in terms of the content of alpha acids, cohumulone content, the content of hop essential oils and myrcene, caryophyllene and farnesene contents. The Saaz Shine variety has numerous identical parameters as well, including hop yield, cohumulone content and the contents of myrcene, farnesene, humulene and selinenes. The Saaz Comfort and Mimosa varieties have only one identical parameter (caryophyllene content and DMX content, respectively). It is important for hop growing that all the new varieties have significantly higher hop yields. The Saaz Comfort variety has a significantly higher content of alpha acids and together with the Mimosa variety significantly higher contents of beta acids than Saaz. All varieties except Saaz Brilliant have significantly higher hop essential oil contents. The newly registered varieties are not identical with Saaz. However, Saaz is substantially represented in their origin, and therefore "Saaz" is part of their names: Saaz Brilliant, Saaz Comfort and Saaz Shine. The Mimosa variety is considerably different from Saaz and its brewing applications differ as well. In conclusion, it is necessary to mention that the results are merely partial. They are based on evaluations performed for 15 years (12 years for Mimosa) but the samples were taken in six locations only.

The results achieved in comparison with Saaz clearly show that these hop varieties do not have identical parameters. They fall within the category of fine aroma hops but are not identical with the Saaz benchmark variety.

The Saaz Brilliant, Saaz Comfort and Saaz Shine varieties are currently being tested in pilot experiments in Chrášťany, Stekník, Běsno, Nesuchyně and Staňkovice. For several years, all of the new varieties have been tested in large and small Czech breweries. 100–300 kg of hops are available from experimental growing areas for brewing tests. The Saaz Brilliant, Saaz Comfort and Saaz Shine varieties will be planted in the fall of 2020 on two hectares of hop fields in Chrášťany.

5 Acknowledgement

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Table 7 *Significant differences of evaluated aroma varieties compared to Saaz*

Parameter	Saaz Brilliant	Saaz Comfort	Saaz Shine	Mimosa
Yield	Higher (99%)	Higher (99%)	Higher (99%)	Higher (99%)
Alpha acids	–	Higher (99%)	–	Lower (99%)
Beta acids	Lower (99%)	Higher (99%)	Lower (99%)	Higher (99%)
Alpha/beta ratio	Higher (99%)	Higher (99%)	Higher (99%)	Lower (99%)
Cohumulone	–	Lower (99%)	–	Higher (99%)
Xanthohumol	Lower (99%)	Higher (98%)	Higher (99%)	Higher (98%)
DMX	Lower (99%)	Higher (99%)	Lower (99%)	–
Content of hop essential oils	–	Higher (99%)	Higher (99%)	Higher (99%)
Myrcene	–	Higher (99%)	–	Higher (99%)
Caryophyllene	–	-	Higher (98%)	Lower (99%)
Farnesene	–	Lower (99%)	–	Lower (99%)
Humulene	Higher (95%)	Lower (99%)	–	Lower (99%)
Selinenes	Higher (99%)	Higher (99%)	–	Higher (99%)

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