



# New Czech Hop Cultivars Art and Uran: A Step Toward Drought-Resistant Hops with High Brewing Potential

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## Abstract

Two new Czech hop cultivars, Art and Uran, were developed within the national hop breeding program of the Czech Republic to improve drought tolerance while maintaining high brewing quality. The cultivars were evaluated for agronomic performance, chemical composition, and sensory properties in both hops and beer. Drought tolerance was assessed by measuring photosynthesis (A) and transpiration (T) rates under water stress using a portable photosynthesis system, complemented by visual evaluation. Art showed the highest drought resistance, maintaining photosynthetic activity and minimal stress symptoms even after ten days without irrigation. The chemical composition of both cultivars was stable. Art contained on average 5.8% w/w of alpha acids with a balanced alpha/beta acid ratio of 1.07, while Uran reached 11.9% w/w and a ratio of 2.34, confirming its classification among bitter hops. Art expressed a fine aroma–flavour character with citrusy and herbal tones, whereas Uran combined bitter and flavour attributes with woody and spicy notes. In brewing trials, both cultivars effectively transferred their aroma into beer. Art produced a delicate bitterness with fruity–herbal notes, while Uran yielded a moderate bitterness with hoppy–woody tones. Both represent promising, drought-tolerant cultivars expanding the diversity of Czech hops.

**Keywords:** hops; hop breeding; Uran; Art; climate change; draught tolerance; beer aroma

## 1 Introduction

The Czech Republic ranks as the third most important hop producer worldwide, following the United States and Germany, and is particularly renowned for the exceptional quality of its fine aroma hop cultivar, Saaz. This cultivar is characterized by its fine hop aroma, a balanced ratio of alpha to beta acids, and a notably high proportion of farnesene (8–20%) (Olšovská et al., 2024a). As a “fine aroma” hop, Saaz is indispensable for brewing high-quality lager beers (Olšovská et al., 2024b). Currently, Saaz is cultivated on 3,952 ha, representing approximately 82% of the total hop-growing area in the Czech Republic (CISTA, 2025). Due to its outstanding brewing and aroma

properties, Saaz has become the genetic foundation for breeding new aroma hop cultivars.

The first hybridizations were performed in the 1950s as a minor component of the breeding program focused on the genetic improvement (reselection within the Saaz population) of Saaz (Linhart and Nesvadba, 1994). Until that time, conventional crossing techniques had not been a breeding priority, as Saaz dominated Czech hop cultivation. The first registration of hybrid hop varieties, Bor, Sládek, and Premi-ant, therefore occurred relatively late – between the 1980s and early 1990s (Rigr et al., 1997). Since 2004, additional Czech aroma cultivars have been registered, including Har-

monie, Bohemie, and Saaz Late (Nesvadba and Charvátová, 2021). In recent years, hop breeding has focused on developing varieties with improved drought tolerance. This effort led to the registration of two new fine aroma cultivars, Saaz Shine and Saaz Comfort, in 2019 – both genetically derived from Saaz (Olšovská et al., 2024a; Nesvadba and Charvátová, 2020). Among them, Saaz Shine shows strong potential, being increasingly adopted by both craft and industrial breweries, and by 2025 its cultivation area has expanded to nearly 10 ha (Olšovská et al., 2024b).

After 2000, Czech hop breeding underwent substantial conceptual changes, adopting new objectives to satisfy the needs of both hop growers and brewers. The foundation of this breeding program lies in the rich collections of hop genetic resources (Charvátová et al., 2017) and wild hop accessions (Nesvadba et al., 2009). One of the key goals was the development of the first bitter-type hops, achieved in 2001 with the registration of the cultivar Agnus (Nesvadba and Krofta, 2002). Subsequent bitter cultivars – Rubín (2007), Vital (2008), Boomerang, and Gaia (2017) – expanded this group (Nesvadba et al., 2023, 2020). The most widely cultivated bitter variety, Agnus (72 ha), is known for its strong hop aroma with subtle spicy notes, high essential oil and beta acid content, and an alpha/beta acid ratio of approximately 2.

Further breeding efforts focused on the development of “flavour” hop cultivars. The first of these, Kazbek, was registered in 2008, followed by Mimosa in 2019 (Nesvadba and Charvátová, 2020; Krofta et al., 2019). Kazbek is currently cultivated on 17.6 ha and is distinguished by its high yield potential (up to 3 t/ha) and intense citrus aroma (Krofta et al., 2019). In 2022–2023, a new generation of Czech flavour hops – Juno (2022), Ceres (2023), Saturn (2023), Jupiter (2023), Eris (2023), and Pluto (2023) – was registered. These varieties exhibit distinctive fruity, citrus, spicy, and woody notes and have already been successfully implemented in the brewing process of several Czech breweries.

A crucial step in the characterization of new hop varieties involves brewing trials that assess their technological and sensory performance in beer production. These trials typically include direct comparisons between new and reference cultivars through single-hop beers, where bitterness character and mouthfeel are evaluated (Nesvadba et al., 2021). In the case of flavour hops, special attention is given to the transfer of aroma compounds from hops to beer (Dresel et al., 2015; Nance and Setzer, 2011), as well as to the bitterness profile under dry-hopping conditions (Straková et al., 2020). Such studies are of great importance for brewing practice, particularly when evaluating hop combinations and synergistic aroma transfer (Nesvadba et al., 2023).

Since 2021, Czech hop breeding has increasingly focused on climate resilience – particularly drought tolerance. New breeding material is systematically tested for drought response, supported by a recently developed and published methodology for determining hop genotype tolerance to water deficit (Olšovská et al., 2024a; Olšovská et al., 2023). This approach has been applied both to Saaz-derived cultivars and to new genotypes. Promising lines are subsequently evaluated for agronomic performance and brewing quality. These efforts have led to the registration of two new hop varieties registered in 2025, Art and Uran, both exhibiting high drought tolerance.

The objective of this study is to evaluate the agronomic and quality characteristics of these two new hop varieties, assess their drought tolerance, and determine their aroma transfer into beer through brewing trials. This comprehensive characterization represents a key step for the successful integration of new Czech hop cultivars into brewing practice.

## 2 Materials and methods

### 2.1 Characterization of Evaluated Hop Varieties

A set of hop (*Humulus lupulus* L.) genotypes was selected for testing drought tolerance. The selected genotypes exhibited low interannual variability in both hop yield and hop resin content. These genotypes were vegetatively propagated and tested for drought tolerance under greenhouse conditions using the gasometric method. This method is based on measuring the rate of photosynthesis and transpiration after irrigation cessation and after 10 days of water stress, including visual evaluation of plant condition (Olšovská et al., 2024a; Olšovská et al., 2023). For this purpose, an LCpro SD portable photosynthesis system (ADC Bioscientific Ltd., UK) was used.

Based on the obtained results, six promising hop genotypes (5165, 5304, 5432, 5461, 5465, and 5559) were selected for field testing during official registration trials. As a result of long-term evaluation, two new hop varieties – Art (genotype 5559) and Uran (genotype 5165) – were officially registered.

**Art** (crossing year 2013) originated from the progeny of the cultivar Kazbek and the male parent 03/3, a multiple hybrid combination of American, European bitter varieties, and Saaz. The reference cultivar used for comparison was Saaz. The plant exhibits a vigorous cylindrical growth habit with medium-length laterals. Cones are compact and of medium size. The variety is classified as mid-late in maturity. The average hop yield ranges between 1.8 and 2.6 t·ha<sup>-1</sup>.

**Uran** (crossing year 2006) originated from the progeny of hybrid crosses involving American and European bitter cultivars and open pollination. The reference cultivar used for comparison was Agnus. The plant displays an inverted conical growth habit with reddish-purple bine coloration and long laterals. Cones are firm and large. The variety is also classified as mid-late in maturity. The average hop yield ranges between 2.1 and 2.8 t·ha<sup>-1</sup>.

Field trials were conducted at the hop breeding stations in Stekník (GPS 50.3299241, 13.5957385) and Nesuchyně (GPS 50.1838557, 13.6883724), located in the Žatec hop-growing region of the Czech Republic.

## 2.2 Evaluation of Drought Tolerance

Five plants of each genotype were propagated and planted in 5 L pots filled with a standard growing substrate. Three plants in the most similar growth phase were selected for measurement. The initial measurements of all genotypes were taken on well-irrigated plants that had not been subjected to drought stress. After this baseline measurement, irrigation was stopped, and the effect of drought stress on the visual and physiological responses of the plants was monitored using a portable photosynthesis system LCpro-SD (ADC Bio-Scientific Ltd., UK).

Ten days after the first measurement, the same plants were measured again. The rates of photosynthesis (A) and transpiration (T) were determined under conditions of water and partial heat stress (greenhouse conditions), where plants were unable to compensate for heat load by evaporative cooling due to the lack of irrigation.

Simultaneously with the measurement of A and T, a visual evaluation (V) was performed after ten days of stress, according to the following scale:

- (1) negligible growth retardation; slightly yellowish lower leaves; minimal drought symptoms;
- (2) slowed growth; plants with yellowish lower leaves; fast regeneration after watering;
- (3) wilted leaves; dried lower leaves; growth stopped; regeneration and continued growth after watering;
- (4) completely dried-up plants; no regeneration after watering (Olšovská et al., 2024a).

## 2.3 Chemical Parameters of Evaluated Hops

The performance evaluation of hop cultivars was carried out between 2011 and 2025. Each cultivar was represented by eight plants. At technological maturity, all plants were harvested, and a composite sample was prepared for chemical analyses. The samples were dried at 55 °C to a final moisture content of approximately 7%.

The content and composition of hop resins were determined according to the official EBC analytical methods using liquid chromatography with UV detection (Analytica EBC, 2018), while essential oil content was analyzed by liquid chromatography coupled with mass spectrometric detection (LC-MS) (Krofta, 2003).

Basic statistical methods were applied to evaluate the obtained data, including the calculation of mean, standard deviation, and variability expressed as the coefficient of variation (in %). The significance of differences in alpha acid and essential oil contents was assessed using a paired t-test comparing results obtained within the same year to account for year-to-year variability. To determine trends in the traits over the eleven-year cultivation period, linear regression analysis was applied, and the strength of the relationship was expressed by the coefficient of determination ( $r^2$ ). The percentage value of  $r^2$  represents the proportion of variability in the trait explained by the time series (Meloun and Militký, 1994).

## 2.4 Sensory Analysis of Hops

After harvest, dried hop samples were subjected to sensory evaluation focused on aroma characteristics. The intensity of specific aroma descriptors – hoppy, citrus, fruity, floral, herbal, grassy, spicy, and woody – was scored on a 0–10 point scale (0 = none; 10 = very strong). The results were visualized using a radar (spider) plot.

The sensory panel consisted of 46 trained assessors (balanced gender ratio, 1:1; age range 20–65 years). Each assessor evaluated all hop samples under controlled sensory laboratory conditions to ensure reproducibility and minimize bias.

## 2.5 Brewing Trial

Hop cones were harvested at the stage of technological ripeness and dried at a temperature of 55–60 °C. The dried material was packed under an inert atmosphere and stored at 0 °C. Just before analysis and brewing, the hop cones were ground.

The beer samples (250 L each) were prepared in the research brewhouse of Kaspar-Schulz (Germany). The grist composition for each brew consisted of 31.5 kg of Pilsner malt (Benešov, Czech Republic) with an extract content of 81.5% (dry basis) and a color of 4.2 EBC units. A single-decoction mashing regime was used, with mash-in and mash-out temperatures of 35 °C and 77 °C, respectively. The maximum turbidity of the sweet wort was adjusted to 20 EBC, and the final turbidity to 50 EBC. The sweet wort volume before boiling was 210 L.

Single-kettle hopping with 100% of the tested hop variety was performed in three additions over a 75 min boiling period: 40% at the beginning of boiling, 35% at

the 20th minute, and 25% at the 15th minute before the end of boiling. Additional hops were added to the whirlpool at a dosage of  $1 \text{ g}\cdot\text{L}^{-1}$  to enhance the hop aroma.

Beer samples were fermented identically at  $12 \text{ }^\circ\text{C}$  with *Saccharomyces pastorianus* yeast strain W34/70 (Fermentis, France) in cylindroconical tanks for seven days. Maturation took place at  $2 \pm 0.5 \text{ }^\circ\text{C}$  for 21 days. Finally, the samples were filtered using a plate filter with S10N filter sheets (Hobra Školník, Broumov, Czech Republic) and bottled under oxygen-free conditions. The beers were filled into 0.5 L glass bottles and stored in a refrigerator at  $7 \pm 1 \text{ }^\circ\text{C}$ . The samples were subjected to sensory evaluation one week after bottling.

Brewing trials were performed in three consecutive harvest years (2022, 2023, and 2024), and the obtained data were jointly evaluated.

### 2.6 Sensory Analysis of Beer – Bitterness and Hop Aroma

Sensory analyses of beers brewed with the evaluated hop varieties were carried out by a professional 12-member sensory panel. The assessors were selected and trained according to ISO 8586:2023 and ISO 11132:2021 standards (ISO 8586, 2023; ISO 11132, 2021). All evaluations were conducted in a sensory laboratory equipped in compliance with ISO 8589:2007 (ISO 8589, 2007).

Assessors were trained using certified beer flavor standards (FlavorActive™, Oxfordshire, UK). Beer samples were served in glass cups (volume  $\approx 100 \text{ mL}$ ) at  $10 \pm 2 \text{ }^\circ\text{C}$ .

Bitterness intensity was evaluated on a five-point sensory scale (1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high), while the bitterness character was assessed on a five-point qualitative scale (1 = very mild, 2 = mild, 3 = moderate, 4 = rough, 5 = very rough). The sensory analyses were performed on beer samples obtained from the brewing trials conducted in 2022, 2023, and 2024, and the results were averaged for evaluation.

## 3 Results and discussion

### 3.1 Evaluation of Tolerance to Water Stress

Table 1 shows the evaluation of hop plants exposed to water stress. The assessment focused on the rate of photosynthesis (A), rate of transpiration (T), and visual evaluation (V). For comparison, the results of the new cultivars Art and Uran are presented alongside those of the reference fine aroma variety Saaz, the existing aroma varieties Sládek and Premiant, the bitter variety Rubín, and the recently registered “flavour” varieties Ceres, Juno, and Saturn.

The results clearly show that the traditional varieties Saaz, Premiant, and Sládek exhibit the weakest tolerance to water stress. After ten days without watering, they displayed A close to zero and a very low T, while V (4) corresponded to completely dried-up plants with no regeneration after re-watering. The cultivar Sládek showed a very similar pattern.

In contrast, the new “flavour” hop varieties Ceres, Juno, and Saturn demonstrated very good tolerance to water stress. After a ten-day drought period, they maintained relatively high A and T values, confirming that photosynthetic activity was still ongoing. The visual score for these cultivars was 2, which corresponds to slowed growth, plants with slightly yellowish lower leaves, and fast regeneration after re-watering. It can be seen that the “flavour” hop varieties Juno, Saturn, and Ceres have a higher rate of photosynthesis and a lower rate of transpiration than the other aromatic and traditional hop varieties, resulting in a better visual evaluation.

A similar visual evaluation was recorded for the new cultivar Uran, which also exhibited satisfactory A ( $4.88 \text{ } \mu\text{mol CO}_2/\text{m}^2/\text{s}$ ) and T ( $1.32 \text{ mmol H}_2\text{O}/\text{m}^2/\text{s}$ ) val-

**Table 1** Assessment of plants for water stress

Variety	Initial measurement			Measurement after 10 days of stress		
	A ( $\mu\text{mol CO}_2/\text{m}^2/\text{s}$ )	T ( $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$ )	V	A ( $\mu\text{mol CO}_2/\text{m}^2/\text{s}$ )	T ( $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$ )	V
Saaz	8.23	2.13	2	0.00	0.25	4
Sládek	11.02	2.35	1	0.00	0.43	3
Premiant	7.14	1.59	2	0.00	0.48	4
Rubín	6.69	1.51	1	0.00	0.45	4
Ceres	12.06	2.79	1	1.99	0.19	2
Juno	12.80	2.42	1	1.55	0.24	2
Saturn	7.65	2.32	1	3.26	0.78	2
Uran	8.25	2.03	2	4.88	1.32	2
Art	9.62	2.45	1	9.05	1.69	1

ues.

The highest tolerance to water stress was observed in the new cultivar Art, which, even after ten days of drought, achieved a visual score of 1, corresponding to negligible growth retardation, slightly yellowish lower leaves, and minimal drought symptoms. The cultivar also maintained very high physiological activity, with A of 9.05  $\mu\text{mol CO}_2 \text{ m}^2/\text{s}$  and T of 1.69  $\text{mmol H}_2\text{O m}^2/\text{s}$ , values nearly identical to those measured before stress (A 9.62  $\mu\text{mol CO}_2 \text{ m}^2/\text{s}$ ; T 2.45  $\text{mmol H}_2\text{O m}^2/\text{s}$ ).

These results indicate that Art is a highly promising cultivar with strong potential for long-term drought tolerance.

### 3.2 Evaluation of the Content and Composition of Hop Resins

The variety Art showed an average alpha acid content of 5.82% w/w and beta acid content of 5.50% w/w, corresponding to an average alpha/beta acid ratio of 1.07 (Table 2). The lowest alpha acid content was recorded in 2019 (5.08% w/w), while the highest was observed in 2024 (6.80% w/w), data not shown. This variety is characterized by a relatively low average proportion of cohumulone (21.10% rel.) and colupulone (42.67% rel.). Both cohumulone and colupulone contents showed high stability, with variability coefficients of only 6.2% and 4.4%, respectively. The variability of alpha acids (11.6%) and beta acids (15.7%) was also low (data not shown).

The balanced ratio of alpha to beta acids in Art likely originates from its Saaz ancestry, as Saaz also exhibits a similar alpha/beta acid ratio (Olšovská et al., 2024a). However, the alpha acid content in Art is significantly higher, since Saaz typically contains around 3% w/w of alpha acids (Krofta et al., 2024; Mikyška et al., 2023). The higher beta acid content in Art was most probably inherited from the cultivar Kazbek, which shows an average alpha acid content of 5.42% w/w (Trefilová et al., 2022).

Compared to Saaz, Art exhibits markedly lower variability in both alpha and beta acid contents. During the period 2010–2019, the cultivar Saaz exhibited relatively high variability coefficients, with 25.4% for alpha acids

and 22.8% for beta acids (Nesvadba et al., 2020).

The results of hop resin content and composition clearly indicate that Uran belongs to the group of bitter hops (Table 3). The average alpha acid content was 11.86% w/w. The lowest alpha acid content was recorded in 2019 (8.34% w/w), while the highest was observed in 2022 (14.31% w/w). The average beta acid content was 5.10% w/w, which is relatively low and resulted in a high average alpha/beta acid ratio of 2.34. Uran also showed a lower average proportion of cohumulone (24.22% rel.) and colupulone (44.63% rel.). Both cohumulone and colupulone fractions were stable, with variability coefficients of only 8.1% and 6.2%, respectively (data not shown). Similarly, the variability of alpha acid (14.2%) and beta acid (13.3%) contents was low (see Figure 1).

The average alpha acid content of Uran was slightly higher than that of the reference variety Agnus, although the difference was not statistically significant according to the paired t-test. Agnus exhibited an average alpha acid content of 10.69% w/w in the period 2010–2019 (Nesvadba et al., 2020) and 10.24% w/w over 2010–2022 (Nesvadba et al., 2022). A distinct difference between these two varieties was observed in the proportion of cohumulone, as Agnus typically contains 30–35% rel. of this fraction (Nesvadba et al., 2023).

Uran has already been cultivated at four different locations on a larger scale, which allowed for the establishment of a linear regression model describing changes in alpha acid content over the years 2016–2025 (Figure 1). The regression analysis shows that during the ten years of cultivation there was no decrease in alpha acid content; on the contrary, a slight upward trend can be observed. However, the 100-fold coefficient of determination ( $r^2$ ) indicates that this trend is not statistically significant.

Nevertheless, the linear regression confirms good stability of alpha acid content in the cultivar Uran. In contrast, the reference variety Agnus showed a declining trend in alpha acid content over a ten-year period, with a higher degree of dependence ( $r^2 = 0.27$ ), as reported by

**Table 2** Content and composition of bitter acids in Art (2016–2025)

Parameter	Alpha acids (% w/w)	Beta acids (% w/w)	Ratio alfa/beta	Cohumulone (% rel.)	Colupulone (% rel.)
M	5.82	5.50	1.07	21.10	42.67
Med	5.87	5.38	1.09	21.20	42.20
SD	0.676	0.865	0.159	1.311	1.875
CV (%)	11.6	15.7	14.8	6.2	4.4
Min	5.08	4.37	0.81	19.20	40.40
Max	6.80	6.67	1.25	22.90	45.20

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

**Table 3** Content and composition of bitter acids in Uran (2016–2025)

Parameter	Alpha acids (% w/w)	Beta acids (% w/w)	Ratio alfa/beta	Cohumulone (% rel.)	Colupolone (% rel.)
M	11.86	5.10	2.34	24.22	44.63
Med	12.24	5.01	2.35	24.30	44.60
SD	1.681	0.678	0.268	1.952	2.766
CV (%)	14.2	13.3	11.4	8.1	6.2
Min	8.34	3.75	1.71	20.90	40.10
Max	14.31	6.62	2.90	29.00	51.30

(M) mean, (Med) median, (SD) standard deviation, (CV)

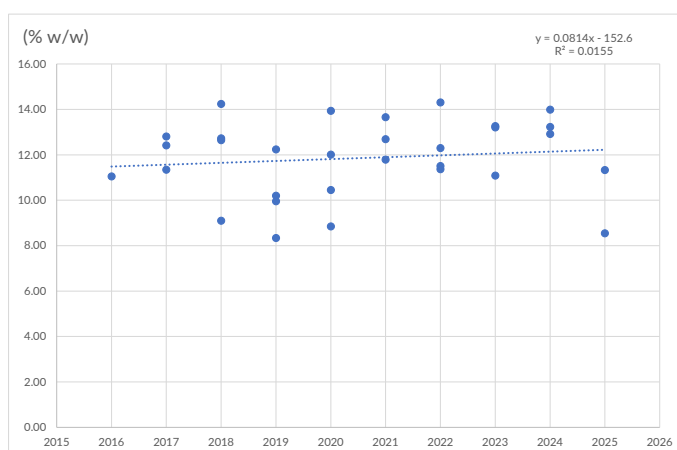
Nesvadba et al. (2023).

### 3.3 Evaluation of the Content and Composition of Essential Oils

The variety Art showed an average essential oil content of 1.27% w/w (Table 4). The composition of essential oils differs from that of Saaz, which exhibits a lower proportion of myrcene (11–32% rel.) and caryophyllene (5–12% rel.), but a higher proportion of farnesene (8–20% rel.) (Olšovská et al., 2024a).

In Art, the proportion of myrcene showed a strong dependence on the harvest year. In 2024, the myrcene content ranged between 50 and 67% rel., while in other years it varied between 21.30 and 38.40% rel. The consistently low proportion of farnesene does not allow Art to be classified among the group of new Saaz-derived cultivars such as Saaz Brilliant, Saaz Comfort, and Saaz Shine, which inherited a higher farnesene content from Saaz (Olšovská et al., 2024a).

The total essential oil content of Art was found to be stable, with year-to-year variability of only 17.1% (data not shown). However, individual oil components exhibited higher variability, ranging from 24.6% for humulene to 77.9% for farnesene (data not shown). The essential oil composition of Art was likely inherited from its maternal parent, the cultivar Kazbek, which typically contains more than 1% w/w of essential oils and shows a very

**Figure 1** Trend of alpha acids content in Uran in the years 2016–2025

similar range in the relative proportions of major components (Krofta et al., 2019).

As shown in Table 5, the variety Uran exhibited a high average essential oil content of 1.67% w/w. The highest essential oil content (2.45% w/w) was recorded in 2024, and values above 2.00% w/w were also observed in 2017 and 2018.

Uran is characterized by a high average proportion of myrcene (46.08% rel.), a medium proportion of farnesene (12.41% rel.) and humulene (7.81% rel.), and a low proportion of caryophyllene (5.42% rel.) and selinenes (2.11% rel.). Once again, the proportion of

**Table 4** Content and composition of hop oils in Art (2016–2025)

Parameter	Total (% w/w)	Myrcene (% rel.)	Caryophyllene (% rel.)	Farnesene (% rel.)	Humulene (% rel.)	Selinenes (% rel.)
M	1.27	36.33	12.31	0.25	23.24	3.03
Med	1.32	28.60	11.60	0.10	25.90	2.52
SD	0.227	16.891	4.134	0.191	5.711	0.966
CV (%)	18.0	46.5	33.6	77.9	24.6	31.8
Min	0.85	21.30	6.73	0.10	15.50	2.14
Max	1.53	67.00	20.20	0.50	30.50	4.65

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

myrcene was strongly affected by the harvest year: the highest values were observed in 2024 (above 70% rel.) and 2017 (above 60% rel.), whereas the lowest values (below 30% rel.) occurred in 2022 and 2023 (data not shown).

Comparable proportions of myrcene and selinenes were found in the reference variety Agnus (myrcene 25–50% rel., selinenes 2–4% rel.). In contrast, Agnus exhibited a wider range and higher average contents of caryophyllene (10–15% rel.) and humulene (15–35% rel.) (Nesvadba et al., 2021).

Importantly, Uran represents the first Czech bitter

flavour varieties. Figure 3 shows that the cultivar Uran exhibits a high intensity of spicy (black pepper, ginger, lovage, garlic, onion) and woody (coniferous, resinous) notes, which were likely inherited from American hop ancestry. Hoppy, grassy, herbal, and fruity (sweet fruit, green apple, blackcurrant) aromas were less pronounced. The aroma profile of Uran differs markedly from that of the reference variety Agnus, which is dominated by a strong hoppy character with subtle spicy undertones.

Given its high alpha acid content, Uran can be classified among bitter hops; however, its distinctive aroma

**Table 5** Content and composition of hop oils in Uran (2016–2025)

Parameter	Total (% w/w)	Myrcene (% rel.)	Caryophyllene (% rel.)	Farnesene (% rel.)	Humulene (% rel.)	Selinenes (% rel.)
M	1.67	46.08	5.42	12.41	7.81	2.11
Med	1.71	44.25	5.90	11.70	7.35	1.65
SD	0.418	14.991	1.543	2.535	2.201	1.194
CV (%)	25.1	32.5	28.5	20.4	28.2	56.7
Min	0.73	24.30	2.80	7.27	5.14	0.66
Max	2.45	75.50	7.44	16.67	12.30	4.66

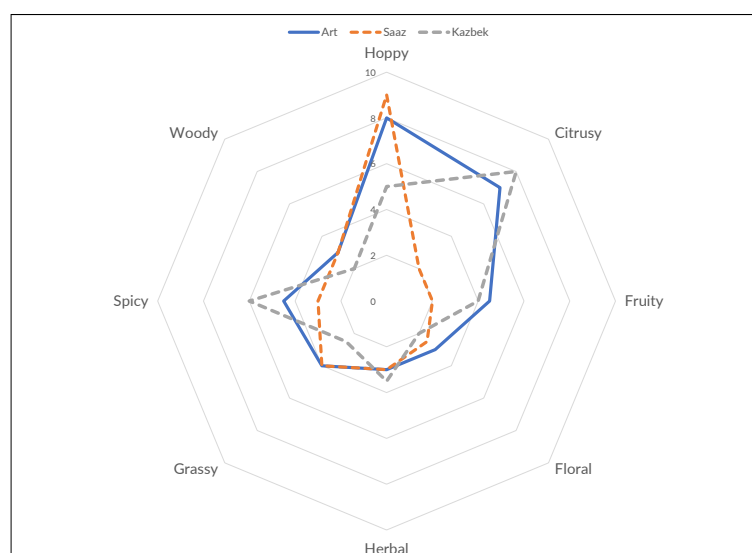
(M) mean, (Med) median, (SD) standard deviation, (CV) coefficient of variation, (min) minimum value, (max) maximum value

hop variety that shows a higher proportion of farnesene compared to other bitter cultivars, which is a remarkable finding for this hop group.

### 3.4 Evaluation of Hop Aroma in Hops

During the registration trials conducted between 2022 and 2025, the aroma of dried hop cones was evaluated each year after harvest. As shown in Figure 2, the cultivar Art is characterized by a dominant hoppy aroma preserving the Saaz lineage, complemented by citrus notes (lemon, orange peel, spicy lime) and fruity tones (sweet tropical fruits such as mango and papaya) inherited from its maternal parent Kazbek. The variety Kazbek is well known for its pronounced citrus aroma (Nesvadba et al., 2021). The cultivar Art also exhibited a weaker intensity of spicy notes (mint, white and black pepper).

From the perspective of hop classification according to the content of bitter acids and aroma characteristics (fine aroma, aroma, bitter, and flavour hops), Art represents a transitional type between fine aroma and



**Figure 2** Aroma profile of the hop variety Art in comparison with Saaz and Kazbek

profile also positions it at the boundary with the “flavour” hop group. Both new cultivars, Art and Uran, therefore display characteristics that overlap between two aroma categories – fine aroma/flavour for Art and bitter/flavour for Uran.

### 3.5 Evaluation of Bitterness Hop Aroma in Beer

The transformation of hop aroma into beer during brewing

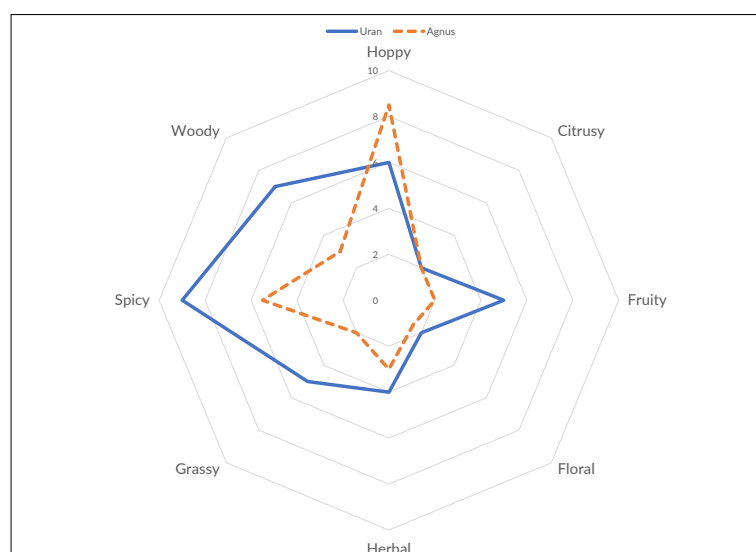
trials is illustrated in [Figure 4](#) (Art) and [Figure 5](#) (Uran). Brewing was conducted using the decoction mashing method and brewed as single-hopped beers with three hop additions during wort boiling, followed by whirlpool hopping and fermentation with bottom-fermenting yeasts under cold-contact conditions.

Both beers exhibited a medium bitterness intensity with a pleasant after-taste. The beer hopped with the Art variety displayed a mild bitterness character, corresponding to level 2, comparable to that of traditional lagers brewed with the fine aroma variety Saaz. Next, the beer hopped with Uran showed a moderate bitterness intensity.

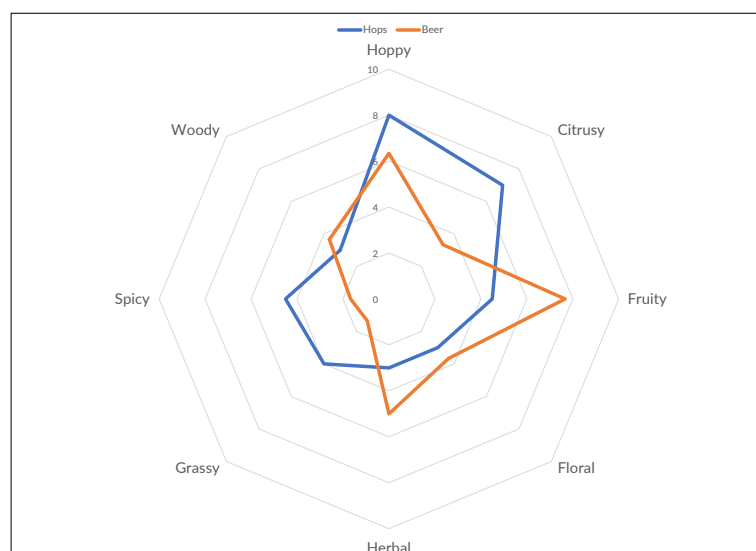
The beer hopped with Art exhibited a distinct fruity, hoppy, and herbal aroma with subtle woody undertones. Compared with the aroma profile of the hop itself, the dominant citrus aroma was transformed into a complex fruity character, which can be explained by chemical modifications of essential oils during wort boiling and biotransformations occurring during fermentation. A similar trend was observed in the transformation of hoppy and spicy notes into herbal tones ([Figure 4](#)).

The key contributors to citrusy and fruity aromas are monoterpene alcohols such as linalool, geraniol,  $\beta$ -citronellol, nerol, and  $\alpha$ -terpineol, which are readily subject to such transformations, in contrast to classical monoterpenes such as myrcene ([Hasbeck et al., 2018](#); [Takoi et al., 2017](#); [Dresel et al., 2015](#)). Another factor influencing the transformation of hop volatiles during fermentation is the release of glycosidically bound aroma compounds, in which hop-derived volatiles are linked to a glucose unit ([Kollmannsberger et al., 2006](#)).

When evaluating the overall sensory profile of beer, synergistic and antagonistic interactions among contributing aroma-active compounds must also be considered. Therefore, a holistic approach is required, and a direct correlation between hop aroma and the chemical composition of hop essential oils cannot be established ([Vrzal and Olšovská, 2019](#)). A deeper investigation of essential oil transformations was not conducted in this study and will be the subject of future comprehensive research.



**Figure 3** Aroma profile of the hop variety Uran in comparison with the reference variety Agnus



**Figure 4** Aroma profile comparison between the hop variety Art and beer hopped with Art

The beer hopped with Uran was characterized by a pronounced hoppy, woody, fruity, and herbal aroma, complemented by a spicy background note. The sensory profile closely mirrored that of the original hop, with the only notable change being the attenuation of spicy aroma components during the brewing process ([Figure 5](#)).

The results obtained for the new Czech hop cultivars Art and Uran demonstrate the successful integration of multiple breeding objectives – agronomic resilience, chemical stability, and brewing performance. Both cultivars combine desirable traits of their parental lines, reflecting the ongoing adaptation of hop breeding to the challenges of climate change and the evolving require-

ments of modern brewing. The outstanding drought tolerance of Art and the strong resistance of Uran, together with the stable resin and essential oil composition, confirm the effectiveness of the current selection approach based on physiological and sensory evaluation. Their distinct aroma profiles – fine aroma/flavour in Art and bitter/flavour in Uran – extend the sensory diversity of Czech hops and provide brewers with new options for lager and craft-style beer production. These findings underline the strategic importance of developing climate-resilient hop cultivars that maintain traditional quality attributes while expanding the aromatic potential of Czech hop breeding.

#### 4 Conclusion

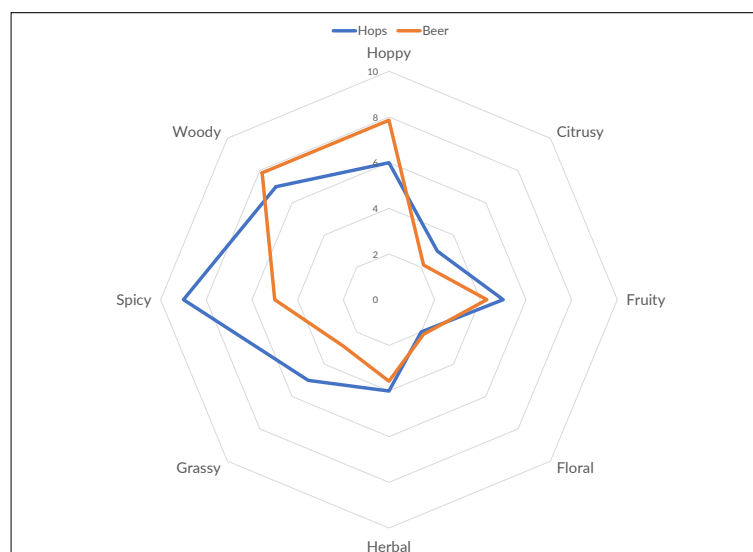
The newly registered Czech hop varieties Art and Uran represent a significant advancement in hop breeding aimed at improving resilience to drought while maintaining high brewing quality. Both cultivars exhibited stable chemical compositions and distinct aromatic profiles, reflecting their complex genetic backgrounds. Art demonstrated exceptional tolerance to water stress and combines the delicate bitterness of fine aroma hops with fruity and herbal tones, whereas Uran integrates the strength of bitter hops with a refined woody and spicy aroma. Brewing trials confirmed that both cultivars transfer their aromatic potential effectively into beer, producing well-balanced sensory profiles suitable for both lager and craft beer styles. These findings highlight the potential of Art and Uran to enhance the sustainability and diversity of Czech hop production under changing climatic conditions.

#### 5 Acknowledgement

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**Figure 5** Aroma profile comparison between the hop variety Uran and beer hopped with Uran

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