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Chemical and sensory characterization of new Czech flavor hop varieties (Juno, Saturn, Pluto, Ceres, Eris, and Jupiter) with evaluation of drought and disease resistance

This study characterizes six new Czech flavor hop cultivars – Juno, Saturn, Pluto, Ceres, Eris, and Jupiter – using long-term datasets (2015 – 2025) that integrate chemistry, sensory profiling, and stress-resistance testing. Across cultivars, alpha acids were consistently moderate (4.6 – 7.2 % w/w), while total hop oils spanned 0.68 – 1.57 % w/w. These compact ranges, coupled with specific aroma profiles, support their suitability for dry hopping. Sensory results showed clear differentiation: Juno, Saturn, and Ceres expressed fruit-forward profiles; Pluto and Eris were citrus-driven; Jupiter exhibited a heavier woody-spicy character. Stress-tolerance assessments highlighted robust agronomic performance in several cultivars. Juno, Saturn, and Ceres combined favorable aroma with improved drought tolerance; among breeding lines tested in parallel, drought resistance frequently exceeded that of registered checks. Disease screening against downy mildew (*Pseudoperonospora humuli*) revealed high resistance in Saturn and very good resistance in Juno, Eris, and Ceres, whereas Pluto and Jupiter were less resistant. Overall, the new Czech flavor hops deliver modern aroma signatures with moderate alpha acids and practical advantages in drought and disease resilience. These traits have already driven adoption in Czech craft breweries and position the cultivars as versatile options for lager and top-fermented styles, particularly in dry-hopped applications.

Descriptors: Flavor hops, hop resins, hop oils, aroma profile, sensory analysis, drought tolerance, downy mildew resistance

1 Introduction

In 2025, hop research in the Czech Republic celebrates its centenary. Over the course of a hundred years, hop breeding has evolved dramatically and can be divided into three distinct stages.

The first stage, historically the longest, was focused on the refinement of the traditional Saaz variety, one of the world's classic fine aroma hops. Exactly a century ago, Karel Osvald initiated clonal selection within Saaz populations, which later resulted in the registration of Osvald's Clones 31, 72, and 114 [1]. From the 1960s onwards, hybridization became the method of choice in Czech hop breeding, and since 1996 it has been applied exclusively [2]. This approach paved the way for the release of new cultivars such as Bor, Sládek, and Premiant [3], followed by further fine aroma members of the Saaz family – Saaz Late, Saaz Brilliant, Saaz Comfort, and Saaz Shine [4]. These varieties share typical characteristics: alpha acids contents of 2.5 – 6.0 % w/w, balanced alpha/beta acid ratios, cohumulone proportions below 27 % rel., elevated farnesene levels (7 – 20 %), and, most importantly, the delicate noble aroma that makes them essential in traditional Pilsner-style lagers [5]. A comprehensive review summarizing the history, genetic data, agronomic parameters such as yield, sensory characteristics, concentrations of key technologically relevant hop compounds, long-term datasets (2004 – 2021), and similarities and differences within the Saaz family was recently published [6]. Subsequent investigations evaluated the use of these cultivars in pilsner-type lagers, assessing their similarities and differences through both chemical and sensory profiling in brewing trials [7,8]. More recently, additional aroma cultivars – Harmonie, Bohemie, Country, Jazz, and Blues – have enriched this group [9], being characterized by alpha acids contents of 2.5 – 8.0 % w/w and alpha/beta ratios of 1 – 2 [10].

The second stage of breeding responded to the demand from breweries for cultivars with higher alpha acids contents. The first bitter cultivar, Agnus, was registered in 2001 [11], followed in the subsequent decade by Rubín, Vital, Boomerang, and Gaia (2007 – 2017). Bitter cultivars (with the exception of Rubín) are distinguished by their high beta acid contents, resulting in alpha/beta ratios of around 2 [12,13]. These varieties are predominantly used for the first and second hopping in lager brewing, but they also find application in top-fermented beers. Vital deserves special mention, as it was also registered for pharmaceutical purposes due to its exceptionally high content of xanthohumol and desmethylxanthohumol [14].

The third and most recent stage was triggered by the boom in craft brewing in the Czech Republic after 2010. With more than

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Fig. 1 Hop cones of Juno (1a), Saturn (1b), Pluto (1c), Ceres (1d), Eris (1e), and Jupiter (1f)

500 craft breweries now active, interest grew rapidly in so-called “flavor hops” with non-traditional aroma profiles – fruity, citrusy, spicy, herbal, woody, etc. The first Czech cultivar of this type, Kazbek, registered in 2008, became widely recognized for its intense citrus notes [15]. In 2019, Mimosa followed, offering a softer citrus profile and unusual bittering characteristics due to its high beta acid content (up to 7 % w/w) and low alpha/beta ratio of 0.3 [4]. In 2022 and 2023, a completely new generation of Czech flavor cultivars was launched: Juno, Ceres, Saturn, Jupiter, Eris, and Pluto [16]. These varieties cover a broad spectrum of aroma impressions from fruity and citrusy to herbal, spicy, and woody. A more detailed investigation of aroma transfer from these cultivars into beer, based on sensory and Bayesian analysis, demonstrated that the probability of perceiving a specific hop aroma in the final beer given its perception in the raw hop was highest for spicy (100 %), resinous (100 %), herbal (100 %), citrusy (40 %), floral (38 %), fruity (43 %), and grassy (100 %) aromas. Aromas such as spicy, resinous, and herbal were consistently perceived in the final beer regardless of their perception in the corresponding hops [17].

The aim of this study was to characterize the new Czech flavor hop cultivars Juno, Saturn, Pluto, Ceres, Eris, and Jupiter. The evaluation focused on the variability of hop resin and essential oil contents and compositions, based on data collected from 2015 to 2025. These results were complemented by sensory assessment of hop aroma, the most important attribute of this hop group. In addition, given the increasingly warm and dry conditions in the Czech hop-growing regions (Žatecko, Úštěcko, and Tršicko), the new flavor genotypes were tested for drought tolerance using a previously published methodology [6]. Finally, resistance to fungal diseases was also assessed, with particular attention to downy mildew (*Pseudoperonospora humuli*), the most serious hop pathogen that damages shoots, leaves, inflorescences, and cones and thereby reduces both yield and quality [18].

2 Materials and methods

2.1 Characterization of evaluated hop varieties

All of the evaluated hops were registered within 2022 – 2023.

Juno was registered in 2022. The cultivar was bred from Kazbek [15] and a wild hop originating from Canada. The plant exhibits a cylindrical shape with medium-length laterals. Cones are large, measuring 3 – 6 cm (see fig. 1a). It is a semi-late variety. The yield of this hop variety amounts to 1.7 – 2.2 t/ha^{-1}.

Saturn was registered in 2022. The cultivar originated from Kazbek [15] and the paternal plant 11/08 of European breeding origin. The plant is cylindrical to club-shaped with medium to long laterals. Cones are large, measuring 4 – 7 cm (see fig. 1b). It is a semi-late variety. The yield of this hop variety amounts to 1.9 – 2.5 t/ha^{-1}.

Pluto was registered in 2022. The cultivar was obtained by inbreeding crossing of Harmonie with a paternal plant derived from Saaz. The plant shows a cylindrical shape with short to medium-length laterals. Cones are large, 3 – 5 cm in size (see fig. 1c). It is a medium-early variety. The yield of this hop variety amounts to 1.7 – 2.2 t/ha^{-1}.

Ceres was registered in 2023. The cultivar originated from Kazbek [15] and the paternal plant 11/12 of European breeding origin. The plant is cylindrical in shape with medium-length laterals. Cones are large, measuring 3 – 5 cm (see fig. 1d). It is a semi-late variety. The yield of this hop variety amounts to 1.6 – 2.1 t/ha^{-1}.

Eris was registered in 2023. The cultivar was bred from Kazbek [15] and paternal plants of older breeding material. The plant is conical to cylindrical in shape with long laterals. Cones are medium-sized, 2 – 5 cm (see fig. 1e). It is a late variety. The yield of this hop variety amounts to 1.4 – 2.0 t/ha^{-1}.

Jupiter was registered in 2023. The cultivar originated from Kazbek [15] and a paternal plant of American and European breeding origin. The plant is cylindrical to club-shaped with very long laterals. Cones are large, 3 – 6 cm in size (see fig. 1f). It is a late variety. The yield of this hop variety amounts to 1.7 – 2.3 t/ha^{-1}.

2.2 Location of hops evaluation

The evaluation was carried out in the Žatec hop-growing region, in the village of Stekník. The trial field is situated at an altitude of 215 meters within the Žatec region and the Ohře River Basin hop-growing location. The area is characterized as warm and dry, with an annual sum of temperatures above 10 °C ranging between 2,600 to 2,800 degree-hours.

Soil characteristics at the site consists of alluvial soils with colluvial and alluvial sediments. These soils are light, well-aerated, but prone to drought. The terrain is completely flat, without signs of sheet water erosion, and fully exposed to surrounding influences. The soil profile is deep (more than 60 cm) and free of skeletal particles.

2.3 Chemical parameters of evaluated hops

The content and composition of hop resins were determined according to the EBC 7.7 method [19]. The essential oil content and composition were analyzed following the methodology [20]. Each cultivar was represented by eight plants. At technological maturity, all plants were harvested and processed separately using a Wolf experimental picking machine. For chemical analyses, composite samples were prepared, dried at 55 °C to a final moisture content of 7 %, and subsequently analyzed in the accredited laboratory of the Hop Research Institute in Žatec. The evaluation of resin and essential oil contents was carried out over the period 2015 – 2025, and these long-term datasets form the basis of the present study.

2.4 Evaluation of Drought Tolerance

Drought tolerance was evaluated using a previously published methodology [6]. Five plants of each genotype were propagated and grown in 5 L pots with standard substrate. Three plants in a comparable growth phase were selected for measurements. Initial physiological parameters were determined under irrigated conditions, after which irrigation was stopped to induce drought stress. Visual and physiological responses, including photosynthesis and transpiration rates, were monitored and re-measured ten days later under greenhouse conditions. A detailed description of the methodology is available in the cited reference [6].

2.5 Resistance to Fungal Diseases

Resistance to *Pseudoperonospora humuli* was evaluated using the Hop Classifier point-scale system, which assesses both primary and secondary infection. Primary infection was determined based on the occurrence of spike-like shoots: a score of 3 indicated high resistance (no spike-like shoots), 5 indicated medium resistance (1 – 5 spike-like shoots), and 7 indicated low resistance (six or more spike-like shoots). Secondary infection was evaluated according to cone damage: a score of 3 indicated high resistance (no cone damage), 5 indicated medium resistance (damage below 10 % of cones), and 7 indicated low resistance (damage above 10 %) according to a previously published method [18].

2.6 Sensory Analysis of Hops

Each year after harvest, dried hop cones were evaluated for aroma. The assessment focused on the intensity of selected aroma attributes – hoppy/herbal, spicy, fruity, woody, citrusy, grassy, and floral – rated on a 0 – 10 point scale. In addition, specific aroma characteristics were described. The sensory evaluation was conducted annually with the participation of at least 50 trained panelists.

2.7 Statistical Evaluation

Basic statistical methods were applied across all evaluated varieties, including mean values, standard deviation, and variability expressed as a percentage (100 × coefficient of variation). To determine the significance of differences in alpha acids and essential oil contents, a paired t-test was used, comparing only results obtained within the same year to account for year-to-year variability. For long-term trends over the eleven-year evaluation period, linear regression was applied, and the strength of the relationship was expressed by the coefficient of determination (r^2). The percentage value of r^2 indicates the extent to which an observed increase or decrease is explained by the time series [21]. All statistical analyses were processed using Microsoft Excel.

3 Results and discussion

3.1 Tolerance to Drought

Within the five-year project QK21010136 "Application of new varieties and genotypes of drought-resistant hops to cultivation and brewing practice", a total of 16 hop varieties and genotypes were tested. Besides the newly registered flavor cultivars Jupiter, Eris, Pluto, Ceres, Juno, and Saturn, the original Czech cultivars Sládek and Premiant were included, along with several advanced breeding lines (5165®, 5304®, 5432®, 5461®, 5465®, 5559®) currently under registration. In addition, a wild hop originating from the Caucasus was tested as a potential source of resistance traits.

Table 1 Assessment of plants for water stress

Genotype	End of irrigation			After 10 days of water stress		
	A (µmol CO_2/ m^2/s)	T (mmol H_2O/ m^2/s)	V	A (µmol CO_2/ m^2/s)	T (mmol H_2O/ m^2/s)	V
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
Jupiter	9.05	2.36	1	0.00	0.48	4
Eris	10.23	2.54	1	0.23	0.62	3
Pluto	7.65	2.32	1	0.18	0.56	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
5165®	8.25	2.03	2	4.88	1.32	2
5304®	9.65	2.36	2	3.27	0.86	3
5432®	10.50	2.29	2	8.77	1.61	2
5461®	11.79	2.92	1	5.15	1.11	1
5465®	6.36	1.38	2	6.02	1.26	2
5559®	9.62	2.45	1	9.05	1.69	1
Wild Cau	9.99	2.01	2	7.08	1.54	2

(A) rate of photosynthesis, (T) rate of transpiration, (V) visual evaluation: (1) – negligible growth retardation; slightly yellowish lower leaves; minimal drought symptoms, (2) – slowed growth; plants with yellowish lower leaves; fast regener-ation 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

Table 1 summarizes the evaluation of plants exposed to water stress. The assessment focused on the rate of photosynthesis (A), the rate of transpiration (T), and a visual evaluation of stress symptoms (V). The results demonstrate that the flavor hop varieties Juno, Saturn, and Ceres exhibited higher photosynthetic activity and simultaneously lower transpiration rates compared to other flavor hops and older Czech cultivars. Consequently, these varieties also achieved better visual ratings. The findings clearly indicate that Juno, Saturn, and Ceres possess improved drought tolerance. Furthermore, the new generation of breeding genotypes (designation®) showed even higher resistance to water stress than all registered Czech hop cultivars. The wild hop from the Caucasus also proved to be of particular interest, suggesting potential for further utilization in breeding programs.

Table 2 **The resistance of evaluated varieties to *Pseudoperonospora humuli***

	Primary Infection	Secondary Infection
Juno	High (0)	Medium (2.23 ± 0.655)
Saturn	High (0)	High (0)
Ceres	Medium (2.06 ± 0.562)	Medium (6.54 ± 1.233)
Pluto	Medium (3.23 ± 0.855)	Low (18.19 ± 1.758)
Eris	High (0)	Medium (7.713 ± 1.381)
Jupiter	Medium (3.15 ± 1.002)	Low (16.65 ± 2.855)

3.2 Resistance to Fungal Diseases

Pseudoperonospora humuli is the most widespread fungal disease in the Czech Republic [18]. The resistance of flavor varieties was evaluated, and the results are summarized in table 2. Saturn showed the highest resistance to downy mildew, while Juno, Eris, and Ceres also demonstrated very good resistance. In contrast, Pluto and Jupiter exhibited low resistance, which will likely result in higher costs for chemical protection.

3.3 Evaluation of Hop Resin Content and Composition

Table 3 summarizes the average values of hop resin content and composition obtained during the period 2015 – 2025. The highest alpha acids content was observed in Saturn (7.51 % w/w), accompanied by the highest alpha/beta ratio and a high proportion of cohumulone. Eris also showed a high alpha acids content (7.25 % w/w) and the highest cohumulone level (49.05 % rel.), with an alpha/beta ratio of 1.54. Pluto and Ceres both averaged more than 6 % alpha acids, but differed markedly in their resin profile. Pluto exhibited the lowest alpha/beta ratio (1.30) and the lowest cohumulone proportion (21.44 % rel.), while Ceres had a higher alpha/beta ratio (1.80) and intermediate cohumulone content. Juno and Jupiter reached below 5 % alpha acids, with similar alpha/beta ratios, but Juno had a cohumulone content more than 10 % rel. higher than Jupiter.

All varieties, except Pluto, are descendants of Kazbek, the first Czech flavor hop. Their alpha acids contents were consistent with Kazbek (5 – 8 % w/w) [15]. Pairwise t-tests showed no significant differences only between Eris and Pluto, Pluto and Ceres, and Juno and Jupiter. Juno displayed the lowest variability in alpha acids content (13.15 %), while Jupiter had the highest (21.36 %). Cohumulone proportions were stable across years, with variability ranging from 5.85 % (Juno) to 10.93 % (Jupiter). Jupiter also exhibited the highest variability in beta acids (15.42 %) and in the alpha/beta ratio (27.61 %), indicating a potential instability in resin composition.

Table 3 **Content and composition of bitter acids (2015 – 2025) in evaluated varieties**

Variety	Alpha acids* (% w/w)	Beta acids* (% w/w)	Ratio alfa/ beta*	Cohumulone*	Colupolone*
Juno	4.98 ± 0.655	3.77 ± 0.525	1.33 ± 0.128	37.59 ± 2.198	62.45 ± 2.091
Saturn	7.51 ± 1.513	3.61 ± 0.464	2.08 ± 0.327	45.33 ± 3.953	62.96 ± 3.070
Pluto	6.79 ± 0.912	5.27 ± 0.516	1.30 ± 0.208	21.44 ± 1.464	44.89 ± 1.683
Ceres	6.05 ± 1.137	3.38 ± 0.473	1.80 ± 0.301	35.07 ± 3.401	53.61 ± 3.326
Eris	7.25 ± 1.129	4.71 ± 0.657	1.54 ± 0.145	49.05 ± 2.940	72.54 ± 2.789
Jupiter	4.58 ± 0.979	3.38 ± 0.521	1.39 ± 0.384	27.50 ± 3.006	46.78 ± 4.325

*Mean value ± standard deviation

Table 4 **Trend of dependence (y) and dependence tightness with respect to the alpha acids content evaluated in hop varieties in the years 2015 – 2024**

Hop variety	y	r	r^2
Juno	0.0013x + 2.3281	0.01	0.0001
Saturn	0.0102x - 12.784	0.04	0.0014
Pluto	0.0655x + 125.38	0.25	0.0645
Ceres	-0.0991x + 206.63	0.38	0.1438
Eris	-0.0161x – 39.720	0.05	0.0022
Jupiter	-0.0116x + 28.027	0.03	0.0012

The predictor variable is year, and the significance level is $\alpha < 0.1$ (P < 90 %). The α values for all results in the table are greater than 0.1, indicating that they are statistically non-significant

Linear regression analysis (table 4) revealed decreasing trends in alpha acids content for Ceres, Eris, and Pluto, while other varieties showed increasing trends. However, the determination coefficients (r^2) were generally low, indicating weak statistical significance. The steepest decline was observed in Ceres, but the time series explained only 14.38 % of the variation.

3.4 Evaluation of hop oil content and composition

Table 5 presents the average values of hop oil content and composition. The highest hop oil content was found in Saturn (1.57 % rel.), while Jupiter showed the lowest value (0.68 % rel.). The highest average proportion of myrcene was observed in Juno (42.23 % rel.) and Jupiter (40.85 % rel.); the remaining cultivars showed comparable levels. Caryophyllene content was relatively balanced across all varieties, ranging from 8.32 % rel. (Pluto) to 12.53 % rel.

Table 5 Total content and composition of bitter acids (2015 – 2025) in evaluated varieties

Variety	Total content (% w/w)	Myrcene (% rel.)	Caryophyllene (% rel.)	Farnesene (% rel.)	Humulene (% rel.)	Selinenes (% rel.)
Juno	1.03 ± 0.310	42.23 ± 13.045	11.42 ± 2.027	0.27 ± 0.243	2.82 ± 1.907	5.80 ± 1.780
Saturn	1.57 ± 0.524	34.54 ± 10.860	10.63 ± 2.190	0.20 ± 0.155	26.10 ± 4.960	2.12 ± 0.925
Pluto	1.34 ± 0.403	29.86 ± 12.306	8.32 ± 1.493	0.29 ± 0.269	21.08 ± 4.575	1.87 ± 0.900
Ceres	1.11 ± 0.380	34.70 ± 9.247	10.96 ± 2.077	0.28 ± 0.273	27.41 ± 3.588	1.83 ± 0.955
Eris	1.23 ± 0.318	30.02 ± 9.677	11.28 ± 1.869	0.27 ± 0.213	23.64 ± 3.898	2.89 ± 1.058
Jupiter	0.68 ± 0.155	40.85 ± 13.466	12.53 ± 3.386	0.43 ± 0.280	4.46 ± 2.180	8.46 ± 3.149

*Mean value ± standard deviation

(Jupiter). Farnesene levels were consistently very low in all cultivars (< 0.5 % rel.). Juno and Jupiter differed from the others by having lower humulene and higher selinene proportions, which may be explained by their genetic background, as the paternal plants originated from North American germplasm.

Paired t-tests confirmed significant differences in hop oil content: Saturn had a significantly higher oil content (95 % probability) compared with Ceres, Eris, and Juno, while Jupiter was shown with 99 % probability to have significantly lower hop oil content than all other cultivars.

In terms of variability, Jupiter exhibited the lowest variation in hop oil content (22.80 %), while Ceres showed the highest (34.18 %). Variability in myrcene content ranged from 26.65 % (Ceres) to 41.21 % (Pluto). Caryophyllene variability was relatively low across all cultivars, from 16.58 % (Eris) to 27.03 % (Jupiter). In contrast, both humulene and selinene proportions showed high variability. The lowest variability in humulene was observed in Ceres (13.09 %) and the highest in Juno (67.54 %). For selinenes, Juno had the lowest variability (30.70 %) and Ceres the highest (52.11 %) (data not shown).

For comparison, Nesvadba et al. reported that the flavor variety Kazbek contained an average of 1.13 % w/w hop oils between 2011 and 2020 [12], which corresponds to the level found in Ceres. These two cultivars also shared a similar composition of myrcene (Kazbek 34.93 % rel.), caryophyllene (11.06 % rel.), and farnesene (0.29 % rel.). However, Kazbek differed by its higher average humulene content (18.76 % rel.) and selinenes around 3.40 % rel. The results indicate that many of the new Czech flavor varieties inherited key traits in hop oil composition from their maternal parent, Kazbek.

3.5 Evaluation of hop aroma

Aroma evaluation was carried out annually after harvest, and the results presented here summarize data collected since 2015 (see section 2.6). All tested varieties belong to the flavor hop group, which generally exhibit a less pronounced hop aroma compared with traditional aroma or bitter hops.

Juno shows medium aroma intensity with a broad mixture of notes. The aroma profile is fruity (apple, banana, mango, honey melon), citrusy (lemon, lime zest, tangerine, orange), hoppy, floral, herbal, and spicy. The dominant fruit note reached 7.5 points, while hoppy, citrus, floral, and spicy notes all scored around 5 points (fig. 2a). Preliminary results suggest that Juno is suitable for both bottom- and top-fermented beer styles.

Saturn is characterized by medium to high aroma intensity. The aroma profile is mainly fruity aroma (apricot, peach, watermelon, mango) with citrusy (lemon, grapefruit, tangerine, ginger), floral (rose, licorice), spicy (black pepper, anise, garlic), and woody background. The dominant fruity aroma scored 8.5 points, while hoppy and citrus notes scored around 5 points, and woody notes reached 3 points (fig. 2b). Saturn is suitable for a wide range of bottom- and top-fermented beers. Results indicate that for dry hopping in IPL, the optimal dosage is up to 3 g/L; higher rates may emphasize pungent spicy/garlic notes at the expense of pleasant fruitiness [22].

Pluto exhibited low to medium aroma intensity. The profile is dominated by fruity notes (green fruits, pineapple, banana, forest fruit), sweet (vanilla, almond), and citrus (lemon, tropical). Grassy and herbal impressions (menthol, basil, chamomile, green tea) were also recorded. The strongest attributes were fruity (8 points) and citrusy (6 points), while Pluto achieved the highest grassy score (5 points) among all varieties (fig. 2c). This variety is particularly suitable for top-fermented beer styles.

Ceres showed low to medium aroma intensity. Its profile is defined by citrus (lemon, lime, grapefruit, orange) and fruity (apricot, watermelon) notes, supported by grassy (tomato leaf, nettle, fresh cut grass), spicy (star anise), and woody (bark, tobacco) nuances. Citrus reached the highest score (8 points) and fruity aromas scored 6 points (fig. 2d). Ceres is recommended for top-fermented beers and dry hopping. It is also suitable for combined hopping strategies, particularly in combination with Pluto [22].

Eris displayed the highest aroma intensity of all tested cultivars, ranging from high to very high. The profile is dominated by citrus (lime, grapefruit, tangerine, orange; 9 points) and tropical fruit (apricot, peach, watermelon, mango), supported by grassy, herbal (lovage, lemon balm, sage), and pine notes at lower intensities (fig. 2e). Eris is well suited for top-fermented beers, dry hopping, and especially NEIPA-style beers.

Jupiter exhibited medium aroma intensity but was unique in scoring the highest woody impression among all varieties (8 points). Its aroma is dominated by woody (resin, pine, needles) and spicy (star anise, bay leaf, black pepper) notes, complemented by lighter

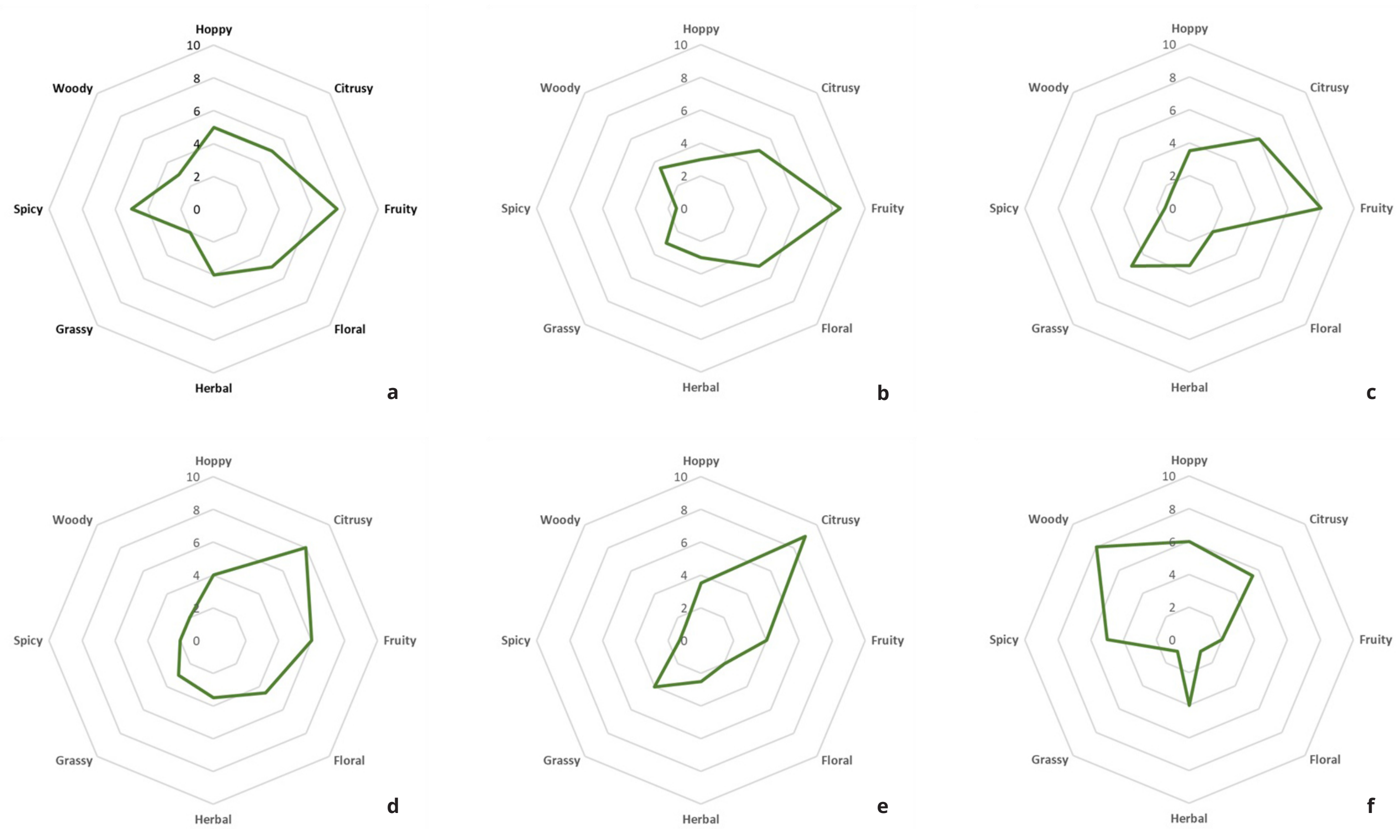

Fig. 2 Aroma profile of Juno (2a), Saturn (2b), Pluto (2c), Ceres (2d), Eris (2e), and Jupiter (2f)

citrus, herbal (mint, lemon balm), and sweet fruit nuances. Hoppy, citrus, and spicy notes scored above 5 points (fig. 2f). Overall, Jupiter has a "heavy" aroma character, lightened by fresh citrus tones. It is recommended for strong styles such as DIPA, BIPA, and Stout.

Until 2020, only two Czech flavor hop varieties had been registered, namely Kazbek (2009) and Mimosa (2019) [15, 4]. In terms of bitter acid composition, Kazbek is comparable to the new flavor cultivars Juno, Saturn, Pluto, Ceres, Eris, and Jupiter. Kazbek averages 5.72 % w/w alpha acids and 4.20 % w/w beta acids [10]. As shown in table 3, Eris, Saturn, Pluto, and Ceres exceeded Kazbek in average alpha acids content, while only Pluto and Eris also surpassed Kazbek in beta acids. Kazbek is well known for its distinct citrus aroma, supported by herbal and spicy undertones [9]. Among the newly developed flavor varieties, citrus notes were also characteristic for Pluto and Eris. In Eris, citrus clearly dominates, while Pluto expresses a more balanced aroma with stronger fruity, floral, and grassy notes.

In contrast, Mimosa represents a markedly different profile, with an average alpha acids content of only 2.40 % w/w and beta acids as high as 7.60 % w/w [23]. These values are considerably lower in alpha acids, but higher in beta acids, compared to all new Czech flavor varieties. Mimosa is described as citrusy, fruity, and herbal, yet its overall aroma intensity is much lower than that observed in the new cultivars Juno, Saturn, Pluto, Ceres, Eris, and Jupiter.

4 Conclusion

The new generation of Czech flavor hop varieties is characterized by a lower alpha acids content, ranging from 4.6 % w/w in Jupiter to 7.2 % w/w in Eris, combined with specific aroma profiles. These two traits make them particularly suitable for dry hopping, where cultivars with attractive aroma and low alpha acids content are preferred. High alpha acids hops may oxidize during dry hopping and negatively affect the bitterness profile of beer [24,25].

Juno, Saturn, and Ceres are defined by dominant fruity aromas, Pluto and Eris by citrus character, and Jupiter by a "heavy" woody-spicy profile. Another major advantage of Juno, Saturn, and Ceres is their high resistance to downy mildew (*Pseudoperonospora humuli*) and tolerance to drought, which are key attributes under current climate change conditions.

As a result, these varieties have already established a solid position among Czech craft breweries and are gradually being adopted by industrial breweries as well. In 2025, interest has also emerged from breweries in Slovakia, Germany, and the United Kingdom. However, increasing market demand still exceeds current production volumes.

Field trials of these cultivars were successfully established in 2022 under dry conditions without irrigation, with expected yields in 2025 ranging from 300 kg for Jupiter to 1,500 kg for Saturn. Further planting of new hop fields is planned in 2025. Jupiter will likely see reduced cultivation, as it shows high variability in alpha acids content and limited demand due to its heavy aroma character.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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