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Drought-tolerant hop genotypes – A promising solution to the problem of climate change for the hop industry?

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Abstract

Climate change can negatively influence hop yield and its quality. Cultivation areas limited by the prohibition of using water from small water sources are most at risk. In order to prevent these areas from completely disappearing in the future, planting hops with varieties or genotypes tolerant to drought could be a promising solution. Therefore, Czech hop breeding targets drought-tolerant genotypes with high crop yield and stability of quantitative and qualitative parameters which will also be well-usable in the Czech brewing industry. Twelve promising genotypes (5165 (Uran), 5194, 5304, 5348, 5398, 5432, 5461, 5464, 5465, 5646, 5669, and 5693) were selected after measurement of their physiological parameters and their basic chemical and sensorial properties were determined. Simultaneously, they were assessed from the point of view of brewing quality using sensory and chemical analysis using a brewing test. For this purpose, experimental beer using identical decoction single-hopped technology, where a hop aroma was highlighted using hopping in a whirlpool was prepared. The results show that three genotypes belong to the category of bitter varieties (5165, 5194, and 5304), whereas the other are genotypes exhibiting the character of aromatic varieties. From a grower's point of view, genotypes 5165 (Uran), 5194, 5348, 5398, and 5461 show a very high yield. The overall impression of all beer samples is very good, bitterness is fine in most samples and hop aroma is mostly hoppy, herbal, woody, spicy, and in some cases also fruity (5304, 5461, 5465, 5646, and 5693).

Keywords: hop; breeding; aroma; new hop genotypes; draught-tolerant varieties; brewing test

1 Introduction

Czech hops are unique crops that are highly exportable and take part in foreign trade of the Czech Republic. However, climate change, especially the lack of moisture, has reduced hop yields in the Czech Republic in recent years (Nesvadba et al., 2021; Straková et al., 2020; Mozny et al., 2009). Therefore, the growing areas that have a possibility of irrigation are at an advantage, but its use is often limited by the prohibition of using water from small water sources. Hop cultivation areas without any irrigation at all may soon disappear, and even might stop being used for agricultural purposes. This problem could be solved by planting hops with varieties or genotypes tolerant to drought. The use of cultivated areas will remain preserved, there will be no erosion threat to the agricultural soil fund or increased consumption of surface water for irrigation. Hence, the diversity and stability of landscape cultures can be preserved.

Czech hop breeding reflects on this problem and currently focuses on breeding new drought-tolerant genotypes with high crop yield and stability of quantitative

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and qualitative parameters, which means the content of valuable compounds such as bitter acids and hop oils. Simultaneously, the ongoing project QK21010136 *"Application of new varieties and genotypes of drought-resistant hops to cultivation and brewing practice"* supported by the Ministry of Agriculture of the Czech Republic emphasizes the properties of hops from the point of view of suitability of its use for production of both traditional Czech lager and new interesting types of beer that today's consumer demands.

Czech hop breeding has a long tradition. Originally, it was associated with the cultivation of aromatic hop varieties. Saaz (semi-early red bine hop) has been for centuries considered as aromatic hop varieties with the best quality in the world. The founder of modern breeding methods using clonal selection in the original regional stands was Karel Osvald, who was involved in clone selection from 1927 when 150 clones were selected. Finally, three Oswald clones, clone 114, clone 31, and clone 72 were chosen for planting by the leading growers themselves (Vent 1999; Osvald, 1931; Osvald, 1929). These clones were officially recognized in 1946 and their cultivation was allowed in 1952. Currently, these clones, well-known as Saaz variety, are still grown on 90% of the total area on which hops are grown in the Czech Republic. The variety Saaz has a fine aroma with a typical pure hop aroma and herbal and floral background that ensures excellent taste of traditional Pilsner Lager (Nesvadba et al., 2020).

Later, in the 1960s, a crossing method for hop breeding began to be used. Bor and Sládek were the first two hybrid cultivars registered in the Czech Republic in 1994 (Rigr et al., 1997) and Premiant was registered in 1996. These aromatic varieties have a lower content of alpha acids and a balanced ratio of alpha and beta-acids ranging from 0.8 to 1.5 (Nesvadba et al., 2022a).

Later, after year 2000, bitter varieties Agnus, Vital and Rubín were registered followed by Gaia and Boomerang in 2017 (Nesvadba et al., 2017).

The hop-crossing method is still used for breeding new hop varieties in the Czech Republic. Concerning the brewing industry in the Czech Republic, hop breeding has always focused on varieties suitable for lager-type beers, for which other hop varieties Harmonie, Saaz Late, Saaz Special, Bohemie, and Kazbek were registered in 2004–2010.

Since 2012, new hop genotypes with a high intensity of a specific flavor have been bred using this method (Nesvadba et al., 2018). The basis of such breeding is a collection of genetic resources of hops which is part of the *National Program for the Conservation and Utilization of Plant Genetic Resources and Agrobiodiversity* (Charvátová et al., 2017). The collection includes all the world's varieties of hops as well as wild hops, which began to be used in breeding due to their specific aroma. The most commonly used varieties are Kazbek, Columbus, Cascade, and wild hops from North America.

The study aims to test drought resistance of 12 promising genotypes selected from original 70 ones after crossing, which meet chemical and sensory quality parameters in order to be well-saleable in the market. Therefore, promising selected genotypes were grown and characterized using sensory and chemical analysis. Since the genotypes are completely new and no information about their brewing properties exists, they were tested using identical decoction single-hopped technology, where a hop aroma was highlighted using hopping in a whirlpool. Twelve experimental beers from new varieties with the breeding designation 5165 (Uran), 5194, 5304, 5348, 5398, 5432, 5461, 5464, 5465, 5646, 5669, and 5693 were assessed from the point of view of brewing quality using sensory and chemical analysis.

2 Materials and methods

2.1 A method of selecting drought-tolerant hop genotypes

The selected 70 breeding genotypes were propagated for greenhouse trials at the same time in order to keep the plants in the same growth phase. For the purpose of measuring physiological parameters of hops using the LCpro SD device (ADC Bioscientific, Ltd., Great Britain), 5 plants of each genotype were propagated and planted in 5 L pots and a standard growing substrate. Subsequently, three plants in the most similar growth phase and condition were selected to measure the physiological parameters. An initial measurement of all genotypes took place on irrigated plants that were not stressed by drought. Each leaf was measured for 8 minutes, of which the first 3 minutes were the stabilization of values after closing the leaf into the measuring chamber, and only the values measured between the 4th and 8th minute are considered as measurement results. The conditions in the measuring chamber were set at a temperature of 30 °C with a photosynthetic photon flux density (PPFD) of 650 μmol/m^2/s. After the initial measurement, their irrigation was always terminated and an effect of drought stress on the visual and physiological manifestations of the plants was subsequently monitored.

After 10 days of the first measurement, the same plants were measured again. The rate of photosynthesis and transpiration was determined after the action of water and also partially of thermal stress when the plants could not compensate for the thermal stress by cooling down due to irrigation (greenhouse conditions).

Thanks to the measured and calculated parameters, but also the visual scoring of the genotypes, it is possible to assess which genotypes show better/worse performance parameters from the point of view of photosynthetic activity after water stress (including comparison with values during irrigation) and thus have potential for application in times of significant weather fluctuations, mainly due to uneven rainfall and longer tropical periods (Nesvadba et al., 2022b).

Based on the preliminary results, 12 hop genotypes that show high or moderate drought resistance were selected. The varieties Sládek and Premiant were chosen as controls.

2.2 Visual evaluation (V) after 10 days of stress

1 – negligible growth retardation; slightly yellowish lower leaves; minimal drought symptoms;
2 – slowed growth; plants showed yellowish lower leaves; fast regeneration after watering;
3 – wilted leaves; lower leaves dried up; stopped growth; the plant regenerated and continued to grow after watering;
4 – completely dried up plants; no regeneration after watering.

2.3 Brewing technology

Experimental samples of beer were prepared in a pilot scale (Pacovské strojírny, Czech Republic) research brewhouse with a maximum capacity of 50 L using the recipe as described below. The grist composition for each brew was 10 kg of Pale Ale malt from the Czech malthouse Benešov (extract-dry basis 81.6%, color 5.2 EBC). The volume of cold wort was approx. 50 L. A decoction mashing regime was used with the mash-in temperature of 35 °C and a rest of 10 min, followed by heating to 52 °C with the temperature gradient of 0.8 °C/min and a rest of 30 min. This was followed by heating to 63 °C with a rest of 20 minutes and separation of mash. Then, the mash was heated to 72 °C with a temperature gradient of 0.8 °C/min and rest to ideal saccharification. This was followed by heating the mash to boil with a temperature gradient of 1.3 °C/min and the duration of boiling of 15 min. This was followed by mixing the mash and the rest of the brew together to a mash-out temperature of 77 °C. A standardized lautering process was controlled according to the clarity and pressure difference below and above the false bottom. The maximum turbidity of sweet wort was set to 30 units EBC and the last running to 60 units EBC. The volume of sweet wort before boiling was 65 L. The atmospheric wort boiling duration was 75 min.

Then, beer was hopped using hop pellets three times, the 1st dosage (40%) at the beginning, the 2nd dosage (35%) in the 20th minute of a boil, and the 3rd dosage (25%) 15 minutes before the end of the boil. Individual doses calculated based on alpha acid content are given in Table 1. The next dosage of 60 g was added into a whirlpool. The target bitterness in beer was 30 BU.

All beer batches were fermented identically at 10 °C with Fermentis W34/70. Maturation took place in a lager cellar at 3–4 °C ± 0.5 °C for 21 days.

Finally, the beer was filtered on a plate filter with S10N filter plates (Hobra Školník, Broumov) and bottled without oxygen access.

Table 1 *Individual hop doses calculated based on alpha acid content.*

Genotype	Total (g)	1st Dosage (g)	2nd Dosage (g)	3rd Dosage (g)
5165 Uran	38.2	15.3	13.4	9.6
5194	49.3	19.7	17.3	12.3
5304	40.4	16.2	14.1	10.1
5348	64.6	25.8	22.6	16.2
5398	152.2	60.9	53.3	38.1
5432	63	25.2	22.1	15.8
5461	56.1	22.4	19.6	14.0
5464	81.5	32.6	28.5	20.4
5465	63.9	25.6	22.4	16.0
5646	132.1	52.8	46.2	33.0
5669	91.3	36.5	32.0	22.8
5693	136.4	54.6	47.7	34.1

2.4 Chemical analysis of hops and beer

The determination of bitter acids and hop oils was performed according to EBC 75 and the method of Krofta (2003).

The determination of an original, real, and apparent extract and original gravity, alcohol, bitterness, color, and pH were performed according to the EBC methods 9.4, 9.2.6, 9.8, 9.6, and 9.35, respectively (EBC 9.4, 2004; EBC 9.2.6, 2018; EBC 9.8, 2020; EBC 9.6, 2018; EBC 9.35, 2018).

2.5 Sensory analysis of hops

An evaluation of the aroma hops was carried out organoleptically. An evaluation of dry cones within 14 days after the harvest was done using the sense of smell where only the dominant aroma was assessed. Hops were dried immediately after harvesting at a maximum temperature of 54 °C.

2.6 Sensory analysis of beer

Sensory analysis of beer was performed by the expert 12-member panel of the Research Institute of Brewing and Malting (RIBM). The panel assessors were selected and trained in compliance with ISO 8586:2015 and ISO 11132:2012. Sensory analysis was performed in the sensory laboratory equipped according to ISO 8589:2008 (*General Guidance for the Design of Test Rooms according to the EBC 13.2 method*). The samples were served in tasting glasses and tempered to 10 ± 2 °C.

A basic profile of beer together with a hop was evaluated. The basic profile included fullness, intensity of bitterness, bitterness culmination (after 15 s), bitterness aftertaste (after 40 s), bitterness character, astringency, sweetness and sourness evaluated on a scale from 0 to 5, where 0 is none and 5 is maximal sense. The overall impression of beer was rated on a scale of 1 to 9, where 1 was the best beer.

For the evaluation of hop aroma, description analysis for the main aroma and background aromas was used. Descriptors such as hoppy, fruity, citrussy, flowery, resinous, woody, herbal, and spicy were used for this purpose.

3 Results and discussion

3.1 Characterization of selected genotypes (breeding, aroma, yield)

3.1.1 Bitter genotypes

5165 (Uran), is a very perspective genotype already marketed under the name "Uran". It is a multiple hybrid of American and European varieties crossed in 2006. A high content of alpha acids is ranging from 10 to 14% wt. This genotype is characterized by a strong hoppy-spicy aroma with scents of blackberry. The yield of hops is 2.5 t/ha.

5194 was obtained by crossing selection from American and European varieties (female) with a high content of alpha acids and the Czech aromatic varieties Sládek and Harmonie (male) in 2006. This genotype has a strong pleasant hoppy aroma. The yield of hops is 2.7 t/ha.

5304 was obtained by selection of the varieties of Agnus and Taurus by crossing in 2007. The genotype has a sharp spicy aroma changing to garlic during late harvest. The yield of hops is 2.3 t/ha.

3.1.2 Aromatic genotypes

5348 – was obtained by selection of the varieties of the dwarf English variety First Golg, which was freely pollinated in a breeding hop house in 2007. The genotype has a pleasant hoppy aroma. The yield of 2.5 t/ha was achieved under experimental conditions.

5398 – was obtained by backcrossing within the progeny of genotypes 5194 (female) and Czech aromatic varieties Sládek and Harmonie (male) in 2009. The genotype has a weak hoppy aroma with spicy in the background. The yield of 2.7 t/ha was achieved under experimental conditions.

5432 – was obtained by crossing selection of the progeny of European varieties with a high content of alpha acids (female) and Saaz (male) in 2010. The genotype has a fine hoppy aroma. The yield of 2.1 t/ha was achieved under experimental conditions.

5461 – was obtained by crossing selection of an offspring of American varieties with a high content of alpha acids (female) and Czech aromatic varieties Premiant and Harmonie (male) in 2011. The genotype has a sharp spicy aroma. The yield of 2.6 t/ha was achieved under experimental conditions.

5464 – was obtained by selection of an offspring of bitter American and European varieties by crossing in 2011. The genotype has a spicy and herbal aroma. The yield of 2.3 t/ha was achieved under experimental conditions.

5465 – was obtained by backcrossing within the progeny to the Sládek (female) variety and the Sládek and Harmonie varieties (male) in 2011. The genotype has a sharp hop aroma. The yield of 2.2 t/ha was achieved under experimental conditions.

5646 – was obtained by crossing selection of the progeny of the Kazbek variety and bitter American and European varieties and Saaz (male) in 2013. The genotype has a fruity aroma. The yield of 2.1 t/ha was achieved under experimental conditions.

5669 – was obtained by selection of an offspring of the Kazbek and Fuggle varieties by crossing in 2013. The genotype has a fruity aroma with woody and piney in the background. The yield of 2.4 t/ha was achieved under experimental conditions.

5693 – was obtained by selection of an offspring of the Kazbek and Fuggle varieties by crossing in crossing. The aroma is fruity and woody, and piney in the background. The yield of 2.4 t/ha was achieved under experimental conditions.

3.2 Drought tolerance of selected genotypes

The drought tolerance of selected genotypes was assessed by a visual assessment (V ranging from 1 to 4) and measurement of instantaneous photosynthetic efficiency of water use (WUEi – water-use efficiency, Kirhham, 2005). Results are given in Table 2, where the tested genotypes are ranked according to the highest instantaneous photosynthetic efficiency of water use after the ending of irrigation and after 10 days of water stress. The control varieties Sládek and Premiant are included.

As shown in Table 2, genotypes 5432, 5348, 5465, 5646, 5461, 5464, and 5165 (Uran) demonstrate the best visual evaluation after water stress (V=2). Simultaneously, they had the highest value of WUEi (ranging from 5.40 to 4.03). Therefore, these genotypes can be said to show high tolerance to drought. Genotypes 5398, 5304, 5194, 5669, and 5693 show medium resistance according to a visual and WUEi assessment. Finally, genotypes 5669 and 5693 show a significant decrease in WUEi after 10 days of stress causing the stopped growth (V=3). The worst results were obtained for the reference varieties Sládek and Premiant which were completely dried up after 10 days of stress.

Table 2 *Visual assessment (V) and measurement of instantaneous photosynthetic efficiency of water use (WUEi) of selected genotypes tested for drought resistance.*

Genotype	End of irrigation		After 10 days of stress	
	V	WUEi	V	WUEi
5432	1	4.67	2	5.40
5348	1	4.00	2	5.21
5465	1	4.61	2	5.14
5646	1	4.41	2	5.14
5461	1	4.05	2	5.09
5464	1	5.57	2	4.31
5165 (Uran)	1	4.28	2	4.03
5398	1	4.04	3	4.01
5304	1	4.50	3	3.93
5194	1	3.24	3	3.45
5669	1	5.86	3	2.92
5693	1	5.08	3	1.78
Sládek	1	4.69	4	0.00
Premiant	1	4.49	4	0.00

V: (1) – negligible growth retardation, slightly yellowish lower leaves, drought symptoms were minimal; (2) – slowed growth, plants showed yellowish lower leaves, fast regeneration after watering; (3) – wilted leaves, lower leaves dried up, stopped growth, the plant regenerated and continued to grow after watering; (4) – completely dried up plants, no regeneration after watering

3.3 Chemical analysis of selected hop genotypes

The content of bitter acids is given in Table 3. The genotypes 5165 (Uran), 5194, and 5304 belong to a group of bitter varieties due to a high concentration of alpha-acids which is 12.30, 9.53, and 11.63% wt., respectively, also similar to bitter varieties such as Agnus, Rubín, and Vital, whose concentrations are on average higher than 10% wt. The ratio of alpha/beta acids is higher than 2, genotype 5304 even has 3.26. Genotype 5398 has an interesting acids ratio, namely 0.59.

The other genotypes have a lower content of alpha acids (ranging from 3.09 to 8.39% wt.), thus, they belong to aromatic varieties. Genotypes 5646 and 5669 are distinguished from the others by a high content of cohumulone (34.00 and 41.70% rel.) and colupulone (58.00 and 66.90% rel.), respectively. For such varieties, a higher yield of iso-alpha acids during wort boiling can be assumed, as was demonstrated in previous studies. First who described this phenomenon was Rigby (1972), followed by Ono et al. (1984) and Irwin et al. (1985). They demonstrated that during wort boiling the relative amount of formed isocohumulone was significantly higher in comparison with isohumulone and isoadhumulone. Moreover, a relative amount of isocohumulone lost during fermentation is lower than that of isohumulone and isoadhumulone. Next, Irwin et al. (1985) published that cohumulone is better utilized than humulone or adhumulone, probably due to higher losses of humulone and adhumulone in a kettle and of isohumulone and isoadhumulone in a fermenter (Irwin et al., 1985; Ono et al., 1984; Rigby, 1972).

And finally, Jaskula et al. (2008) and Protsenko et al. (2020) determined this phenomenon using a detailed kinetic study.

The total content of hop oils and the content of main specific hop oils such as myrcene, caryophyllene, farnesene, humulene, and selinene group are given in Table 4. Most genotypes have a low content of hop oils with the exception of genotypes 5465, 5165 (Uran), and 5348, which have concentrations of hop oils 2.06, 1.78, and 1.54% wt., respectively. Furthermore, the variability of specific hop oils among the varieties is high. Genotype 5165 (Uran) has the highest ratio of myrcene (24.30% rel.), genotypes 5693 and 5348 have the highest concentration of caryophyllene (13.10% rel.) and humulene (24.70 and 20.20% rel.). Humulene is characteristic also for genotype 5432 (22.70% rel.). Only genotype 5165 (Uran), has a significant concentration of

Table 3 *Content of hop resins in tested genotypes.*

Genotype	Alpha acids (% wt.)	Beta acids (% wt.)	Ratio α/β	Cohumulone (% rel.)	Colupulone (% rel.)
5165 Uran	12.30	5.13	2.40	25.10	45.00
5194	9.53	4.53	2.10	29.00	51.00
5304	11.63	3.57	3.26	25.30	48.60
5348	7.28	4.68	1.56	25.00	49.90
5398	3.09	5.24	0.59	22.50	39.80
5432	7.46	4.12	1.81	24.70	43.80
5461	8.39	3.53	2.38	29.70	52.90
5464	5.77	4.87	1.18	24.70	44.30
5465	7.36	3.62	2.03	22.20	46.60
5646	3.56	1.76	2.02	34.00	58.00
5669	5.15	2.36	2.18	41.70	66.90
5693	3.45	1.75	1.97	21.70	45.90

farnesene (11.50% rel.), the other genotypes have it negligible. Genotypes 5304, 5194, 5461, 5464 and 5465 have a quite significant percentage of selinens, especially genotype 5304 in which a garlic aroma was detected.

3.4 Chemical analysis of beer

The basic chemical characteristics of experimental beers are given in Table 5. The dispersion of values of original gravity ranging from 10.44 to 12.23% wt. and related parameters corresponds to possibilities of an experimental brewhouse.

Table 4 *Content of basic hop oils in tested genotypes*

Genotype	Total content (% wt.)	Myrcene (% rel.)	Caryophyllene (% rel.)	Farnesene (% rel.)	Humulene (% rel.)	Selinens (% rel.)
5165 Uran	1.78	24.30	7.44	11.50	7.19	7.66
5194	1.00	11.50	10.30	0.55	16.00	13.40
5304	1.36	13.80	10.90	< 0.5	18.20	17.50
5348	1.54	12.50	13.10	< 0.5	20.20	3.09
5398	0.80	12.20	9.44	< 0.5	12.80	8.34
5432	1.12	17.70	11.50	< 0.5	22.70	4.56
5461	1.49	12.40	7.54	< 0.5	6.58	14.20
5464	1.01	14.40	7.95	< 0.5	11.90	11.30
5465	2.06	14.50	10.60	< 0.5	17.00	14.50
5646	1.06	13.20	8.56	< 0.5	12.50	4.12
5669	0.92	10.00	7.61	< 0.5	8.24	3.81
5693	0.89	14.60	13.10	3.48	24.70	3.45

Table 5 *Basic chemical parameters of experimental beers*

Genotype	OG % wt.	Alc % vol.	Alc % wt.	$Extract_{app}$ % wt.	$Extract_{real}$ % wt.	$Ferm_{app}$ %	$Ferm_{real}$ %	pH	Bitterness BU
5165 Uran	10.44	4.46	3.5	1.96	3.6	81.2	65.6	4.78	33
5194	10.85	4.65	3.65	2.04	3.74	81.20	65.50	4.59	41
5304	10.87	4.74	3.72	1.89	3.62	82.70	66.70	4.54	33
5348	10.59	4.12	3.22	2.79	4.29	73.70	59.40	4.75	27
5398	11.51	4.88	3.83	2.30	4.07	80.04	64.62	4.49	40
5432	10.84	4.63	3.63	2.06	3.75	81.00	65.40	4.56	27
5461	11.45	4.66	3.65	2.66	4.36	76.70	61.90	4.63	36
5464	11.31	4.55	3.56	2.72	4.38	75.94	61.29	4.62	30
5465	12.23	5.31	4.16	2.25	4.17	81.61	65.91	4.46	26
5646	11.68	5.16	4.05	1.94	3.81	83.38	67.34	4.48	36
5669	11.43	4.92	3.86	2.14	3.93	81.27	65.62	4.59	38
5693	11.10	4.33	3.38	2.93	4.51	73.57	59.36	4.64	32

OG – original gravity; Alc % vol. – alcohol by volume; Alc % wt. – alcohol by weight; $Extract_{app}$ – apparent extract; $Extract_{real}$ – real extract; $Ferm_{app}$ – apparent fermentation; $Ferm_{real}$ – real fermentation.

3.5 Sensory analysis of hop aroma in beer samples

Results of sensory analysis of experimental beers, are given in Table 6 and Table 7. The fullness, sweetness and sourness are very similar among all samples. Slight differences are noticeable in the bitterness profile, where the highest culmination can be found in genotype 5194 (3.8) and the lowest in genotype 5464 (2.9). This genotype also has nearly the lowest after-taste (1.9). Genotype 5194 has, together with a high culmination intensity, the highest bitterness character (3.0), meaning middle-harsh. The other beers have very fine to fine character. Altogether, the overall impression of all samples is very good, their values are ranging from 2.7 to 3.5.

The highest aroma intensity was determined in samples 5165 (Uran), and 5194, the best aroma pleasantness was recorded in samples 5646, 5465, and 5165 (Uran). A detailed hop aroma is described in Table 7.

Table 6 *Sensory profile of experimental beers*

Genotype	Fullness	Bitterness	Bitterness culmination	Bitterness after-taste	Bitterness character	Astringency	Sweetness	Sourness	Overall impression
5165 Uran	2.7	1.8	3.2	2.2	2.4	1.3	1.4	1.6	2.7
5194	2.6	2.0	3.8	2.3	3.0	1.2	1.2	1.6	3.1
5304	2.6	1.7	3.1	1.9	2.5	1.0	1.6	1.4	3.4
5348	2.7	1.7	3.3	2.1	2.5	0.8	1.3	1.7	3.1
5398	2.9	1.2	3.1	1.8	2.3	1.1	1.2	1.7	3.5
5432	2.7	1.9	3.4	2.1	2.3	0.9	1.6	2.1	2.8
5461	2.7	1.2	3.1	1.8	2.2	0.9	1.3	1.6	3.1
5464	3.1	1.6	2.9	1.9	2.0	1.4	1.4	1.5	3.5
5465	2.8	1.5	3.1	2.0	2.6	1.0	1.3	1.5	2.8
5646	2.9	1.7	3.4	2.4	2.8	1.5	1.3	1.5	3.3
5669	2.9	1.4	3.6	2.7	2.9	1.5	1.3	1.2	3.3
5693	2.4	1.3	3.2	2.1	2.4	1.1	1.4	1.5	3.3

Uncertainty is 0.5

4 Conclusion

An application of drought-tolerant hop varieties has a long-term effect. Drought-tolerant hop varieties will increase efficiency and productivity, and thus competitiveness in the Czech and world markets for hop growers who lack water for cultivation.

One-off pilot experiments cannot draw a definite conclusion about the use of varieties in brewing in the future. As only a limited amount of hops were available, only one type of beer was prepared, namely lager. However, all the experimental beers were evaluated very positively and from this it can be concluded that they will be usable in the brewing industry.

Further, of the 12 hop genotypes tested, 5 genotypes (5165 (Uran), 5304, 5432, 5461, and 5465) were accepted in the CISTA (Central Institute for Supervising and Testing in Agriculture of the Czech Republic) registration tests in 2022. The best genotypes can be registered as the first Czech drought-tolerant hop varieties as early as 2025. The very promising genotype 5165 (Uran) is currently grown on an area of 0.5 ha and is being tested in a number of industrial breweries and microbreweries.

From a grower's point of view, genotypes 5165 (Uran), 5194, 5348, 5398, and 5461 show a very high yield.

Currently, all genotypes are tested on two semi-operational areas. The first location is without irrigation in a dry area in Nesuchyně in Rakovník region (GPS 50.4717842N, 13.4068403E). Quantitative and qualitative marks of tolerant genotypes of hops in a dry area are monitored and compared here, with a comparison to a control area with sufficient water intake and irrigation. This semi-operational area is located in Rybňany in Žatec region by the river Ohře (GPS 50.3497122N, 13.5701819E).

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Table 7 *Sensory analysis of hop aroma in beer samples*

Genotype	Aroma intensity	Aroma pleasantness	Hop aroma description
5165 Uran	3.0	2.7	Pleasant fine bitterness with longer after-taste, herbal, grassy, flowery (rose), resinous
5194	2.8	3.5	Middle-harsh bitterness with a strong culmination and long after-taste, earthy, herbal, woody, spicy (pepper, allspice), acrid, green hoppy
5304	2.6	3.2	Fine bitterness with pleasant after-taste, herbal (mint), spicy, resinous, green hoppy, scent of fruity and citrusy
5348	2.4	3.2	Fine bitterness with a middle intensive culmination, herbal (mint, thyme), resinous, spicy (pepper, juniper), green hoppy
5398	2.0	3.2	Fine bitterness with a middle intensive culmination, citrusy, resinous, flowery, herbal
5432	2.3	3.1	Dry fine bitterness with a middle intensive culmination, resinous, woody (pine tree), herbal (thyme, mint), flowery, scent of citrusy
5461	1.9	3.6	Pleasant fine bitterness, resinous, fruity, citrusy, herbal, green hoppy
5464	2.0	3.2	Very fine bitterness with a middle intensity of culmination, fruity, flowery, scents of herbal, spice and green-hoppy, traces of a chemical aroma
5465	1.9	2.6	Middle-harsh bitterness with a middle intensity of culmination, flowery, herbal, spicy, fruity, sweety/toffee
5646	2.3	2.4	Middle-harsh bitterness with a strong culmination and long after-taste, fruity (tropical, citrusy), spicy, woody
5669	2.6	3.0	Harsh bitterness with a highly intensive culmination, resinous, woody, herbal, tobacco, spicy (pepper)
5693	2.1	3.4	Fine bitterness with a middle intensive culmination, green-hoppy, resinous, citrusy, sweety/toffee, scents of herbal and flowery

Aroma intensity: 0–none, 1–very low, 2–low, 3–middle, 4–high, 5–very high

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