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Evaluation of Czech hop cultivars since 2010 till 2019

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Abstract: Czech hop cultivars were evaluated from 2010 to 2019. A total of 13 cultivars were assessed. The highest yield per plant was found out in cv. Kazbek (3.66 kg/plant), whereas the lowest in cv. Saazer (2.02 kg/plant). Rubín and Boomerang are the cultivars with the lowest variability of the yield per plant. On the contrary, the highest variability was shown by cv. Kazbek. Conclusively the highest content of alpha acids was recorded in cv. Gaia (13.81%), whereas Saazer is the cultivar with the lowest content (2.87%). Significantly highest content of beta acids were recorded in cvs. Gaia, Vital, Boomerang and Bohemie. On the contrary, the lowest content of beta acids was found in cvs. Saazer, Rubín and Bor (below 4%). Kazbek is the cultivar with the highest ratio of cohumulone (36.67% rel.). Cvs. Premiant and Harmonie show the lowest ratio of cohumulone (19.63% rel.). The lowest ratio of myrcene (18.91% rel.) and caryophyllene (8.26% rel.) was recorded in cv. Saazer. The highest ratio of farnesene was found in cv. Saazer (13.34% rel.) and cv. Saaz Late (10.22% rel.). A wide range was found in the ratio of humulene: from 2.15% rel. (cv. Vital) to 35.76% rel. (cv. Bor). Cv. Gaia has the highest ratio of selinene (19.77% rel.).

Keywords: *Humulus lupulus* L.; hop resins; hop oils; productivity; aroma and bitter cultivars

Hop breeding in Czech Republic (CR) has a long tradition. The first clonal selections were carried out as early as 1853 by Kryštof Semš in Vrbice near Roudnice in the Úštěk hop growing region. Semš made positive selection in his hop garden. The founder of modern breeding methods based on clonal selection from original regional hop gardens was Karel Osvald who had been engaged in it since 1927. Thanks to his work, three clones were released, which were named after the breeder Osvald's clone No. 31, Osvald's clone No. 72 and Osvald's clone No. 114. At present, these clones represent 90%, which is 4 947 hectares of the hop growing area in Czech Republic. Cv. Saazer is grown on 4 201 hectares. Hybridisation started to be used since 1960's as well. In 1994, Bor and Sládek were the first two hybrid cultivars registered in Czech Republic (Rigr et al. 1997). Cv. Premiant was released in 1996. In 2001, the first Czech bitter cultivar Agnus, was registered. Since 2004 till 2010 other six cultivars (Harmonie, Rubín, Kazbek, Bohemie, Saaz Late and Vital) were registered by the Hop Research Institute in Žatec (Nesvadba et al. 2013). In 2017, Gaia and Boomerang – two other bitter cultivars were released. New aroma cultivars Saaz Brilliant, Saaz Comfort, Saaz Shine and Mimosa were registered in 2019. The breeding focused on dwarf cultivars resulted in releasing of Country, Jazz and Blues, in 2018 and 2019. In the past, breeding was aimed at first at productivity, typical aroma and higher alpha acid contents and tolerance to diseases (Henning et al. 2015). Many important characteristics are based polygenically (Nesvadba et al. 1999). Hop is a dioecious plant and just female plants bear cones. It is the reason why male plants

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enter the breeding process as an unknown pollinator (Neve 1991). Therefore, it is very important to test also males. Testing breeding is important because it brings knowledge about characteristics given to progeny by male plants. Chemical analyses aimed at contents of hop resins and essential oils help enrich this knowledge as well (Krofta 2003). Hop resins and hop essentials oils are important for the bitterness and aroma of beer. Hop cultivars can be divided into aroma, bitter and others (IHGC hop variety list 2018). As hop plants are grown at the same place minimally for ten years, emphasis is put on stability of yield and content of alpha acids. All the registered hop cultivars are followed by maintaining breeding, where stability and uniformity are assessed. Origin of the cultivars is tested with the help of DNA analyses (Patzak and Henychová 2018). Maintaining breeding serves also as a base for selection of mother plants used for obtaining virus-free planting material for hop growers (Svoboda and Kopecký 1996). The following parameters are demanded: resistance to fungal diseases, agrotechnical aspects, storage ability, productivity and content of alpha acids (Nesvadba et al. 2003). Quarantine disease, *Verticillium nonalfalfae*, which causes wilt, occurred for the first time in CR in 2017. It was found in two Moravian hop gardens in Trsice hop growing region. Therefore, testing for tolerance/resistance of hop cultivars as well as new genotypes to this disease has been included since 2018. According to the current results, cvs. Sládek, Kazbek, Vital and Agnus seem to be tolerant to *Verticillium nonalfalfae*.

The aim of the study was to determine the productivity of Czech hop cultivars.

MATERIAL AND METHODS

Assessment of productivity was focused to genotypes suitable for high trellis within maintaining hop breeding: bitter cultivars: Agnus, Rubín, Vital, Gaia, Boomerang; aroma cultivars: Saazer, Bor, Sládek, Premiant, Harmonie, Kazbek, Bohemie, Saaz Late. Original mother plants, not virus free plants, are included into maintaining breeding. Therefore, productivity of some cultivars can be lower in comparison with hop gardens planted by virus free hop plants (Nesvadba et al. 1999). Each cultivar is followed within maintaining breeding in the number of at least forty plants in a line according to requirements of the Central Institute for Supervising and Testing in Agriculture. Ten mother plants are evaluated each year. Morphological characteristics including deviations from uniformity within a cultivar are regularly assessed. Yield per plant, content and composition of hop resins (EBC 7.4 – Analytica 1997), content and composition of hop oils (liquid chromatography) and mechanical analyses of dry cones are assessed in each mother plant. Each plant is harvested at technological maturity individually by harvested machine "Volf". Yield is expressed in kilograms of raw hop cones per plant. Conversion of the yield derives from the number of hop crowns per hectare, which represents 2 900 hop crowns per hectare under the spacing of 1.14 × 3.0 m. The soil of hop garden is alluvial, sandy with colluvial and alluvial sediments. The soil is skeletal, more than 60 cm deep.

By comparing the course of temperatures and precipitation in the years 2010 to 2019 with the normal, the individual years can be divided as follows (Klabzuba et al. 1999):

– temperature: normal (2010, 2013 and 2017), warm (2011, 2012 and 2014), strongly warm (2015, 2016 and 2019) and extremely warm (2018).
– precipitation: dry (2018 and 2019), normal (2012, 2015, 2016 and 2017), very humid (2013) and extremely humid (2010, 2011 and 2014).

The following basic statistic parameters were used: mean (x) and standard deviation (s). Relative variability is used if arrays varying by their level are compared. As relative variability values are non-dimensional numbers (usually in %), it enables to compare statistical features differing in units of measurement. Variance coefficient (Vk) was used to process the data. It expresses the extent of variability in %. Differences in significance among the cultivars were set up with the help of the t-test. Difference of arrays is determined based the level of significance (α) which says to what probability are the tested arrays different (Meloun and Militký 1994), e.g. level of significance, where $\alpha = 0.01$ says that the assessed arrays are different with 99% probability.

RESULTS AND DISCUSSION

It is obvious from Table 1 that the highest yield (kilograms of raw hop cones) was reached in cv. Kazbek (3.66 kg/plant). The other cultivars Bor, Gaia, Saaz Late, Vital and Rubín show the yield at the level of 3.0 kg/plant, which is 2.18 t/ha. The lowest yield was found in cv. Saazer (2.02 kg/plant), which is 1.46 t/ha. Czech cultivars show relatively high variability. The lowest one have been found for cvs. Rubín and

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Table 1. Average yield and variability in Czech hop cultivars (Stekník, Czech Republic, 2010–2019)

Cultivar	Yield (kg/plant)	s	Variance coefficient (%)
Kazbek	3.66	1.351	36.87
Bor	3.39	1.141	33.61
Gaia	3.25	0.887	27.31
Saaz Late	3.24	0.892	27.50
Vital	3.06	0.597	19.53
Rubín	3.01	0.521	17.31
Bohemie	2.93	1.031	35.24
Sládek	2.81	0.894	31.77
Agnus	2.81	0.825	29.37
Harmonie	2.79	0.634	22.76
Premiant	2.51	0.504	20.14
Boomerang	2.31	0.402	17.42
Saazer	2.02	0.431	24.39

s – standard deviation

Boomerang, whereas the highest for cv. Kazbek. A high variability was shown also for cvs. Bohemie, Bor and Sládek. Because of high variability there is very low significance of differences in the yield within the assessed cultivars. Conclusively, according to *t*-test the significantly lowest yield was shown in cv. Premiant compared with cvs. Kazbek, Bor, Gaia, Saaz Late, Vital and Rubín. Cvs. Boomerang and Saazer have significantly lower yield than cvs. Bohemie, Sládek, Agnus and Harmonie. Within cultivars tolerant to *Verticillium nonalfalfae*, cv. Kazbek shows the highest yield but unfortunately under higher variability. The yield (raw hop cones) of world hop cultivars tolerant to *Verticillium nonalfalfae* is in the range from 1.16 kg/plant (cv. BramlingCross) to 3.37 kg/plant (cv. Target) (Nesvadba and Charvátová 2020).

Average content of alpha acids in the studied Czech hop cultivars amounts to 8.14% *w*/*w*, but under a relatively high variability (42.45%) as obvious from Table 2. The highest content of alpha acids was observed in cv. Gaia. Statistical conclusiveness of higher content of alpha acids of this cultivar was determined with the help of *t*-test. Only cvs. Gaia, Vital and Boomerang overpass the level of x + s (11.59% *w*/*w*). Cvs. Vital, Boomerang, Rubín and Agnus have the content of alpha acids above the level of 10.0% *w*/*w* and show significantly higher content than the other followed cultivars. The alpha acid contents correspond to the category of bitter hops (Krofta and Patzak 2011). Other cultivars belong to the group of aroma hops (Nesvadba et al. 2013). Premiant (7.54% *w*/*w*) and Bor (7.47% *w*/*w*) are the most productive among aroma cultivars. Conclusiveness was not found out only in relation to cv. Harmonie, which shows significantly higher content of alpha acids than cvs. Bohemie, Saaz Late and Saazer. Only cvs. Saaz Late and Saazer showed the value of x – s under 4.69% *w*/*w*. Average content of beta acids amounts to 5.38% under the variability of 25.11%. As obvious from Table 2, conclusively the highest content of beta acids was observed in cvs. Gaia, Vital, Boomerang as well as the only aroma cultivar Bohemie. Only cvs. Gaia, Vital and Boomerang have simultaneously higher content of beta acids above the level of x + s (6.74% *w*/*w*). On the contrary, the lowest content of beta acids was shown in cvs. Premiant, Kazbek, Saazer, Rubín and Bor. Under the level of x – s (4.03% *w*/*w*) only Saazer, Bor and Rubín were reported.

Table 2. Average content and composition of hop resins in Czech cultivars (Stekník, Czech Republic, 2010–2019)

Cultivar	Alpha acids	Beta acids	Alpha/beta ratio	Cohumulone (% rel.)
	(% *w*/*w*)			
Gaia	13.81	7.56	1.91	24.38
Vital	12.31	7.35	1.70	22.03
Boomerang	11.60	6.83	1.71	31.59
Rubín	11.38	3.88	2.94	27.81
Agnus	10.69	5.33	2.07	33.62
Premiant	7.54	4.28	1.84	19.63
Bor	7.47	3.69	2.10	21.11
Harmonie	7.00	5.74	1.23	20.92
Sládek	5.94	5.39	1.14	24.91
Kazbek	5.72	4.20	1.37	36.67
Bohemie	5.48	6.50	0.86	24.06
Saaz Late	4.06	5.32	0.75	23.36
Saazer	2.87	3.93	0.77	21.95
x	8.14	5.38	1.57	25.54
s	3.45	1.35	0.63	5.33
Vk	42.35	25.11	40.28	20.86
x – s	4.69	4.03	0.94	20.21
x + s	11.59	6.74	2.20	30.87
x – 2s	1.25	2.68	0.30	14.88
x + 2s	15.04	8.09	2.83	36.20

x – mean; s – standard deviation; Vk – Variance coefficient

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Average ratio of cohumulone is 25.54% rel. under variability of 20.86%. As obvious from Table 2, cv. Kazbek has significantly the highest ratio of cohumulone (36.67% rel.). It is the only cultivar with the ratio of cohumulone above the level of x + 2s (36.20% rel.). High ratio of cohumulone was recorded also in cvs. Agnus and Boomerang, which is significant in relation to the other cultivars and at the same time it is above the level of x + s (30.87% rel.). Only cv. Premiant was under the level of x – s (20.21% rel.). It is interesting that even though cvs. Gaia, Boomerang, Agnus and Vital are genetically close, cv. Vital shows a low ratio of cohumulone.

Within cultivars tolerant to *Verticillium nonalfalfae* Vital and Agnus have significantly higher content of alpha acids than cvs. Sládek and Kazbek. Cv. Vital has significantly higher content of beta acids than cvs. Sládek, Agnus and Kazbek. On the contrary, cv. Kazbek shows significantly lower content of beta acids than cvs. Vital, Sládek and Agnus. A significant difference in the ratio of cohumulone among cvs. Kazbek, Agnus, Sládek and Vital was determined with the help of *t*-test.

Variability in the contents and composition of hop resins from 2010 till 2019 is shown in Table 3. Cv. Boomerang has the lowest year-to-year variability in the content of alpha acids (8.19%) and beta acids (8.03%). Cv. Rubín shows also very low variability in the content of both alpha and beta acids. Cv. Rubín has also the lowest variability in the ratio of alpha/beta. The highest variability in the content of alpha acids was found in cv. Saaz Late, whereas cv. Bor showed the lowest variability in the content of beta acids. It is interesting that the highest variability in the ratio alpha/beta was found in cv. Saazer. It was caused by the fact that in 2010, 2012, 2014 and 2017 the alpha/beta ratio was 0.6, whereas in 2013, 2016 and 2019 it was much higher (up to 1.1). Very low variability is in the ratio of cohumulone: from 6.15% (cv. Sládek) to 12.74% (cv. Harmonie). Probably it is a genetically based characteristics, which is not substantially influenced by environment. It is also the reason why there are significant differences among the individual cultivars, even though the average value is not very different.

Table 3. Variability in the content and composition of hop resins in Czech cultivars (Stekník, Czech Republic, 2010–2019)

Cultivar	Variability (%)			
	alpha acids	beta acids	alpha/beta ratio	cohumulone
Boomerang	8.19	8.03	10.89	12.13
Rubín	10.05	9.44	8.80	10.25
Vital	10.38	15.32	17.15	9.23
Gaia	10.59	23.49	20.91	11.05
Bohemie	13.12	17.27	20.48	6.92
Premiant	14.14	29.41	20.03	10.09
Agnus	14.37	22.40	18.46	9.50
Bor	16.96	30.18	17.09	8.25
Kazbek	19.16	14.36	15.01	6.55
Sládek	20.79	28.32	19.64	6.15
Saazer	25.38	22.75	34.19	6.32
Harmonie	29.64	27.63	20.83	12.74
Saaz Late	39.14	15.03	30.04	6.69

Cv. Vital shows the lowest variability in the content and composition of hop resins from the group of cultivars tolerant to *Verticillium nonalfalfae*.

Composition of essential oils in all tested cultivars is shown in Table 4. The cultivars have average ratio of myrcene (31.61% rel.) under 20.42% variability. On the basis of statistical analyses, only cv. Saazer has a very low ratio of myrcene. It nearly reaches the level of x – 2s (18.70% rel.). On the contrary, the highest ratio of myrcene is shown in cv. Boomerang, which is above the level x + 2s and cv. Vital, which is above the level of x + s. The average ratio of caryophyllene is 10.33% rel., under variability of 19.87%. Ratio of myrcene and caryophyllene show the lowest variability within the hop essential oils. The ratio of caryophyllene under the level of x – s was recorded by cvs. Vital, Bohemie and Saazer. On the contrary, the highest ratio of caryophyllene, above the level of x + s, was observed in cvs. Saaz Late and Sládek. Surprisingly, the ratio average ratio of farnesene amounts to 2.88% rel. but under a high variability (147.82%). The highest average ratio of farnesene was recorded in cv. Saazer, which exceeds the level of x + 2s. High ratio of farnesene was also reported in cv. Saaz Late, which is above the level of x + s. Ratio of farnesene under the level of 1.0% was found in cvs. Harmonie, Rubín, Sládek, Kazbek, Agnus and Bor. The average ratio of humulene amounts to 20.92% rel. under 48.56% variability. Only cvs. Vital and Gaia were under the level of x – s (10.76% rel.). On the contrary, the highest ratio of humulene was recorded in cvs. Bor and Premiant. The average ratio of selinene is also remarkable, being 8.11% rel., yet, it is highly variable (94.53%). None of the cultivars show the ratio of selinene under the level of x – s

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Table 4. Composition of essential oils in Czech hop cultivars (Stekník, Czech Republic, 2010–2019)

Cultivar	Myrcene	Caryophyllene	Farnesene	Humulene	Selinene
			(% rel.)		
Gaia	37.05	11.93	5.03	2.58	19.77
Vital	40.02	7.30	1.61	2.15	18.83
Boomerang	44.97	8.87	3.12	18.03	0.92
Rubín	28.02	8.82	0.17	21.50	18.83
Agnus	29.83	12.15	0.27	19.57	3.02
Premiant	27.27	11.76	1.68	35.29	2.73
Bor	29.35	11.22	0.31	35.76	2.04
Harmonie	31.62	8.58	0.13	22.54	16.76
Sládek	30.08	13.14	0.23	29.33	1.80
Kazbek	34.45	10.95	0.26	18.76	3.39
Bohemie	28.60	8.08	1.01	21.17	10.82
Saaz Late	30.80	13.16	10.22	18.85	4.70
Saazer	18.91	8.26	13.34	26.40	1.80
x	31.61	10.33	2.88	20.92	8.11
s	6.46	2.05	4.25	10.16	7.66
Vk	20.42	19.87	147.82	48.56	94.53
x – s	25.16	8.28	–1.38	10.76	0.44
x + s	38.07	12.39	7.13	31.08	15.77
x – 2s	18.70	6.23	–5.63	0.60	–7.22
x + 2s	44.53	14.44	11.38	41.23	23.44

x – mean; s – standard deviation; Vk – Variance coefficient

or x – 2s. The highest ratio of selinene, above the level of x + s, was found in cvs. Rubín, Vital, Gaia and Harmonie. Cultivars tolerant to *Verticillium nonalfalfae* differ only in the ratio of caryophyllene. Cv. Vital was under the level of x – s (7.30% rel.), whereas cv. Sládek was above the level of x + s (13.14% rel.). None of these cultivars exceed the level of x – s or x + s in the other components of essential oils. High ratio of myrcene is not desirable. High ratio of farnesene characterises the origin after cv. Saazer. High ratio of selinene adversely affects the hop aroma. The contents of hop essential oils in world hop cultivars amount from 0.5% to 3.5% nevertheless for the flavour hops the low content of compounds is also important (Vollmer and Shellhammer 2016).

Ten-year results are very valuable. The stability of the monitored features is important. Cvs. Rubín, Boomerang and Vital have the lowest variability of hop yield (below 20%). These cultivars will show stable production in cultivation practice. On the contrary, cvs. Kazbek, Bohemie, Bor and Sládek, which have variability over 30%, will show an unstable yield. Cv. Boomerang has the lowest year-on-year fluctuations in alpha and beta acid content (variability is below 10%). On the other hand, cv. Saaz Late (variability 39.14%) and cv. Bor (variability 30.18%) have the highest fluctuations in the alpha acid content and weather dependence. The dry years 2018 and 2019 did not suit cv. Saaz Late because it had the lowest alpha and beta acid contents. The dry years 2018 and 2019 also did not suit cv. Bohemie, which had the lowest yields. On the contrary, cv. Rubín had the highest hop yield in 2019. An exceptionally warm year was not suitable for the cvs. Vital and Agnus, which had the lowest content of alpha and beta acids in 2018. In dry years, also cv. Premiant had the lowest hop yield. Fixed productivity is a very important feature. The obtained results are very important not only for hop growers but for hop merchants and brewers as well. It is obvious, which cultivars show fixed production and in which cultivars year-to-year fluctuations can be expected. The data are also important for hop breeding process, where stable cultivars are commonly used for getting new genotypes tolerant/resistant to abiotic factors.

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