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Evaluation of hop yield stability in Czech bitter hop varieties

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Abstract

Between the years 2011 and 2022, the Czech hop varieties Agnus, Rubín, Vital, Gaia and Boomerang were evaluated in terms of their hop yield. The highest hop yield was recorded in Gaia (2.99 kg/plant) and Vital (2.92 kg/plant). Boomerang had the lowest yield (2.11 kg/plant.). The lowest variability of yield was determined in Vital (19.74%) and the highest in Boomerang (33.29%) and Agnus (32.98%). Vital demonstrated the lowest decreasing trend of hop yield over a period of 12 years. Rubín showed the highest decreasing trend.

Keywords: hop; Humulus lupulus L.; yield; variability

1 Introduction

Saaz is the best known Czech hop variety around the world. The fine aroma hops have a mild hoppy aroma, a content of alpha acids ranging between 2.5 and 4.5% w/w, and a balanced ratio of alpha and beta acids (Nesvadba et al., 2012). The hop oils of Saaz typically have a higher share of farnesene (Nesvadba et al., 2013). Saaz is the most suitable hop variety for lager beer. This hop cultivar was gained by clonal selection and is currently grown in the form of three Osvald clones – 31, 72 and 114 (Fric, 1992). Hop hybridization or cross-breeding was introduced in the 1960s (Rígr, 1997). Hop breeders still aimed to develop new aroma hop varieties, i.e. hops with a hoppy aroma but a higher content of alpha acids and a higher yield. In 1994, the first hybrid aroma hop varieties – Bor and Sládek – were registered. The registration of additional aroma hop varieties such as Premiant, Harmonie, Bohemie and Saaz Late followed (Krofta and Patzak, 2011).

At the end of the 20th century, hop breeding focused on the development of high-alpha hop varieties. High-alpha hops such as Target, Magnum, Taurus (Germany) and Columbus (US) with an alpha acid content between 10 and 15% were registered abroad. Later on, this group of hops was referred to as bitter hops. The Czech Republic´s first bitter hop variety – Agnus – was registered in 2001 (Nesvadba, 2002). Rubín was registered as the second bitter hop variety in 2007. Rubín is characterized by a higher content of alpha acids and a lower beta content, and therefore its alpha/beta ratio is about 3 (Nesvadba, 2008). Vital was registered in 2008, primarily for biomedical applications. The hop variety is characterized by a xanthohumol content above 1% w/w and a content of desmethylxanthohumol over 0.4% w/w (Krofta et al., 2011). Hop breeding focused on aroma hops but the breeding of bitter hops continued as well. The objective was to gain hop varieties with a higher content of alpha bitter acids and a higher hop yield (Nesvadba et al., 2016). In 2017, two new bitter hop varieties – Gaia and Boomerang – were registered (Nesvadba, 2017). In 2022, bitter hop varieties are grown on 76 ha (Kršková, 2022).

Hop breeding has several objectives. The main objective of hop breeding is resistance to fungal diseases (Trefilova et al., 2022). When it comes to profitability of hop growing, hop yield and most importantly its stability are crucial (Čerenak, 2015). Stability of hop yield is important not only for hop growers but also for breweries. The growing areas of hop varieties correspond to the require-

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ments from breweries. If there is a high variability in hop production, breweries experience problems with hop supply. On the other hand, if hop yields are very high, the hops tend to be unsellable. Climate change has caused high variability of hop yield in some hop varieties (Nesvadba et al., 2020). Currently, hop breeding is focused on achieving drought resistance and reducing year-on-year variability in hop yield (Nesvadba et al., 2022a).

The aim of this study is to evaluate a stability of hop aroma in bitter hop varieties. Monitoring a stability of specific characteristics in the desired hop varieties that are regularly delivered to breweries is essential. Varieties with high variability are not reliable to ensure the quality of hop production (Nesvadba and Krofta, 2005).

2 Materials and methods

Five bitter hop varieties that are currently registered in the Czech Republic were evaluated between the years 2012 and 2022. They are as follows:

- **Agnus** (registered in 2001) was gained by selection from hybrid descendants with the Sládek, Bor, Saaz, Northern Brewer and Fuggle hop varieties as well as additional breeding materials in their origin.
- **Rubín** (registered in 2007) was gained by selection from the descendants of Bor and a male plant that is a multiple cross of hybrid materials (Saaz and Northern Brewer).
- **Vital** (registered in 2008) was developed from the Agnus maternal variety and a paternal plant from semi-finished breeding materials.
- **Gaia** (registered in 2017) was gained from Agnus and a male plant originating from the Yeoman hop variety from England and breeding materials of Czech and foreign hop varieties.
- **Boomerang** (registered in 2017) was developed by selection from hybrid descendants originating from the multiple hybridization of Agnus, Magnum and Premiant as well as semi-finished breeding materials with Saaz, Sládek, Northern Brewer and Fuggle in their origin.

The Gaia and Boomerang varieties have already been evaluated during their registration tests since 2011.

The evaluation was carried out in the Žatec region in the village of Stekník (GPS 50.324085; 13.523169).

The evaluated genotypes are grown under the following conditions: The hop field is located at an altitude of 215 meters in the Žatec hop growing region and the Ohře River Basin hop growing location. The region is warm and dry. The sum of temperatures above 10 °C amounts to 2,600–2,800 °C per year. The hop plants have been grown since 2010.

Soil characteristics: From a pedological perspective, there are alluvial soils, which are light with colluvial and alluvial sediments and they can get dry. Soil angle shows a complete plain with no signs of sheet water erosion, the land is exposed on all sides. The soil is skeletonless with a depth of more than 60 cm.

This evaluation was part of a more extensive analysis of maternal plants in maintenance breeding. Such plants are not revived since they constitute an original maternal material. At least 40 plants of each hop variety are monitored in maintenance breeding and 10 mother plants are evaluated annually. Each mother plant is evaluated in terms of its morphological characteristics. Deviations from uniformity of the hop variety are monitored. Characteristics evaluated in every mother plant include hop yield, content and composition of hop resins, content and composition of hop oils, mechanical analyses of dry hop cones and aroma of hop cones.

Each plant is harvested separately. An experimental Wolf picking machine is used for hop picking. Yield is shown in kg of fresh hops per plant (hereinafter: kg/plant). The conversion of hop yield is based on the number of plants per hectare, which amounts to 2,900 plants at a spacing of 1.14 × 3.00 m. The coefficient of dry matter in fresh hops and dry hops is 4 (Krofta, 2008), and this parameter allows estimating the yield of dry hops. For example, if the yield of fresh hops is 3 kg per plant and the number of plants is 2,900 per hectare, the expected yield of dry hops is 2.2 t/ha.

The following statistics were prepared: average (x) and standard deviation (s). Relative amount of variability is used to compare a set with different levels. Resulting variability amounts are dimensionless numbers (mostly in %). This makes it possible to compare the variability of statistical features differing in measure units. Coefficient of variation (CV), showing the extent of variability in %, was used for data processing. A paired t-test was applied to determine and prove the difference between hop varieties. The difference of sets was determined on the basis of significance level (α), which shows the probability of difference of the tested sets (Meloun and Militký, 1994). For example, if the significance level is determined as $\alpha = 0.01$, it means there is a 99% probability that the sets under review are different. Linear regression was used to evaluate a trend over a period of 10 years. Dependence was determined by using the coefficient of determination (r^2). One hundred times r^2 indicates how much the yield value is affected by the age of the plants.

3 Results and discussion

Figure 1 shows that the highest average yield was recorded in Gaia (2.99 kg/plant). However, the difference of its yield is statistically significant only when compared to Rubín, Agnus and Boomerang (Table 1). The significance of difference was determined by using a paired t-test in order to eliminate the year-on-year variability. This method is used to compare hop yield in a given year and not between years. The Vital variety shows a significantly higher yield than Agnus and Boomerang. The Boomerang variety has the significantly lowest hop yield among the bitter hops, namely 2.11 kg/plant. The converted yield of these hop varieties ranges from 1.58 (Boomerang) to 2.24 (Gaia) tons of dry hops per hectare.

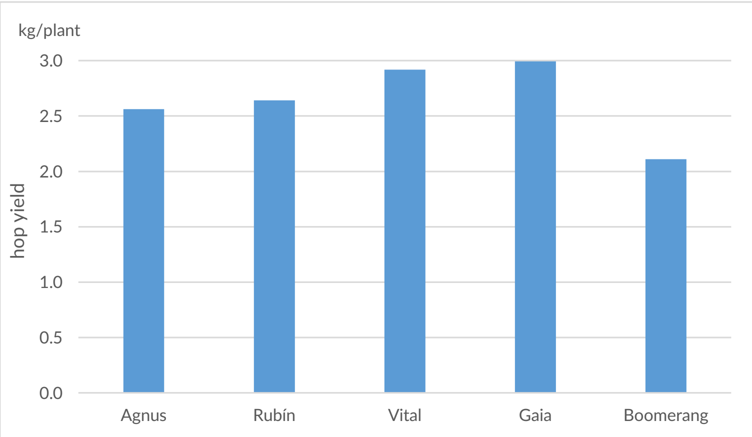

Figure 1 *Average hop yield (Stekník, 2011–2022)*

Evaluation of yield variability is very important for ensuring stability in the production of a particular hop variety. Variability expressed by a centuple of the coefficient of variation shows the impact of the time series on the variability of hop yield. Figure 2 makes it clear that the impact of the growing year on the variability of hop yield in Vital is 19.74%. In contrast, the impact of the growing year on Agnus and Boomerang is above 30%. The results show that the hop yield of Vital has a different genetic basis than that of Agnus and Boomerang. From this perspective, Vital is likely to show a lower year-on-year variability of hop yield.

Compared to the results from the Chrášťany area (Rakovník hop growing region and dry locality), these results are somewhat different (Nesvadba et al., 2022b). Between the years 2018 and 2022, Boomerang has the lowest variability of hop yield (14.97%). Gaia also shows a lower variability in this location (22.05%). A higher variability was determined in Vital (23.19%). Rubín has almost the same variability – 27.81%. Agnus is not tested in this location.

Within an 11-year time series, based on linear regression, all hop varieties show a decrease in hop yield (Table 2). The decrease in hop yield over a period of 11 years demonstrates a high level of reliability in Rubín ($r^2 = 0.58$); (Meloun and Militký, 1994). In contrast, a very low level of reliability was determined in Vital ($r^2 = 0.03$). The remaining hop varieties have a low reliability level as well. The results show that only Rubín experiences a decrease in hop yield due to aging, the impact being 58%. The decrease in the hop yield of the remaining hop varieties is due to other influences (agrotechnology, temperature, precipitation etc.) rather than aging.

Table 1 *Significance of difference determined by using a paired t-test with significance level α*

	Gaia	Vital	Rubín	Agnus
Vital	–			
Rubín	0.1	–		
Agnus	0.1	0.05	–	
Boomerang	0.01	0.01	0.01	0.05

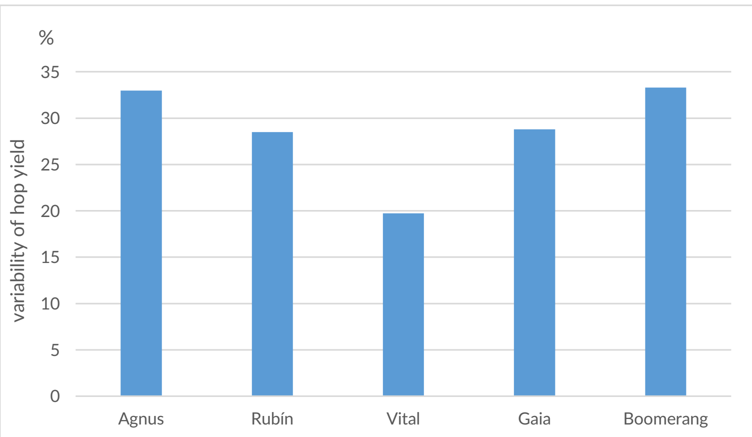

Figure 2 *Average variability of hop yield (Stekník, 2011–2022)*

Agnus has a decreasing linear regression trend (Figure 3). The linear regression line demonstrates an annual decrease of hop yield by 0.12 kg/plant. Agnus had the highest hop yield in 2013 (4.40 kg/plant) and the lowest yield in 2022 (1.27 kg/plant). A low yield was recorded in 2016 as well. In contrast, hop yield above 3.00 kg/plant was determined in the years 2018 and 2019.

Table 2 *Linear regression equation (y) and reliability value (r^2) of hop yield*

Hop variety	y	r^2
Agnus	-0.1169x + 238.37	0.21
Rubín	-0.1879x + 381.66	0.58
Vital	-0.0315x + 66.363	0.03
Gaia	-0.1189x + 242.83	0.21
Boomerang	-0.1026x + 209.13	0.23

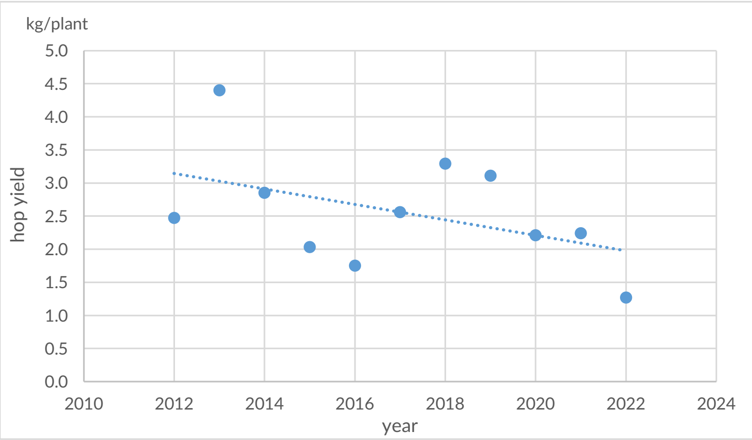

Figure 3 *Hop yield trend of Agnus (Stekník, 2011–2022)*

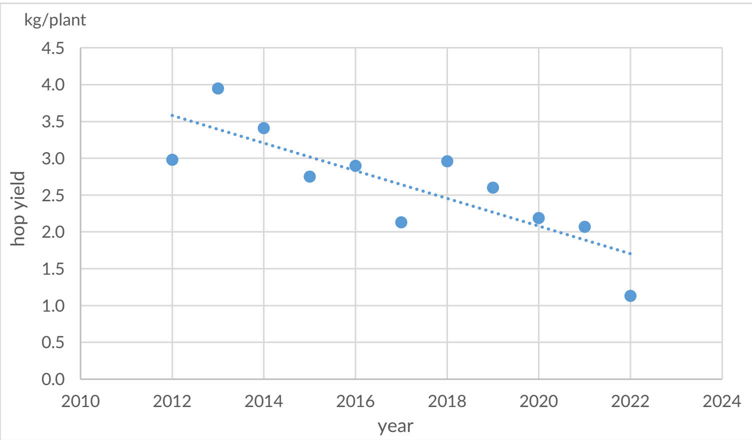

Figure 4 *Hop yield trend of Rubín (Stekník, 2011–2022)*

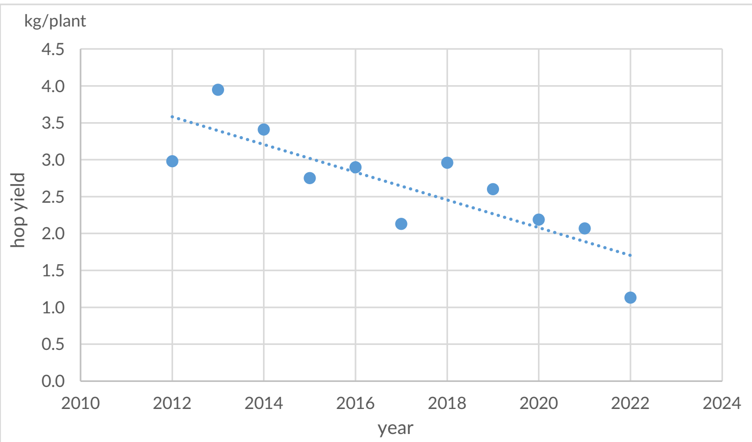

Figure 5 *Hop yield trend of Vital (Stekník, 2011–2022)*

Rubín shows a high decreasing linear trend (Figure 4). The annual decrease amounts to 0.19 kg/plant. This trend was influenced by high yields between the years 2012 and 2014 and low yields in the years 2020 to 2022 (the hop yield was below 2.20 kg/plant in these years). Rubín is likely to show a decrease in hop yield after the eighth year of growing.

Vital also shows a decreasing linear trend. However, it is negligible (Figure 5). Year-on-year decrease of this line is only 0.03 kg/plants per year. The highest yields – 4.00 kg/plant – were recorded in 2013 and 2019. The lowest yields below 2.50 kg/plant were determined in 2014, 2020 and 2022. The results of the hop yield trend in the years 2012 to 2022 show that Vital achieves stable hop yields.

Figure 6 makes it evident that Gaia has a decreasing linear regression trend, similarly to Agnus. The highest yields at the level of 4.00 kg/plant were achieved in the years 2013, 2014 and 2017. The lowest hop yield was recorded in 2012 (1.98 kg/plant). The figure shows that Gaia started generating hop yield at the level of 2.5 kg/plant (i.e. 1.9 tons/hectare) in 2018 (after the sixth year of cultivation).

The nature of the linear regression trend of Boomerang is the same as that of Agnus and Gaia. This trend was influenced by the highest hop yield in 2013 (3.30 kg/plant) and the lowest hop yield in 2022 (0.73 kg/plant). In the remaining years, the hop yield trend ranged between 1.5 and 2.80 kg/plant.

4 Conclusion

The evaluation of variability is of great importance for breweries when it comes to the production stability of requested hop varieties. From the perspective of hop growers, the stability of a hop variety is a good criterion for decisions on the composition of hop varieties to be planted. Hop varieties showing a low variability of hop yield guarantee the same profitability over a cultivation period, which is 10 to 15 years. At the same time, these hop varieties are used in hop breeding aimed at drought resistance. The results demonstrate that Vital has the lowest variability of hop yield. In contrast, Boomerang has the highest variability. It should be mentioned that the results are related to one location only – the location in which Vital shows the best results. It is necessary to use these findings when searching for more suitable growing locations for Boomerang, which has a low hop yield and a higher variability, and also for Rubín, which demonstrates the highest yield decrease trend in this location.

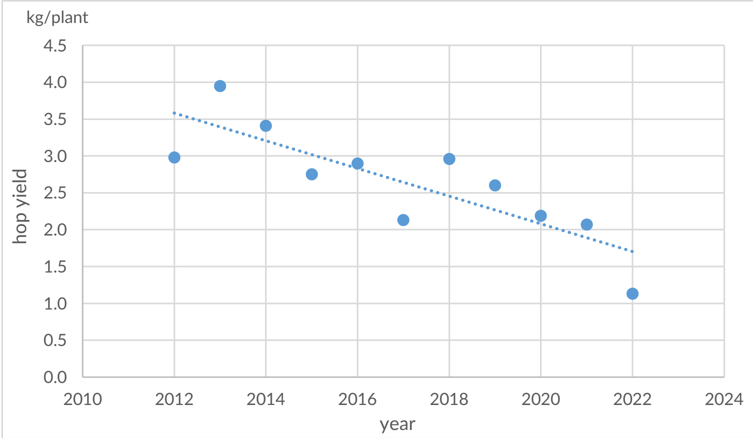

Figure 6 *Hop yield trend of Gaia (Stekník, 2011–2022)*

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