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The impact of dry and wet events on the quality and yield of Saaz hops in the Czech hop growing regions

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Abstract

This study deals to investigate the impact of dry and wet conditions on the inter-annual variability of yield and quality parameters of hops (*Humulus lupulus* L.) in the Czech hop cultivation regions. The Standardized Precipitation Evapotranspiration Index (SPEI) was used to quantify the dry and wet conditions for each month of the year and 6 accumulated lags from 1961 to 2012. The statistical analysis of hop production was conducted using the cultivation area (ha) and yield of Saaz semi-early red bine hop (t/ha) over the Czech Republic as a whole (1920–2012) and for three Czech hop growing regions (1992-2012). Datasets of alpha-acids content (%) of Saaz semi-early red bine hop between 1967 and 2012 for Žatec and from 1992 to 2012 for Úštěk and Tršice regions were processed. Additionally, data of alpha-acids content (%) of Bór and Sládek hybrid varieties growing in Žatec region (1979-2012) was obtained from Hop Research Institute Saaz.

Key words: SPEI, alpha-acids content, hybrid varieties, Bór, Sládek

Introduction

The hop growing in the Czech Republic is concentrated in three hop cultivation regions (Žatec, Úštěk, Tršice) out of which the largest and most important is the Žatec area. At present hops cultivation areas are significantly less represented at 2%. The growing season of hops (from bud burst to cone development) takes 102 days on average with the sum of air temperatures 1537 °C, the duration of sunshine is 731 hours, the rainfall amount is 176 mm and with 28.5 days with precipitation total of at least 1 mm (Hájková L. et al. 2012).

The growth and development of hops plants is adversely influenced by droughts, moreover, an essential part of Žatec hop-growing region is situated in the rain shadow. The lowland regions of the Czech Republic experienced a general drying trend in the spring months at short-term lags, whilst at the end of the 20th century, drought during the April-June period became a factor explaining a considerable proportion of the yield variability (Potop et al., 2014). Moisture deficit during the hop growing season was found to cause reductions in hop cone yield (e.g. Hnilickova et al. 2009).

In this study deals to investigate the impact of drought (wet) on the inter-annual variability of yield and quality parameters of hops using the Standardized Precipitation Evapotranspiration Index (SPEI).

Materials and methods

The statistical analysis of hop production was conducted using the growing area (ha) and the yield of Saaz semi-early red bine hop (t/ha) over the Czech Republic as a whole (1920–2012) and for Žatec, Úštěk and Tršice growing regions (1992-2012). Dataset of the content of alpha-bitter acids (%) of Saaz semi-early red bine hop from 1967 to 2012 for Žatec and from 1992 to 2012 for Úštěc and Tršice regions was processed. In addition, content of alpha-bitter acids (%) of Bór and Sládek hybrid varieties growing in Žatec region in the period 1979-2012 was obtained from Hop Research Institute Saaz.

To identify the impact of the SPEI inter-annual variability of yield and quality parameters of hops, the evolution of cumulative moisture conditions from 1 to 6-month lags from 1961 to 2012 was applied. In the current study, recently improvement methods to calculate the SPEI was used (Beguería et al., 2013). The SPEI dataset used in this paper was downscaled from the SPEI Global Drought Monitor (http://sac.csic.es/spei.htm) at Žatec, Doksany and Olomouc climatological stations coordinates.

The indicator of agricultural drought impact may be represented by the residuals of the de-trended yield. To eliminate bias due to non-climatic factors, the trend was removed using linear regression when calculating yield variability. The residual variation reflects the effects of weather on yield, and the residuals

amplify the yield departures from normal weather conditions. To compare α-acids contents variability among varieties and regions with different mean values and standard deviations, the α-acids contents residuals were standardized for each hop series using the Z-score transformation, quantifying the original score in terms of the number of standard deviations that the score is from the mean of the distribution. Subsequent analyses were done on the standardized content of alpha-bitter acids residuals series. The impact of the SPEI inter-annual variability on the yield and quality parameters of hops was evaluated by correlations of the non-parametric Spearman's Rho coefficient.

Results

Statistical analysis of productivity parameters of hop varieties

A more detailed analysis of the average Saaz yields (tha^{-1}) and cultivated areas (ha) over the Czech Republic as a whole (1920–2012) and for three Czech hop growing regions (1992-2012) was conducted (Table 1). At the national level, the Saaz yield series show significant inter-annual variation and their average value for the 1920-2012 period was 0.9 tha^{-1} with a large values of the variation coefficient (Cv=0.28). The highest historically yields was achieved in 2010 (1.9 tha^{-1}), while the lowest harvested yields in 1952 (0.3 tha^{-1}).

As shown in tab. 1, the extent of Saaz hop land area has been reduced. The highest cultivation area was recorded in 1929 (17264 ha), and the lowest in 2012 (only 4366 ha). The year 1929 was significantly for the Czech Republic and undoubtedly was the largest producer of hops in the world, both in terms of production areas and export. The reduction cultivation areas are most pronounced in the 2000s over Uštěk and Tršice hop-growing regions.

In the tab. 1 is also statistically processed quality parameters such as average α-acids content (%) of Saaz hops in the three growing areas. The longest time series of α-acids content are available between 1967 and 2012 at Žatec, while at Uštěk and Tršice for the period 1994-2012. The alpha-acid contents varied from year to year and from region to region. In Žatec the lowest α-acid was achieved in 1999, and the highest in 1968. Whilst in Uštěk and Tršice regions,

the minimum α-acids content was recorded in 1994, and reached a peak in 1996.

Tab. 1 The quality and yield parameters of Saaz semi-early red bine hop at the country and region levels

		Žatec	**Uštěk**	**Tršice**
	1920-2012	1992-2012		
yield tha^{-1}				
mean	0.9	1.0	1.1	1.3
min	0.3 (**1952**)	0.8 (**2000**)	0.9 (**1994**)	0.8 (**1993**)
max	1.9 (**2010**)	1.5 (**2010**)	1.5 (**2005**)	1.8 (**2005**)
Cv	0.28	0.18	0.15	0.23
cultivation areas (ha)				
mean	9181.3	4988.2	920.9	778.4
min	4366.0 (**2012)**	3400.0 (**2012**)	466.0 (**2012**)	500.0 (**2012**)
max	17264.0 (**1929**)	7672.0 (**1993**)	1884.0 (**1993**)	1153.0 (**1992**)
Cv	0.28	0.28	0.46	0.26
alpha-acids content (%)				
	-	1967-2012	1994-2012	
mean	-	3.9	3.5	3.4
min	-	1.9 (**1999**)	2.0 (**1994**)	2.3 (**1994**)
max	-	6.8 (**1968**)	4.4 (**1996**)	4.8 (**1996**)
Cv	-	0.28	0.19	0.23

Tab. 2 The alpha-acids content (%) in hybrid varieties growing in Žatec area (1979- 2012)

	hybrid varieties	
	Bor	Sládek
mean	8.9	8.0
min	5.5 (**1998**)	5.4 (**1983**)
max	13.0 (**1987**)	11.2 (**1988**)
Cv	0.20	0.20

Table 2 shows the descriptive statistics of α-acids content in hybrid varieties for Žatec area over the period 1979-2012. The hybrid varieties are more productive than Saaz hops, and yields are also more stable. The minimum values of α-acids content were in the years 1998 (Bor) and 1983 (Sladek), the maximum values were in the years 1987 (Bor) and 1988 (Sladek). The low temperatures in the first ten-days of August and the lack of soil moisture (SPEI≤-1) in 1998 adversely affected the development of Bor hop cones. The extreme high summer temperature in 1983 adversely affected the α-acids content of Sladek.

Evolution of the hops yield residuals series

Variability of the yield residuals (t/ha) from linear trend of Saaz semi-early red bine hop at the country and region levels are shown in fig. 1. For the entire country, according to the values of yield residuals series from 1920 to 2012, the 39 years are qualified as normal (mean); 28 years correspond to high yield losses and 26 years to high yield increment. The majority of low-yielding years of Saaz hope were concentrated in the periods of 1921-1930, 1941-1950, 1951-1960 and 1990-2000. The 75 % of these years have been identified as severe and extreme drought years by the SPEI (e.g., 1961, 1964, 1974, 1990, 1992, 1994, 2000, 2003 and 2012). The highest-yielding years were in the following years: 1937, 1939, 1963, 1969, 1970, 1988, 2005, 2010, and 2011. The years 1992, 1998, 2000, 2003, 2006, 2007, and 2012 appear to have the highest yield losses over Žatec region. The analysis of the temporal evolution of the yield hop residuals series indicates similar crop failures at Úštěk and Tršice regions (2012, 2003, 2000, 2007, 1994, and 2006). Thus, 2012 ranked at the top with respect to hop yield losses since 1992.

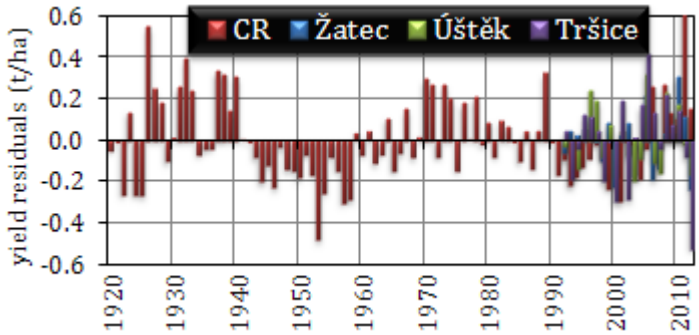

Fig. 1 Variability of the yield residuals (t/ha) from linear trend of Saaz semi-early red bine hop at the country and region levels

Evolution of standardized of α - acids content series

Standardized of alpha-acids content of Saaz semi-early red bine hop for 1967-2012 period at Žatec and 1992-2012 period at Úštěk and Tršice regions are shown in fig. 2. For Saaz hop, quality reduces in the Žatec cultivation area were detected by the standardized of alpha-acids content series for the years 1976 (-2.2), 1983 (-1.9), 1994 (-1.5), 1989 (-1.1) and 2006 (-1.0), and for the Úštěk area during the years 1994 (-1.5) and 2006 (-1.4). Over Tršice region, the

highest alpha-acids content reduces were in 1994 (-1.2), 2002 (-1.2), 2006 (-1.1), and 2007 (-1.0).

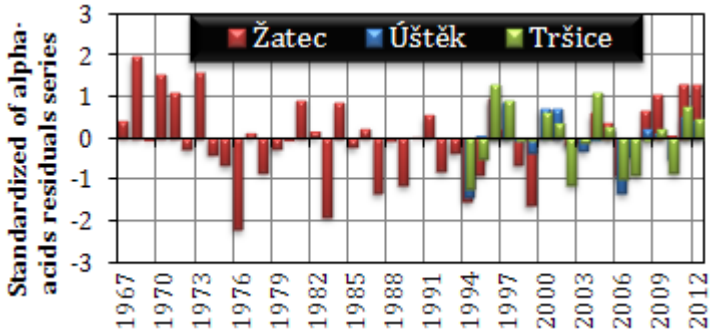

Fig. 2 Standardized of alpha-acids content of Saaz semi-early red bine hop for 1967-2012 period (Žatec) and 1992-2012 period (Úštěk and Tršice regions)

Figure 3 depicts temporal evolution of standardized of alpha-acids content of Bór and Sládek varieties growing in Žatec region for 1979-2012. The number of years with a standardized of alpha-acids content of Bór lower (higher) than -1.0 (+1.0) was 10 (12), whereas for Sládek was 12 (10). The standardized of alpha-acids content of Sládek detected reduces in the following years: 1999, 1983, 1998, 1982, 1990, 1994, 1986, 1992, 2011, 2004, 1989 and 2002 (scored by the highest losses), while for the Bór the highest losses occurred in 1998, 1983, 1994, 1991, 2002, 1992, 2008, 2006, 1979, and 1982.

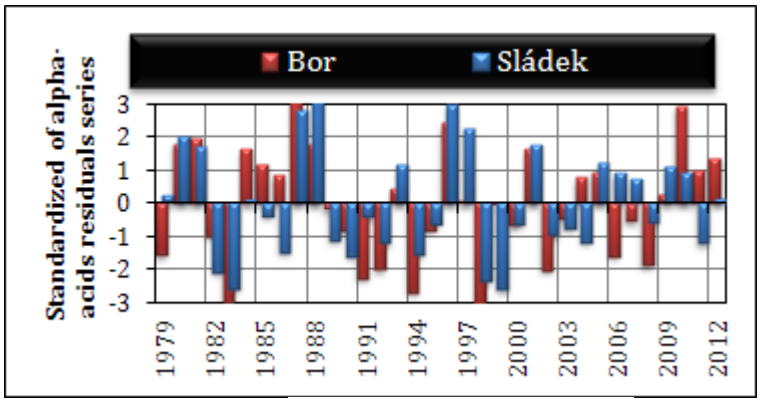

Fig. 3 Standardized of content of alpha-bitter acids (%) of Bór and Sládek varieties for 1979-2012 period (Žatec region)

Evolution of moisture conditions in the Czech hop cultivation areas

Moisture conditions in the Czech hop cultivation areas between 1961 and 2012 are illustrated by SPEI variation. Temporal evolution of dry and wet events quantified by the SPEI at 6-month lags (upper panel) and frequency distribution

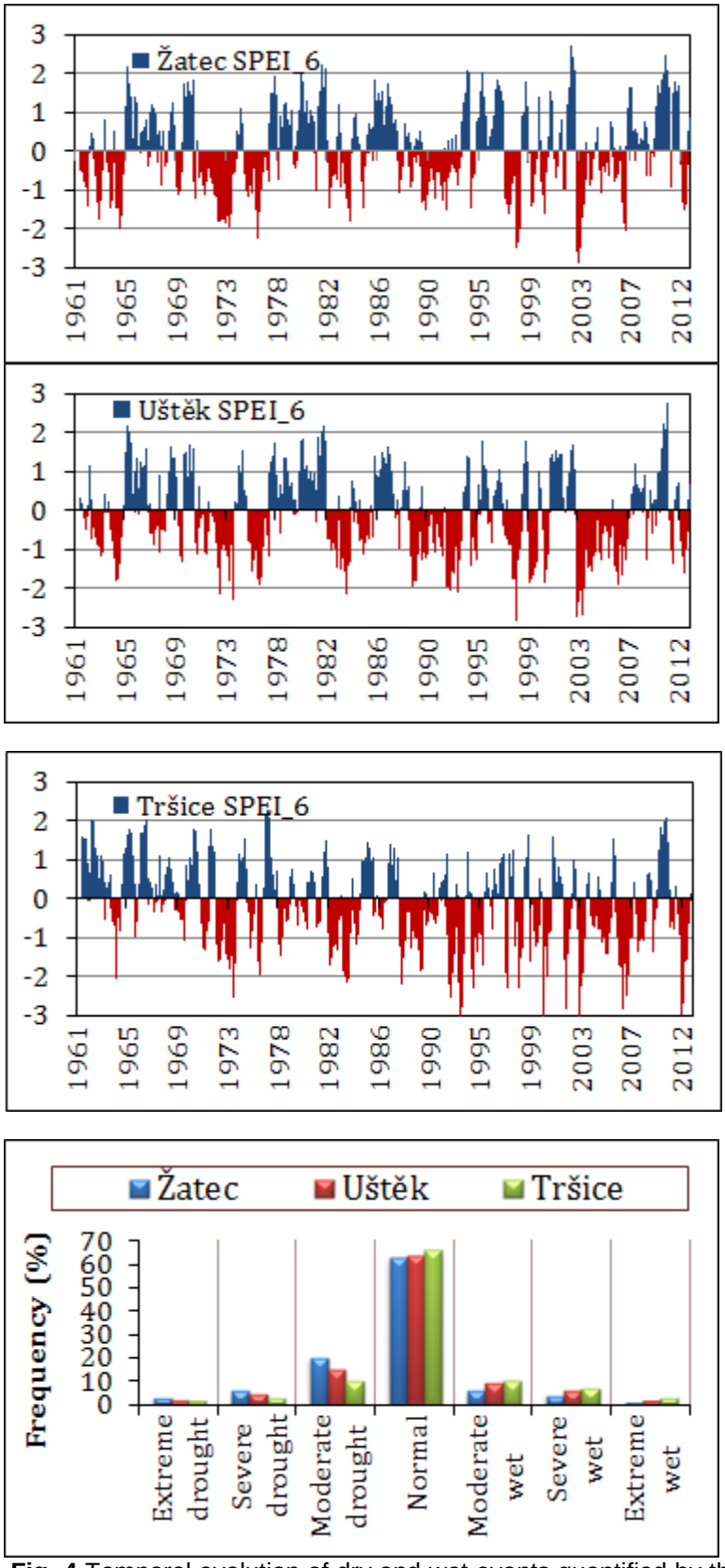

Fig. 4 Temporal evolution of dry and wet events quantified by the SPEI at 6-month lags (upper panel) and frequency distribution (%) of the SPEI values during the growing season (April-September) in 7 classes of moisture categories (bottom panel) for the period 1961-2012

of the SPEI values during the growing season (April-September) in 7 classes of moisture categories (bottom panel) from 1961-2012 are shown in fig. 4.

The 6-month lag contains moisture conditions from the current month and the past five months, and was used for computing the SPEI value for a given month. The normal moisture condition (SPEI values > -0.99 or < 0.99) among the three cultivation areas varies between 63 and 66 %. Moderate drought (ranges from 10 to 20 %) prevailed over moderate wet conditions (from 6 to 10 %). Severe drought (SPEI values from -1.50 to -1.99) and severe wet (SPEI values from 1.50 to 1.99) are almost equally distributed. However, the occurrence of extreme moisture conditions has a tendency toward dry conditions (SPEI≤-2.), especially for the Žatec area.

In the case of the Žatec region, the main and most severe drought episodes occurred in 1961-1964, 1971-1976, 1982-1983, 1989-1994, and 2003-2007, as indicated by the SPEI at 6-mo lags. In Uštěk growing area the main drought episodes were identified by the SPEI-6 in 1961-1964, 1975-1976, and 1988-1994, 1998-2000, 2003-2007, and 2011-2012. In accordance with the SPEI at 6-month lags, the persistence and extent of the droughts were recorded in Tršice in 1982-1983, 1989-1994, and 2003-2009.

The impact of dry (wet) events on the quality and yield parameters

Table 3 summarised the correlation coefficients between the monthly SPEI at 1-, 2-, 3- and 6-month lags, temperatures, precipitation and standardized of α - acids content (yield). The relation between the SPEI and the yield of Saaz hops explained from 20 to 53% of the regional yield variability.

For instance, fig. 5 shows the relationship between the monthly SPEI at 1-month lag during April-August and the annual yield, and alpha-acids of Sazz hops in the period 1992-2012 over Žatec cultivation area. The correlations indicate that year-to-year variations in both yield and α - acids content series are related to the year-to-year variation in the SPEI series. That is, higher yields (α - acids content) are observed in moderately wet and normal years, and lower yields (α - acids content) occurred under severely and extremely dry/wet

conditions. The correlation analysis over the last two decades showed that the yield-responses to drought (wet) conditions increased from the beginning of hop growing season to the month of August. One key result is that, for Žatec region, the appearance of moisture deficit (SPEI≤-1) was more frequent at the very beginning of the growing season (April, r = -0.20, p = 0.05). The strongest correlation of the SPEI was demonstrated for May (r = 0.53, p = 0.01). In June, the correlation weakened (r = 0.21, p = 0.01), while slightly higher but still significant influences were seen in July (r = 0.33, p = 0.05) and August (r = 0.45, p = 0.05).

Tab. 3 Correlation coefficients between the monthly SPEI at 1-, 2-, 3- and 6-month lags, air temperature (t° C), precipitation (p, mm) and yield residuals/ standardized of α – acids

	t °C	p, mm	SPEI-1	SPEI-2	SPEI-3	SPEI-6
yield residuals (t/ha)						
April	-0.44**	-0.13	-0.15	-0.14	-0.19	-0.12
May	-0.30*	0.01	0.10	-0.01	-0.01	-0.10
June	-0.29*	0.11	0.15	0.18	0.10	0.10
July	-0.54**	-0.07	0.31*	0.25*	0.33*	0.24*
August	-0.14	0.10	-0.26*	-0.41	-0.35	-0.23
standardized of α - acids						
April	0.10	0.01	-0.10	-0.27	-0.22	0.00
May	-0.43	0.50**	0.53*	0.43*	0.22	0.34
June	-0.26	0.10	0.21*	0.49**	0.43**	0.32
July	0.15	0.46**	0.33	0.31	0.56**	0.49**
August	-0.41	0.34*	0.45	0.57	0.51	0.57**

*p < 0.05; **p < 0.01

For quality parameters, as shown by fig. 5, correlation between the SPEI and α-acids contents is not noticeable. However, the positive and negative correlation between the SPEI and α - acids content becomes significant in July (r = 0.53, p = 0.01) and August (r = -0.30, p = 0.05), respectively. The impact of drought (wet) events detected by the SPEI from April to June on the alpha-acid content was not statistically significant at the level of risk p < 0.05.

Discussion

The obtained results in this study, as well as results of previous studies (Možny et al., 2009; Kucera and Krofta 2009; Pavlovic et al., 2012) show that temperature and rainfall temperature patterns and drought (wet) conditions,

during the hop vegetation have a stronger influence on accumulation of alpha-acids in technological maturity of hop cones.

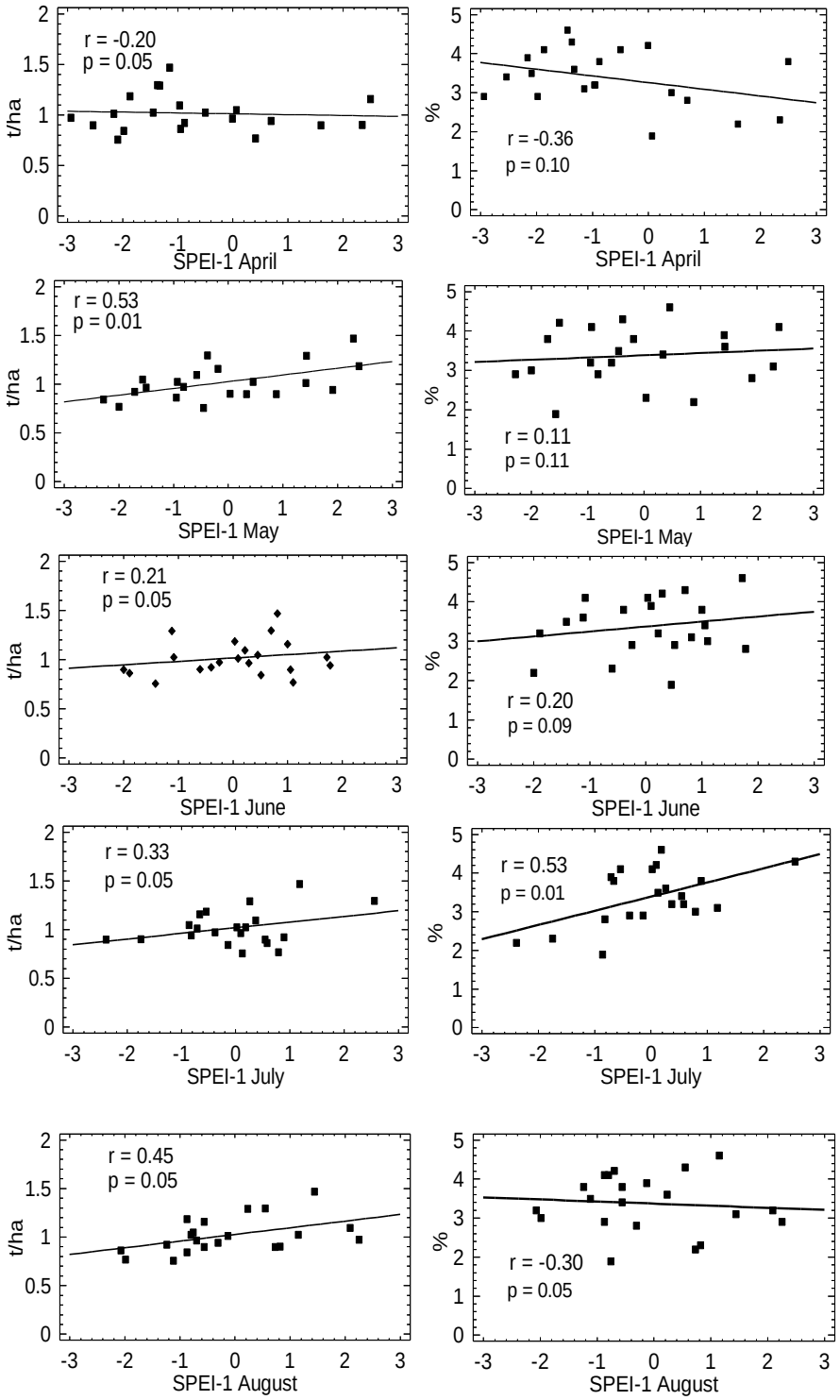

Fig. 5 Relationship between the monthly SPEI at 1-month lag during April-August and the yield (t/ha), and alpha-acids content (%) of Sazz hops in the period 1992-2012 (Žatec)

Several previous observation and modelling studies support this view, demonstrating that the dynamics of hop growth, generative development and the accumulation of α – acids have a very strong impact on yield and quality of hope cones. Mozny et al. (2009) found a positive impact of rainfall and a negative effect of temperature on alpha-acid contents for the period 1954-2006 over Žatec cultivation region. Kucera and Krofta (2009) found that the strongest influence on the alpha-acid content was exerted by air temperatures in July. Rainfall had significant effects during the period from May to July. The results of this study confirm the statements discussed above.

Conclusion

This study can be considered an initial step towards assessing the potential impacts of the dry and wet events detected by the SPEI on the yield and quality of hops varieties in the Czech hop cultivation regions. The evolution of wet, dry and normal episodes during hops growing season and their correlation with variability of the yield and quality parameters of hop varieties have been identified. This study also statistically analysis of the yield and quality of hops datasets in three hop-growing areas and the Czech Republic, as whole for Saaz semi-early red bine hop and selected hybrid varieties such as Bór and Sládek. The temporal evolution of production areas for individual growing region and at the country level was also evaluated. The preliminary obtained results show that the quality parameters of hops do not illustrate strong associations between the α-acids content and the SPEI; only a positive moderate correlation was observed in July.

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Summary

V této práci byla vyhodnocena závislost výnosu a kvality chmele na vláhových poměrech v průběhu vegetačního období chmele. Byl určen vývoj vlhkých, suchých a normálních měsíců vegetačního období v letech 1961-2012. Pro kvantifikaci sucha byl z řady různých charakteristik zvolen Standardizovaný srážkový evapotranspirační index (SPEI). V této práci byl pro hodnocení vláhových poměrů v průběhu vegetačního období chmele zpracován datový soubor z mezinárodního portálu monitoring sucha dle SPEI (http://sac.csic.es/spei/). Data byla stažena dle zeměpisných souřadnic klimatologických stanic Žatec, Doksany a Olomouc za období 1961-2012. SPEI byl počítán pro různé časové intervaly – 1, 2, 3 a 6 měsíců. Intervaly byly vybrány s ohledem na vegetační cyklus chmele a na nerovnoměrnou distribuci srážek a kolísání teplot v kratším intervalu než 6 měsíců.

Podrobněji byla analyzována a provedena korelace proměnlivosti výnosů chmele a obsahu α – hořkých kyselin u Žateckého poloraného červeňáku (ŽPČ) na kumulaci vláhového deficitu v průběhu vegetačního období. Veškerá data byla použita z lokalit Žatecké, Tršické a Úštěcké chmelařské oblasti. Pro každou chmelařskou oblast byla vypočtena četnost výskytu jednotlivých kategorií sucha vymezených podle SPEI: extrémní vlhko, silné vlhko, mírné vlhko, normální, mírné sucho, silné sucho a extrémní sucho. Zároveň byla vyhodnocena dynamika růstu chmele a obsah α - hořkých kyselin jak v ŽPČ pro celou Českou republiku od roku 1920 – 2012 a pro jednotlivé pěstitelské oblasti od roku 1992 do 2012, tak u hybridních odrůd v období 1979 – 2012 pro Bór a Sládek.

Korelaci mezi SPEI a výnosem ŽPČ vysvětluje 20 až 53 % z fluktuace regionálního výnosů. Obsah α – hořkých kyselin ve chmelu je ročníkově značně proměnlivý, je závislý na průběhu povětrnostních podmínek v průběhu vegetační sezóny. Je zřejmé, že chmel v průběhu hlavních růstových fází, vyžaduje vyšší teploty, jež podporují tvorbu alfa hořkých kyselin, avšak i dlouhotrvající vysoké teploty v období počátku tvorby osýpky a počátku hlávkování, mají negativní dopad na výnos a obsah α – hořkých kyselin. Výsledky dále poukazují, že dosahovaný výnos a kvalita chmele v jednotlivých letech jsou ovlivněny průběhem počasí ve vegetačním období, a to především rozložením množstvím srážek a teplotami. Je velice obtížné hodnotit vliv povětrnostních podmínek na kvalitu a výnos chmele. Každý ročník je jiný a chmel pokaždé reaguje jinak, jak na teplotu, tak na srážky. I vysoký úhrn srážek v měsíci srpnu způsobuje pokles tvorby α – hořkých kyselin. Kritický byl rok 2012, jak pro celou ČR, tak pro jednotlivé produkční oblasti. Vlivem povětrnostních podmínek, kdy únorové holomrazy poškodily část porostů a následné sucho, umocněné vysokými teplotami v měsíci srpnu, v nejcitlivějším období tvorby výnosu, měly za následek snížení celkové produkce. Kritický rokem byl rok 2003, za posledních 52 let nejsušší, a i z pohledu alfa hořkých kyselin se ukazuje, že hybridní odrůdy reagují na povětrnostní podmínky odlišně, díky delší vegetační době.

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