Environment and weather influence on quality and market value of hops

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ABSTRACT

The paper analyses the influence of four main weather parameters on alpha-acid contents for the main hop variety Aurora (Super Styrian Aurora) in Slovenian production for the time period 1994–2009. Through inspection of correlation coefficients, it tries to find specific times of the year when the weather conditions affect the alpha-acid content with a view to prediction in Slovenia. The most significant time periods of weather that influenced the alpha-acid contents of the Aurora variety during the growing season are identified as attributes of temperatures calculated from the interval from 25th to 30th week (T_{2530}, $r = -0.88$, $P < 0.01$), as attributes of rainfall and sunshine from the interval from 25th to 29th week (R_{2529}, $r = 0.85$, $P < 0.01$ and S_{2529}, $r = -0.75$, $P < 0.01$) and attributes of relative humidity from the interval from 27th to 32nd week (RH_{2732}, $r = 0.71$, $P < 0.01$). The attribute T_{2530} represents the sum of active temperatures from June 18 to July 29 of that year. Similarly, the attribute R_{2529} corresponds to the rainfall (in mm or L/m^2) that fell during the June 18 to July 22 etc.

Keywords: hop quality; alpha-acids; cv. Aurora; forecasting; weather attributes; hop market

The alpha-acids are important quality parameter in the hop industry since their production significantly defines the global hop supply statistics (Pavlovic et al. 2008). The alpha-acid content of a hop cultivar, which is usually expressed as a percentage of the dry weight of the cones, varies from year to year and from farm to farm (Thomas 1980). Hecht et al. (2004) used isotopically labelled oxygen (^{18}O) and determined that only 10% of the alpha-acids were formed two weeks before harvest, while the balance was present in the plant before this period. De Keukeleire et al. (2007) noted that water stress can lead to poor condition of the plants, with a resulting reduction in alpha-acid levels, since the weather conditions supposedly promote an increased biosynthesis of alpha-acids in hop plants. Srecec et al. (2008) studied the dependence of alpha-acid levels on meteorological parameters over the entire vegetative period for the Aurora cultivar. They found that the sum of the average daily temperatures in the vegetation period was negatively correlated ($r = -0.39$, $P < 0.05$) with alpha-acid levels, while total rainfall during the same period had a positive effect ($r = 0.46$, $P < 0.05$). Kucera and Krofta (2009) and Mozny et al. (2009) indicate a positive impact of rainfall and a negative effect of temperature on alpha-acid content. In addition, 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, while in August the impact of a rainfall was negligible. However, not all these assessments were entirely consistent with respect to which meteorological parameters and precisely which vegetation period of hops had the greatest impact on the alpha-acids in hops.

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To remain competitive in the global hop industry, hop breeders must respond to the ever-changing needs of the brewing community by providing appropriate new hop varieties (Pavlovic et al. 2011). Plant breeding programmes have led to the development of hop varieties that combine unusually high concentrations of alpha-acids with greatly improved resistance against the most relevant diseases (Pavlovic and Pavlovic 2011). The aim of this research was to identify precise periods during the hop growing season which influence the alpha-acid content of hop cones with a view to prediction.

MATERIAL AND METHODS

Alpha-acid content of hops. For the brewing industry, alpha-acid content is an increasingly important quality parameter and determines the market value of the hops. According to the research plan (Kosir and Livk 2009) in this study, 150 samples of the Aurora hop variety were collected for analysis from standard specific farm locations throughout the production region in Northeastern Slovenia each year between 1994 and 2009. The analyzed samples represent the average alpha-acid content for the Aurora cultivar across the annual total production area in Slovenia (960 ha i.e. 59% in 2009). Alpha-acid values were determined by a standardised conductometric method using a toluene extraction of the hops (Analytica EBC 2000). The survey included data for more than 2000 chemical samples of the Aurora hop variety. The Levene's test for equal variance among average values of alpha-acids from three regions was performed in order to check the validity of the equal variance assumption. It did not appear to be enough evidence to suggest that this assumption was violated. The samples also follow a normal distribution. The results illustrate estimated average contents of alpha-acids for the total production area of the country.

Meteorological data. Official meteorological data were obtained for the time interval from January 1, 1994 to December 31, 2009. Altogether, we obtained more than 120 000 data points for the following hop-growing areas in Slovenia: Celje, Smartno pri Slovenj Gradcu and Starse pri Mariboru. Available weather data consisted of (i) daily rainfall values (mm; i.e., L/m^2); (ii) average daily temperatures (°C); (iii) the number of hours of sunshine (h), and (iv) the average daily relative air humidity (%).Variations in these weather data were not significantly different among the stations and no station had consistently higher data values than any other. Thus, all three monitoring stations were equally represented in the calculated average values for meteorological parameters. This average represents a reasonable approximation and includes all sites within the area where hops are planted in Northeastern Slovenia.

Weather attributes. We analysed the impact of the interdependence of the active temperatures sum, the total number of hours of sunshine (i.e. solar radiation), total rainfall, and average relative humidity, on the alpha-acid content of the prevailing hop variety, Aurora, in Slovenia. Attributes were compiled as partial sums of individual meteorological parameters. The average values of meteorological parameters were calculated for each of the three stations that represented areas where hop production occurs in Slovenia.

The plants' need for heat was included in the attribute 'total sum of the average daily temperatures over a growing period'. Water demand was reflected in the attribute 'total rainfall'. The need for light was included in the attribute 'total hours of sunshine' (i.e., solar radiation). These weather attributes are designated in the paper as T (temperature attributes), R (rainfall attributes), S (sunshine attributes) and RH (relative humidity attributes). We determined the most suitable time interval for studying the influence of the selected meteorological attributes on the alpha-acid content for the Aurora hop variety by constructing attributes in two ways:

The first set of weather attributes was built on the basis of fixed monthly intervals for the vegetation period spanning from April until the end of August, and various combinations of monthly sums (4 – April; 5 – May; 6 – June; 7 – July; 8 – August; and 4, 5 – April + May; 4, 5, 6 – April + May + June; etc).

We also constructed a second set of attributes by first transforming the daily meteorological data for T, R and S as weekly sums and RH as average weekly values. We then fixed the start of the attribute intervals at the hop harvest time (week 34). The time intervals were subsequently extended stepwise toward the beginning of the hop plant growth. The beginning of the time intervals for each step was moved back by one week – toward the beginning of the hop plant growth. The values for each meteorological attribute A for the second set of attributes were calculated using the following formula:

$$A_{ab} = \sum_{w=a}^{b} pw$$

$$a = 26 + z - k;\ b = 29 + z;\ k = 1,2, \ldots 12$$
$$z = 0,1, \ldots 5 \quad (1)$$

Where: A – the weather attributes such as T, R, S and RH; p_w – weekly data of a meteorological parameter, which we calculated based on daily meteorological data obtained from the EARS archives; a – the lower limit of the time interval, and b – the upper limit of the interval at which we calculated the values of attributes. Statistical correlations were determined using the Pearson's correlation coefficient.

Factor analysis. Confronted with masses of quantitative variables, factor analysis was used to uncover patterns and discover the factor structure of a measure and to examine its internal reliability. The technique involves data reduction, as it attempts to represent a set of variables by a smaller number. These factors can be used for further analysis and as regressors i.e. independent variables in predictive regression models.

RESULTS AND DISCUSSION

The survey results are presented as two sets – depending on the structure and the analysis of the weather attributes. Interpretation of the impact of weather on the alpha-acids in Aurora is first presented for fixed monthly intervals and then for variable weekly periods. The most critical phases of growth and development of hops are exposed, where the T, R, S and RH demonstrate their significant influences on alpha-acid contents or indirectly on the quality and commercial value of the hops.

1st set of results (alpha-acids contents in hops at fixed monthly intervals). Table 1 shows the meteorological data collected for 1994–2009 for the three meteorological stations covering the hop growing area in Slovenia. The attributes T, R, S, and RH are shown. There are the average values for the whole vegetative period for hops from April to August and then shows separate values for the period June–July, because these two months demonstrated the most statistically significant effects of T and R on the alpha-acid content. The second column indicates the average alpha-acid contents for the cultivar Aurora.

Table 2 shows a detailed analysis of the correlations of attributes based on fixed monthly intervals and alpha-acid contents for the time period 1994–2009.

Table 1. Average alpha-acid contents of the air-dried hops cv. Aurora with 11% humidity and the values of attributes studied during 1994 to 2009

Year	Alpha-acids (%)	Period April–August				Period June–July			
		T	R	S	RH	T	R	S	RH
1994	8.2	2573.2	639.0	1108.1	73.5	1201.7	251.0	509.1	73.7
1995	7.8	2447.1	505.3	1054.7	74.0	1149.7	199.9	454.4	76.7
1996	10.1	2447.0	661.8	1129.4	73.2	1112.9	267.6	541.5	71.2
1997	10.0	2407.0	548.9	1175.0	70.8	1135.2	280.7	456.9	73.0
1998	8.8	2559.6	581.3	1184.3	73.5	1189.8	357.4	487.7	75.0
1999	9.5	2538.9	723.5	1040.5	74.8	1159.3	315.1	476.0	73.7
2000	8.6	2705.6	387.8	1328.1	70.0	1177.4	204.6	569.7	68.6
2001	7.8	2568.6	473.0	1257.7	70.5	1159.1	251.8	520.3	69.6
2002	7.3	2634.3	559.4	1129.7	72.6	1248.8	204.5	549.1	69.4
2003	5.9	2838.1	316.9	1262.4	66.1	1333.3	147.1	548.1	66.7
2004	8.8	2434.8	593.3	985.3	76.0	1130.3	312.7	416.3	76.3
2005	8.8	2489.7	710.4	1048.9	68.8	1174.8	293.0	454.0	67.4
2006	6.3	2528.7	577.6	1042.1	66.7	1249.3	133.7	521.7	61.3
2007	7.4	2729.3	491.7	1223.6	66.2	1260.5	217.7	542.9	63.1
2008	8.8	2594.7	629.4	1095.2	71.1	1206.3	356.4	441.1	71.6
2009	8.4	2681.2	572.4	1162.1	69.2	1172.5	284.5	479.3	69.0
Average	8.3	2573.6	560.7	1139.2	71.1	1191.3	254.9	498.0	70.4

T – temperature; R – rainfall; S – sunshine; RH – relative humidity

Analysis of the temperatures correlation showed that the alpha-acid contents increased from the beginning of hop cutting to the month of July. In August, the correlation again weakened. In this context, the correlations for April ($r = -0.09$), May ($r = -0.25$), June ($r = -0.47$) and August ($r = -0.26$) were weak and not statistically significant at $P < 0.05$ significance level. The strongest correlation of temperatures was demonstrated for July ($r = -0.87$, $P < 0.01$). Strong influence was also in June and July ($r = -0.84$, $P < 0.01$), while slightly lower but still significant influences were seen in May, June, and July ($r = -0.72$, $P < 0.01$) and during April–July ($r = -0.65$, $P < 0.01$). The impact of rainfall per month increased from April to July. The strongest correlation was in May–July ($r = 0.79$, $P < 0.01$), but was slightly lower for June–July ($r = 0.76$, $P < 0.01$). However, precipitation in August did not affect the alpha-acid content. The impact of sunshine on the alpha-acid content was not statistically significant at the level of risk $P < 0.05$, at any interval examined. For relative humidity, the highest correlation ($r = 0.73$, $P < 0.01$) with alpha-acid content was found in July and August.

2nd set of results (alpha-acids contents in hops in floating week intervals). The interdependence of weather attributes and alpha-acid content were examined at week intervals designed to cover the end of the interval and then to extend it toward the beginning of the hop plant cutting. Key results are demonstrated in Table 3.

The most significant time periods of weather that influenced the alpha-acid contents of the Aurora variety during the growing season are identified as attributes of temperatures calculated from the interval from 25th to 30th week i.e. T_{2530} ($r = -0.88$, $P < 0.01$), as attributes of rainfall and sunshine from the interval from 25th to 29th week i.e. R_{2529} ($r = 0.85$, $P < 0.01$) and S_{2529} ($r = -0.75$, $P < 0.01$) and attributes of relative humidity from the interval from 27th to 32nd week i.e. RH_{2732} ($r = 0.71$, $P < 0.01$). The attribute T_{2530} representing the sum of active temperatures from 25th to 30th week of the year i.e., from June 18 to July 29 of that year. Similarly, the attribute R_{2529} corresponds to the rainfall (in mm or L/m^2) that fell during the June 18 to July 22 etc.

The results of this set analysis of data indicate that temperatures strongly affect the alpha-acid content of hop plants from the start of growth until the end of July. The highest correlation of temperatures and alpha-acid content of the Aurora variety is in the interval from the attribute T_{2530} ($r = -0.88$, $P < 0.01$). A slightly lower correlation was shown in the intervals of attributes T_{2529} ($r = -0.85$, $P < 0.01$) and T_{2329} ($r = -0.83$, $P < 0.01$). The last two intervals are completed by July 22 (i.e., four weeks before harvest). The effect of temperatures is significant for the time interval

Table 2. Correlation of weather attributes (A) calculated at monthly intervals and alpha-acid contents for the Aurora hop cultivar

Month intervals	T	S	R	RH
4	−0.09	−0.03	0.05	0.18
5	−0.25	0.08	0.22	0.34
6	−0.47	−0.26	0.43	0.41
7	−0.87**	−0.48	0.56*	0.67**
8	−0.26	0.01	0.05	0.55*
4, 5	−0.22	0.02	0.19	0.27
5, 6	−0.42	−0.14	0.49	0.46
6, 7	−0.84**	−0.42	0.76**	0.58*
7, 8	−0.69**	−0.19	0.41	0.73**
4, 5, 6	−0.39	−0.13	0.40	0.40
5, 6, 7	−0.72**	−0.29	0.79**	0.58*
6, 7, 8	−0.70**	−0.30	0.64**	0.66**
4, 5, 6, 7	−0.65**	−0.24	0.70**	0.51*
5, 6, 7, 8	−0.63**	−0.20	0.65**	0.65**
4, 5, 6, 7, 8	−0.61*	−0.19	0.59*	0.59*

T – temperature; R – rainfall; S – sunshine; RH – relative humidity; A_4 – attribute in April; $A_{4,5}$ – attribute in April + May; etc.; $N = 16$; *$P < 0.05$; **$P < 0.01$

Table 3. Correlation of weather attributes and contents of alpha-acids for the Aurora hop cultivar in floating weeks for 1994–2009

Week intervals	T	S	R	RH
2532	−0.82**	−0.43	0.66**	0.70**
2732	−0.72**	−0.08	0.42	0.71**
2132	−0.75**	−0.15	0.71**	0.59*
2530	−0.88**	−0.72**	0.80**	0.64**
2130	−0.80**	−0.33	0.75**	0.54*
2529	−0.85**	−0.75**	0.85**	0.63**
2329	−0.83**	−0.60*	0.78**	0.59*
2129	−0.74**	−0.37	0.79**	0.52*
2528	−0.74**	−0.55*	0.79**	0.54*
2428	−0.78**	−0.56*	0.80**	0.51*
2128	−0.65**	−0.24	0.76**	0.44

T – temperature; R – rainfall; S – sunshine; RH – relative humidity; $N = 16$; *$P < 0.05$; **$P < 0.01$

Table 4. Correlation matrix of variables used in factor analysis

	S_{2329}	S_{2428}	S_{2529}	T_{2530}	T_{2329}	R_{2129}	R_{2132}	R_{2529}
S_{2329}	1.00							
S_{2428}	0.77	1						
S_{2529}	0.75	0.81	1					
T_{2530}	0.35^{NS}	0.48	0.73	1				
T_{2329}	0.67	0.65	0.78	0.79	1			
R_{2129}	−0.67	−0.64	−0.56	−0.53	−0.66	1		
R_{2132}	−0.55	-0.42^{NS}	−0.50	−0.48	−0.51	0.84	1	
R_{2529}	−0.70	−0.70	−0.82	−0.71	−0.73	0.82	0.78	1

$n = 16$; ^{NS}non-significant at $P < 0.05$

from the beginning of intensive plant growth until the end of flowering. However, the impact of temperatures in August is weak. Rainfall shows the highest correlation with alpha-acid contents from June 18 to July 22. The impact of rainfall begins to decline after July 29. At this time, hop plants reach their full flowering stage and their cones begin to form. The impact of sunshine on the alpha-acids content shows the highest negative correlation for the attribute S_{2529} ($r = -0.75$, $P < 0.01$) in the period from June 18 to July 22.

Slightly lower correlation was shown for S_{2530} ($r = -0.72$, $P < 0.01$) i.e. from June 18 to July 29. These two intervals are completed approximately four weeks before harvest. Also the impact of sunshine in August is weak and not statistically significant at $P < 0.05$. Relative humidity showed a slightly lower correlation than rainfall and temperatures. The highest correlation RH_{2732} ($r = 0.71$, $P < 0.01$) was demonstrated from July 2 to August 12 – at interval that culminated with the development of cones.

Tables 2 and 3 demonstrate the direction of the correlation coefficients for the four weather attributes analyzed. T and S are all negative but R and RH are all positive. Both pairs of parameters generally mirror each other so that one pair is the most negative when the other pair is the most positive. When the sun shines it is generally warmer than when it is cloudy. When it is cloudy it is more likely to be wet than when the sun is shining. Relative humidity is usually lower when it is a sunny day and higher when it is wet.

Factor analysis. To avoid extreme multicollinearity, we first eliminated from the battery of attributes those that were very highly correlated. Principal component method with an orthogonal (varimax) rotation was used of extracting factors

Table 5. Summary of exploratory factor analysis for weather attributes at weekly intervals

Rotated component matrix with Varimax method and Kaiser normalization				
Variable	Component			χ^2
	1	2	3	
S_{2428}	**0.861**	−0.222	0.301	**0.88**
S_{2329}	**0.860**	−0.390	0.124	**0.91**
S_{2529}	**0.700**	−0.211	**0.619**	**0.92**
R_{2132}	−0.177	**0.928**	−0.225	**0.94**
R_{2129}	−0.395	**0.828**	−0.265	**0.91**
R_{2529}	−0.471	**0.638**	−0.520	**0.90**
T_{2530}	0.137	−0.267	**0.939**	**0.97**
T_{2329}	0.484	−0.299	**0.721**	**0.84**
Eigenvalues	5.62	0.87	0.78	
% of variance*	32.9	29.5	28.5	

$n = 16$; Loadings over 0.6 are significant and appear in bold; *percent variance is post-rotation

on 8 items (Table 4). Several well-recognized criteria for the factorability of correlation were used. Firstly, all of items correlated at least 0.3 with all other items, suggesting reasonable factorability. Secondly, an examination of the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.77, above the recommended value of 0.5. The diagonals of the anti-image correlation matrix were all over 0.69, supporting the inclusion of each item in the factor analysis. Bartlett's test of sphericity χ^2 (28) = 109.8, $P < 0.001$ indicated that correlations between items were sufficiently large for analysis. The communalities were all above 0.8 (Table 5), further confirming that each item shared some common variance with other items.

Principle component analysis was used because the primary purpose was to identify and compute composite coping scores for the factors underlying. An initial analysis was run to obtain eigenvalues for each component in the data. Three components had eigenvalues over criterion of 0.7. The initial eigenvalues showed that the first factor explained 70.4% of the variance, the second factor 10.8% of the variance and a third factor 9.8% of the variance.

We used a varimax rotation due to its tendency for the principal factor to disappear. This also simplifies the interpretation because, after a varimax rotation, each original variable tends to be associated with one (or a small number) of factors, and each factor represents only a small number of variables (Abdi 2003). After the varimax rotation factor 1 explains 32.9%, factor 2 explains 29.5%, and a factor 3 explains 28.5% of the variance (Table 5).

The impact of weather parameters on the alpha-acids in hops can be linked with the emergence of certain phases of recorded phenomena in the plants, which do not coincide in time with the dispensation of each month. Generative bodies in the cultivar Aurora begin to develop in the second half of June (week 26), and the plant is in full bloom by the mid July (week 28).

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