Market value assessment of hops by modeling of weather attributes

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ABSTRACT

The effect of major weather factors on the quality of hops in Slovenia from 1994 to 2009 is analyzed and discussed. For this purpose, the three main varieties, namely Savinjski golding, Aurora and Bobek were merged into a model variety which we called Virtual. Through assessment of correlation coefficients, we tried to find specific times of the year when the weather conditions affect the alpha-acid content with a view toward prediction. The most significant time periods of weather that influenced the alpha-acid contents of hops during the growing season are identified as attributes of air temperatures calculated during the interval from the 24th to the 31st week (T_{2431}; $r = -0.92$; $P < 0.01$), as attributes of rainfall and sunshine duration calculated during the interval from the 25th to the 29th week (R_{2529}; $r = 0.83$; $P < 0.01$ and S_{2529}, $r = -0.76$; $P < 0.01$), and as attributes of air humidity calculated during the interval from the 28th to the 33rd week (RH_{2833}; $r = 0.77$; $P < 0.01$).

Keywords: *Humulus lupulus* L.; quality; alpha-acids; weather parameters; model; Slovenia

The alpha-acid values in hop cones are important quality parameters in the hop industry since they significantly define global hop supply statistics from the hop merchants' perspective as well as they influence the cost-benefit effects on a hop growers' level (Pavlovic and Pavlovic 2011). Furthermore, in the year 1888, when Hayducka first used the term 'alpha-acids' for hop substances formatting a bitter resin of acid reaction with ions of lead, and Wöllmer developed the first analytical method for their quantitative detection (Howard and Tatchell 1956, Forster 1993), alpha-acids also became the most important hop chemical compound for the world beer industry. The share of alpha-acids strictly corresponds with the growing conditions during the crop year (Srecec et al. 2008, Pavlovic 2012).

The alpha-acid content of a hop variety, which is generally expressed as a percentage of the dry weight of the cones, varies from year to year and from farm to farm. Hecht et al. (2004) used isotopically-labeled 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 weather conditions supposedly promote an increased biosynthesis of alpha-acids in hop plants. Zattler and Jehl (1962), Thomas (1980), Srecec et al. (2008), Kucera and Krofta (2009), and Mozny et al. (2009) studied the dependence of alpha-acid levels on meteorological parameters over the entire vegetative period for the Aurora cultivar. However, not all of the cited 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.

In this paper, the aim was to recognize precise periods during the hop growing season that have an influence on the alpha-acid content of hops with a view toward prediction. The study presents the results obtained from research into alpha-acid contents from 1994 to 2009 for the three most-exported hop varieties in Slovenia, merged into a model variety called Virtual, during the time period.

MATERIAL AND METHODS

Alpha-acid content of hops. In this study, over 250 samples of all three hop varieties were collected yearly for analysis from standard specific farm locations throughout the production region in Northeastern Slovenia each year between 1994 and 2009 (Kosir and Livk 2009). The analyzed samples represent the average alpha-acid content for the three varieties analyzed. Samples were analyzed (Analytica EBC 2000) in the accredited agrochemical laboratory at the Slovenian Institute for Hop Research and Brewing in Zalec. Alpha-acid values were determined by a standardized conductometric method using toluene extraction of the hops. The complete survey included data for more than 4000 chemical samples of the Slovenian hop varieties known as Savinjski golding, Aurora and Bobek. 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. The samples follow a normal distribution. The results illustrate estimated average content of alpha-acids for the total production area of the country.

Model variety Virtual. The alpha-acid content of the three hop varieties included points throughout all of the years analyzed with very similar tendencies in change related to weather circumstances. The interdependence of the alpha-acids of these three hop varieties throughout the years is strong (Table 1) and statistically significant at $P < 0.01$. For purposes of modeling, we therefore defined a model variety Virtual, and so extended the analysis to all three varieties. This is especially important for the purposes of modeling predictions of alpha-acids at a country level. The levels of alpha-acids of the model variety Virtual were calculated as the arithmetic mean of the levels of alpha-acids of the three most-exported varieties:

$$\text{Virtual}_i = \frac{1}{3} \times \sum_{n=1}^{n} (\text{Aurora}_i + \text{Savinjski golding}_i + \text{Bobek}_i)$$

$$n = 1994 \ldots 2009$$

Meteorological data. Authorized meteorological data were collected 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 totals (mm); (ii) average daily air temperatures (°C); (iii) sunshine duration (h); and (iv) the average daily relative air humidity (%). Variations in these weather data were not significantly different among these 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 analyzed the impact of the interdependence of the plants' need for heat

Table 1. The matrix of interdependence of alpha-acids of the three hop varieties analyzed, which is used in the analysis for the period 1994 to 2009

	Aurora	Bobek	Savinjski golding	Virtual
Aurora	1	–	–	–
Bobek	0.95**	1	–	–
Savinjski golding	0.92**	0.87**	1	–
Virtual	0.99**	0.98**	0.95**	1

**correlation is significant at the 0.01 level (two-tailed) that was included in the attribute 'total sum of the average daily air temperatures over a growing period'. Water demand was reflected in the attribute 'rainfall totals'. The need for light was included in the attribute 'sunshine duration', and the effect of the average relative air humidity on the alpha-acid content of the model hop variety, Virtual, in Slovenia was the fourth attribute. These weather attributes are designated in the paper as T (temperature attributes), R (rainfall attributes), S (sunshine attributes), and RH (relative humidity attributes) and 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. We determined the most suitable time interval for studying the influence of the selected meteorological attributes on the alpha-acid content for the main three hop varieties. The set of weather attributes was built by 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 were calculated using the following formula:

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

$$a = 26 + z - k;\ b = 29 + z;\ k = 1, 2, ...12;\ z = 0, 1, ...5$$

Where: A – 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 – lower limit of the time interval, and b – upper limit of the interval at which we calculated the values of attributes. Statistical correlations were determined using the Pearson's correlation coefficient.

Definition of the attribute k_{TD}. The problem of feature interaction can be addressed by creating new attributes from the basic attribute set. Generally, transformed attributes generated by attribute construction may provide a better discriminative ability than the best subset of given attributes, but these new attributes may not have a clear physical meaning. This method reduces dimensionality by creating a new set of attributes that are mathematically related to the original set, but that contain significantly fewer attributes (Markovitch and Rosenstein 2002).

The influence of the temperature and rainfall amount on the content of alpha-acids was not equally strong in the same time period. To avoid the time interval of the impact of the total rainfall amount and temperatures on alpha-acids, and to study the simultaneous impact of temperature and rainfall on the content of alpha-acids, a coefficient between attributes T and D was introduced. Analysis of total rainfall pointed out that the interdependence between the content of alpha-acids and the total amount of rainfall was not completely linear. That is why a logarithm for the attribute value of the total quantity of precipitation was used. Thus, the values of the coefficient were expressed by the following equation:

$$k_{TD} = \frac{T}{\ln D}$$

Where: T – values of the sum of the attributes of active temperatures (°C) at certain time intervals, and D – value of total rainfall (mm) at time intervals of this attribute. Here it is not necessary that the time interval is equal.

Attribute reduction. Faced with numerous variables in our research goals, we used the principal component analysis (PCA), an additional, and at times very useful, tool for investigating particular features of the structure of multivariate observations, to uncover patterns and discover the component structure of a measure, and to examine its internal reliability. This is as an interdependence technique in which an entire set of interdependent relationships is examined without making the distinction between dependent and independent variables. It involves data reduction, as it attempts to represent a set of variables by a smaller number without losing too much information. To enhance the interpretability of the principal components (PCs), the varimax rotation, which minimizes the number of variables with high loadings on a PC, was used. These PCs can be used for further analysis and as regressors in predictive regression models.

RESULTS AND DISCUSSION

The survey results on the structure and the analysis of the weather attributes are presented. The interdependence of weather attributes and alpha-acid content were examined at weekly intervals designed to cover the end of the interval and then to extend it toward the beginning of the hop plant cutting. 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. Key results are demonstrated in Table 2. Statistical correlations were determined using the Pearson's correlation coefficient.

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 beginning of August. The highest correlation of temperatures and alpha-acid content of the cultivar Virtual is in the interval from the attribute T_{2431} (r = –0.92; P < 0.01). A slightly lower correlation was shown in the intervals of T_{2331} (r = –0.90; P < 0.01) and T_{2432} (r = –0.91; P < 0.01). The attribute T_{2431} represents the sum of active temperatures from the 24th to the 31st week of the year, i.e., from June 10th to August 4th of that year (i.e., four weeks before harvest). The effect of temperatures is significant for the time interval from the beginning of intensive plant growth until the end of flowering.

Rainfall shows the highest correlation with alpha-acid content from the attribute R_{2529} (r = 0.83; P < 0.01), which is from June 18th to July 22nd. High correlations also appear in time intervals that end in week 29, while the beginning of the intervals covers the phase of intensive plant growth R_{1829} (r = 0.79; P < 0.01). The impact of rainfall begins to decline after July 29th. At this time, hop plants reach their full flowering stage and their cones begin to form. The attribute R_{2529} corresponds to the rainfall (mm) that fell during the interval from June 18th to July 22nd.

The impact of sunshine on the alpha-acid content shows the highest negative correlation for the attribute S_{2529} (r = –0.76; P < 0.01) in the period from June 18th to July 22nd. A slightly lower correlation was shown for S_{2530} (r = –0.68; P < 0.01), i.e., from June 18th to July 29th. These two intervals are completed approximately four weeks before a harvest.

Relative humidity showed a slightly lower correlation than rainfall and temperatures. The highest correlation, RH_{2833} (r = 0.77; P < 0.01), was demonstrated from July 8th to August 18th, an interval that culminated with the development of cones.

Interaction between temperature and rainfall was expressed by a factor of k_{TD}. The k_{TD} ratio peaked at the highest correlation, when calculated for the temperature interval T_{3027}, and the logarithmic values of rainfall on the interval R_{1828} (r = –0.95; P < 0.01). Very high values of the correlation coefficient for the k_{TD} were reached on several other intervals, as shown in Table 3.

The results in Table 3 demonstrate that high values of Pearson's correlation coefficient were obtained when including a longer period of rainfall. In addition, the temperatures were particularly important in the period from week 25 to week 30. However, after week 30 the impact started to decrease.

Principal components analysis (PCA). We first put 80 weather attributes through a set of

Table 2. Correlation of weather attributes and contents of alpha-acids for the model variety Virtual in floating weeks for 1994 to 2009

Week intervals	T	S	R	RH
1834	–0.72**	–0.18	0.65**	0.63**
2434	–0.89**	–0.44	0.69**	0.66**
2534	–0.87**	–0.40	0.65**	0.71**
2634	–0.78**	–0.26	0.46	0.73**
2834	–0.76**	–0.13	0.24	0.74**
1833	–0.73**	–0.22	0.71**	0.63**
2433	–0.91**	–0.53*	0.76**	0.67**
2533	–0.86**	–0.49	0.70**	0.72**
2633	–0.77**	–0.34	0.51*	0.75**
2833	–0.76**	–0.18	0.28	0.77**
1831	–0.76**	–0.26	0.69**	0.56*
2431	–0.92**	–0.58*	0.71**	0.58*
2531	–0.87**	–0.62*	0.67**	0.63**
2631	–0.80**	–0.49	0.47	0.65**
2831	–0.81**	–0.27	0.18	0.68**
1829	–0.69**	–0.35	0.79**	0.54*
2429	–0.88**	–0.68**	0.81**	0.55*
2529	–0.86**	–0.76**	0.83**	0.60*
2629	–0.78**	–0.68**	0.64**	0.61*

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

Table 3. Correlation of k_{TD} and contents of alpha-acids for the model variety Virtual in floating weeks for 1994 to 2009

T	R_{1828}	R_{1830}	R_{2529}
2329	–0.86	–0.88	–0.90
2429	–0.90	–0.91	–0.91
2529	–0.94	–0.94	–0.92
2629	–0.93	–0.93	–0.91
2729	–0.92	–0.92	–0.91
2829	–0.89	–0.88	–0.90
2330	–0.88	–0.90	–0.91
2430	–0.92	–0.92	–0.91
2530	–0.95	–0.95	–0.92
2630	–0.95	–0.95	–0.91
2730	–0.95	–0.95	–0.92
2830	–0.92	–0.91	–0.91
2331	–0.88	–0.90	–0.92
2431	–0.91	–0.93	–0.92
2531	–0.93	–0.94	–0.93
2631	–0.92	–0.92	–0.92
2731	–0.92	–0.94	–0.93
2831	–0.90	–0.91	–0.93

n = 16; all values of the Pearson coefficient for correlations are $P < 0.01$ (two-tailed); T – temperature attributes; R – rainfall attributes

explorative PCAs. On the basis of the results of those preliminary PCAs, we identified and excluded redundant and trivial variables. We chose the number of components to extract on the basis of Kaiser's criterion eigenvalue > 1.0. We also put the extracted principal components through a reliability analysis. We calculated the Cronbach's alpha coefficient for each cluster of variables that was compounded in the separate components of the PCA. Therefore, we conducted a final PCA with an orthogonal (varimax) rotation (Abdi 2003) with the remaining nine variables (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 a reasonable factorability. Secondly, tests on sampling adequacy (Kaiser-Meyer-Olkin criterion) and multicollinearity (Bartlett test of sphericity) were undertaken prior to principal component extraction to ensure that the scale items were appropriate for principal component analysis. In this case, the tests of sampling adequacy showed a meritorious correlation of items (KMO = 0.79) indicating that it was acceptable for analysis. The diagonals of the anti-image correlation matrix were all over 0.72, supporting the inclusion of each item in the analysis. Bartlett's test of sphericity presented a significant value (χ^2 (36) = 231.5; $P < 0.001$), meaning that these data did not produce an identity matrix and were thus approximately multivariate normal and acceptable for analysis. The commonalities were all above 0.8 (Table 4), further confirming that each item shared some common variance with other items.

Principal component analysis was used because the primary purpose was to identify and compute composite coping scores for the underlying principal component (PC). An initial analysis was run to obtain eigenvalues for each principal component in the data. Analysis revealed that PC1 and PC2 of the nine principal components meet criterion eigenvalues greater than 1. The initial eigenvalues showed that the first principal component explained 77.3% of the variance and a second one 15.7% of the variance. Varimax rotation PC1 explains 50.8% and PC2 explains 42.2% of the variance (Table 4).

Table 4. Summary of principal component analysis for weather attributes at weekly intervals after varimax rotation (n = 16)

Variable	PC 1	PC 2	χ^2
k_{TD1}	**0.895**	–0.404	0.96
k_{TD2}	**0.807**	–0.414	0.93
RH_{2829}	–0.304	**0.850**	0.88
RH_{1832}	–0.364	**0.780**	0.83
RH_{2832}	–0.352	**0.936**	0.98
RH_{2932}	–0.322	**0.907**	0.93
T_{2529}	**0.909**	–0.306	0.94
T_{2431}	**0.903**	–0.404	0.97
T_{2531}	**0.927**	–0.257	0.96
Eigenvalues	6.96	1.41	
% of variance*	50.8	42.2	

Significant loadings appear in bold. *percent variance is post-rotation. $k_{TD1} = T_{32530}/\ln(D_{1830})$; $k_{TD2} = T_{2730}/\ln(D_{1830})$; RH – relative humidity; T – temperature attributes

Furthermore, commonality values for variables were high. For example, commonality for T_{2431} attribute was 97.0%, indicating that 97.0% of the variance in T_{2431} is accounted for by PC1 and PC2. Reliability, which describes the internal consistency of a set of items, was measured by Cronbach's alpha and item-total correlations. PC1 ($\alpha = 0.98$) was labeled plant conditioner and PC2 ($\alpha = 0.96$) was labeled disease trigger. Corresponding temperatures and rainfall are necessary for a good growth condition of plants, while high relative humidity provides conditions for the development of plant diseases.

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