Mathematical Model for Prediction of Alpha Acid Contents from Meteorological Data for ‘Saaz’ Aroma Variety

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Abstract

Significant influence of weather conditions on alpha acid contents in hop cones is generally accepted. Long-term monitoring of alpha acid content in hops cultivated in the region of central Europe shows notable year to year differences. Mathematical models of the relationship between alpha acid content and meteorological parameters were worked out for ‘Saaz’ aroma variety using data covering the years 1981-2006. Mean alpha acid content was determined by lead conductance method (EBC 7.4, toluol). Meteorological data were provided with CHMI (Czech Hydrometeorological Institute) observatory in Doksany located approximately 2 km from the farm. Using multi-linear regression, a ten parameter model has been outlined. Average temperatures from July and August, average air humidity from June, July and August, average daily sunshine duration from June, July and August and accumulated precipitation from August have been found as key input variables of the model. Correlation coefficient of the relationship between predicted and actual alpha acid contents is r=0.914, coefficient of determinancy r^2=0.835. The model showes that alpha acid content in ‘Saaz’ aroma hops is influenced by weather conditions in a relatively short time period June-August, i.e. stage of flowering, cone forming and ripening. July temperatures are the most significant weather parameter (r_i=-0,24) effecting alpha acid contents in ‘Saaz’ hops confirming empiric experience.

INTRODUCTION

Alpha acid content in hop cones is the most important quaility parameter of hops. During the brewing process alpha acids are isomerized to iso-alpha acids which form the main principle of beer bitterness. Alpha acid content of a hop variety, which is usually expressed as a percentage of weight of cones, varies from year-to-year. The course of weather conditions is generally considered as an important factor of hop resins biosynthesis and an important factor influencing hop yield.

Long-term monitoring of alpha acid content in hops cultivated in the region of central Europe shows notable year to year variations (Krofta, 2007). Therefore, scientists have tried to specify weather parameters important for alpha acid formation. In a study of hops grown in the Hallertau region of Germany over a period of 35 years (1926-1961) Zattler and Jehl (1962) concluded that high alpha was associated with a moist summer and below average temperatures but with an average amount of sunshine. Thompson and Neve (1972) concluded that seasonal fluctuations in alpha acid level were associated with variations in air temperature 40 to 60 days prior to harvest and thus not under the grower’s control. Thomas (1980) investigated year-to-year variation in the alpha acid content of hops in relation to various weather factors using multiple regression analysis. Alpha acid content was shown to be highly correlated with mean temperature from May, 24 to June, 21 whereas temperature or sunshine during the cone-ripening period of August appeared to be of importance only in ‘Bramling Cross’ and ‘Bullion’ varieties. Average day temperatures in the range of 16-18°C within a period July to August are optimal for alpha acid biosyntesis in ‘Saaz’ aroma hops under the conditions of ‘Saaz’ growing region (Krofta et al., 1997). Water supply should be 60 to 70 mm/month.

Temperature increases above optimum up to 20°C can be compensated to some extent by irrigation. Smith (1969) suggested that there was an optimum temperature in the period July-August for each cultivar with respect to alpha acid content in hops. The optimum temperature appeared to be between 16.0 to 17.0°C. Alpha acid content decreased above or below this temperature. Using data from international trials, he considered that the mean August temperature immediately prior to picking was the key factor for alpha acid content. Burgess (1964) also concluded that August temperatures were most influential to alpha acid content in hops. This author stated that alpha acids increased with temperature. Adverse influence of high temperatures on hop resins formation in the period of hop maturation was confirmed by Ljašenko (1985) and Magadan (1999). Optimal temperatures in the period May-August are at the range of 14.7-16.5°C and total rainfall more than 300 mm.

Not only high temperatures but also low temperatures during hop cones ripening adversely influence alpha acid contents in hops as reported Hautke (1979). According to his data the lowest minimum day temperatures should not be below +12°C. High positive correlation (r=0,81-0,89) between alpha acid content and rainfalls and negative correlation between alpha acids and max. daily temperatures were observed by Hacin (1987) in Slovenian varieties 'Aurora', 'Atlas' and 'Savinjski Golding' in the period 1972-1983. Srečec (2008) evaluated the influence of weather conditions on accumulation of alpha acids during six years (2001-2006) within a stationary experiment in cultivar 'Aurora' grown in Serbia. The results showed again a negative correlation between the sum of max. daily temperatures during cone maturation and the accumulation of alpha acids in hop cones, whereas the total amount of rain showed a positive correlation. The total hours of sunshine was found not to be a significant factor. Multilinear mathematical models of the relationship between alpha acid content in hops and meteorological variables were worked out by Park (1988) for variety 'Hallertauer' grown in South Korea in the period 1978-1986. He divided the vegetation cycle of hop into four phases – flower bud differentiation, flowering, cone development and cone ripening. The total hours of sunshine (X_1), maximum temperature (X_3), total precipitation (X_5) in the flowering stage, the maximum temperature in the flower bud differentiation stage (X_4) and the maximum temperature in the cone ripening stage (X_6) influenced hop alpha acid content as decrement weather elements. The maximum temperature in the cone development stage (X_2) affected alpha acid content as an increment weather element.

This paper describes the estimation of a mathematical model for prediction of alpha acid contents from meteorological data for 'Saaz' aroma variety grown in the Czech Republic. The model was outlined on the basis of more than 25 years analytical and weather experimental data.

MATERIAL AND METHODS

A mathematical model of the relationship between alpha acid contents and meteorological parameters was worked out for the 'Saaz' aroma variety on the basis of data analyses in the period of 1981-2006 in the locality Brozany, Czech Republic. 'Saaz' aroma variety has been the only cultivar grown in Czech Republic till the mid 1990s. Brozany is a traditional hop growing locality in the central part of the Auscha growing region (Fig. 1). Altitude of the site is 155 m above sea level. Hop is grown at the area of 50-60 hectares. Content of alpha acids were determined in individual lots of raw hops. Alpha acid content was measured by lead conductance method according to EBC 7.4 (Analytica EBC, 1998). Bitter substances were extracted with toluene from raw hops ground at first to powder. An aliquot of the toluene extract was diluted with methanol and the bitter substances in the resulting solution were determined by conductometric titration with lead acetate solution. The same analytical method for raw hops evaluation was used in the course of the whole investigated period. This way at least 20 individual alpha acid values were obtained from each crop harvest. Average value for model application was counted as arithmetic mean of individuals. Meteorological data were provided with CHMI (Czech Hydrometeorological Institute) observatory in Doksany located in 2 km distance from the farm. Average day temperatures, air humidity, daily sunshine duration and daily precipitation were used as input variables of the model.

The strategy of data analysis was based on the influence of weather conditions in different parts of the season on the alpha acid production. Therefore, the importance of different variables in different months relevant to plant growth and ripening was investigated. 25 years of time series data for all available environmental variables in daily resolution were put together into one file for data processing by Mini 32 software (Environmental Measuring Systems, Brno, CZ). Each environmental variable was split into 8 sub-variables containing data values for a single month (January to August). Therefore, a file containing altogether 33 monthly averages (4 main environmental variables times 8 months completed with the alpha acid percentage) in 25 years was created for the next processing. The data processing was not based on the analysis of plant physiological response to ambient factors but a simple relation between the commonly measured meteorological variables and the alpha acid content was found. We applied a simple "black box" approach based on the linear multiregression analysis. The multiregression analysis was made with a "fit" module in Mini 32 software package which uses an iterative method of finding regression parameters where the best-fitting line is obtained by the method of least squares. By using ordinary linear regression analysis the most important variables were pre-selected for the next step of processing. The following multi-regression analysis was based on 18 pre-selected variables. During the analysis, the most relevant variables were selected according to standard error of parameter estimation. Vice versa, an importance of previously omitted variables was tested, too. In this way, the variables with a significant influence to the alpha acid estimation were selected with respect to coefficient of determination and well balanced standard error of estimation of individual parameters.

RESULTS AND DISCUSSION

The average alpha acid content in 'Saaz' aroma variety grown in Brozany during the period 1981-2006 are summarized in Table 1 and Figure 2. The effect of June and July mean temperatures on alpha acid content is shown in Figure 3. Pearson correlation analysis shows that July temperatures had a significant negative effect on hop resins biosynthesis, (coefficient of determinancy r^2=0.63). Contrarily, June temperatures have little effect on alpha acid content in hops. It is a period of intensive longitudial growth of hop plants and effect on yield is much more pronounced compared to alpha acid content. Both partial conclusions confirm empiric experience. An assessment of the remaining individual meteorological elements effect upon alpha acid content in 'Saaz' aroma hops resulted in a ten-parameter multilinear mathematical model.

The statistical analysis of weather elements showed that only June, July and August meteorological parameters had a significant effect on alpha acid content in 'Saaz' aroma variety. The partial negative correlation between July temperatures and alpha acids significantly was observed as having the greatest influence upon the model. (r_5=-0,236). It is interesting that precipitation is included only marginally in August (r_{10}=-0,004) and indirectly in air humidity and temperature. In some years it happens that intensive rains in the course of August, which come after water stress period, promote the growth of hop cones size but biosynthesis of hop resins falls behind. It results in "dilution" of alpha acids in cones (see Fig. 4). Thus, negative correlation coefficient r_{10} between alpha acid contents and August precipitations confirms empiric experience. In Table 2 actual and predicted alpha acids contents are shown for the 'Saaz' aroma variety in Brozany in the period since 1981 till 2006. In Figure 5 actual and predicted alpha acid contents are shown for the 'Saaz' aroma variety in Brozany in the period 1981-2006. A possible question concerning auto-correlation between some variables arises here. However, this model does not study the hop physiology but it should help to predict the hop quality with respect to recent climatic conditions. Therefore we used maximum variables until they help to reach the best results without taking into account those variables with negligible contribution to final result. Moreover, since all environmental variables are more or less derived from sun activity, all of them are somehow auto-correlated anyway.

Alpha (model) = constant + parameter2*Variable2 + parameter3*Variable3 +……………
+ parameter 10*Variable10

Order	Parameter	Variable	Std. error of parameter. estimation [%]
1	5,916	*Constant (offset)*	57
2	-0,220 (r_2)	mean day sunshine in June (hours)	44
3	0,117 (r_3)	mean day sunshine in v July (hours)	94
4	-0,218 (r_4)	mean day sunshine in August (hours)	81
5	-0,236 (r_5)	mean temperature in July (°C)	100
6	0,163 (r_6)	mean temperature in August (°C)	40
7	-0,092 (r_7)	mean air humidity in June (%)	35
8	0,058 (r_8)	mean air humidity in July (%)	49
9	0,061 (r_9)	mean air humidity in August (%)	45
10	-0,004 (r_{10})	August precipitation (mm)	72

Crop harvest 2007 was the first testing period for the model. The predicted value of alpha acid according to the calculated model was 3,0%, with the actual alpha acid content being 2,9% which suggests good agreement. The quality of the outlined mathematical model confirms the relationship between actual and predicted alpha acid contents in Brozany in the period since 1981 till 2006 shown in Figure 6. Correlation coefficient (r=0,914) and coefficient of determinancy (r^2=0,835) are very high. Generally, conclusive relationships are considered if coefficient of determinancy r^2 is higher than 0,60. It is important to acknowledge that the model only applies to the Brozany growing region and one cultivar. Any extrapolation to other growing regions requires verification. The model was tested on one growing season. It is premature to state that the model is anything more than preliminary and further testing is inevitable.

Global climatic changes cause increase of average temperatures, deficit of the rainfalls during the vegetation period and occurrence of extreme weather phenomena (hailstorm, strong winds, long-term dry spells, floody rainfalls). All these factors significantly affect annual hop crop and alpha acid production in many countries. In the region of central Europe the years 1994 and 2006 were typical for long term hot period during July and August. In both years the historically lowest alpha acid contents in 'Saaz' aroma hops were recorded (Krofta, 2007). The accuracy of the model in such extreme years is worse. Predicted content of alpha acids is higher by 24% and 37% respectively compared to actual ones. Non-linearity for any of the weather parameters in marginal range or by other relevant factors which were not included into the model can cause significant deviations of the model to actual results. One such non-climatic variable is hydrological and or other parameters of the soil. Data for these variables are not commonly available and it is not easy to quantify them. Extreme weather conditions in some vegetation seasons help to understand conjunctions between weather conditions and biosynthesis of brewing valuable substances in hop cones (Srečec, 2004; Forster, 1995) and are helpful in proposing of relationship between weather parameters and alpha acid content in hops.

CONCLUSIONS

The prediction of hop quality in terms of alpha acid content specific to the 'Saaz' hop cultivar grown in the Brozany, Czech Republic can be ascertained according to seasonal weather course based upon knowledge of the main climatic variables within the time period of three months. Mathematical model for prediction of alpha acid contents from meteorological data showed that alpha acid contents in 'Saaz' aroma hops was influenced by weather conditions in a relatively short period June-August, i.e., stage of flowering, cone forming and ripening. July temperatures are the most significant weather parameter (r_i=-0,24) affecting alpha acid contents in 'Saaz' hops, which confirms empiric experience. The quality of modeling in terms of coefficient of determinancy within the investigated period from 1981 till 2006 reaches the value R^2=0,83. Soil moisture values and non-linear fit could be used for increasing for the accuracy of modeling. The performed study might encourage next research work on this field that could lead in particular to more efficient irrigation management of hop gardens.

ACKNOWLEDGEMENTS

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Literature Cited

Burgess, A.H. 1964. Hops, botany, cultivation and utilization. World Crop Books, Leonard Hill, London.

Environmental Measuring Systems, Brno, Czech Republic, software Mini 32, www.emsbrno.cz.

European Brewery Convention. Analytica EBC. 1997. Method 7.4, Zurich.

Forster, A. 1995. Specific problems of hop crop harvest in Germany in 1994. Hopfen-Rundschau 1:7-10 (in German).

Hacin, J. 1987. On the influence of weather factors on the yield and quality of hops. Proc. of VIth Yugoslavian symposium of hop production, Žatec, Slovenia, March 1-4; 71-92.

Hautke, P. 1979. Effect of climatic conditions on the yield and alpha acid content of hops in 1974-1978 harvests. Brauwissenschaft 32(10):288-294 (in German).

Krofta, K., Rígr, A. and Nesvadba, V. 1997. Weather conditions and biosynthetical processes in hop cone. Rostlinná výroba 43(7):301-306.

Krofta, K., Klapal, I., Kopecký, J. and Tichá, J. 2007. The assessement of quality parameters of Czech hops at 2006 crop harvest. Chmelařství 80(4):56-63 (in Czech).

Ljašenko, N.I. 1985. The influence of weather conditions on hop bitter acids formation. Chmelevodstvo 7:37-31 (in Russian).

Magadán, J.A., Benítez, J.L., Del Valle, M.D. and Santamarta, I. 1999. Study of the relationship between some climatic conditions and alpha acids production. Proceedings of the Scientific Commission IHGC, Pulawy, Poland, 81-85.

Park, K.Y. 1988. Modeling for Prediction Yield and Alpha Acid Content in Hop from Meteorological Elements. Korean J. Crop Sci. 33(4):323-328.

Smith, L.P. 1969.The effect of temperature on the quality of hops. Report Dep. Hop Research Wye College for 1968, 47-60.

Srečec, S., Kvaternjak, I., Kaučic, D. and Marič, V. 2004. Dynamics of Hop growth and Accumulation of Alpha Acids in Normal and Extreme Climatic Conditions. Agric. Conspec. Scient. 69(2-3):59-62.

Srečec, S., Kvaternjak, I., Kaučic, D., Špoljar, A. and Erhatič, R. 2008. Influence of Climatic Conditions on Accumulation of Alpha Acids in Hop Cones. Agric. Conspec. Scient.73, in press.

Thomas, G.G. 1980. Weather factors controlling the alpha-acid content of hops (*Humulus lupulus* L.). J. Hort. Sci. 55(1):71-77.

Thompson, F.C. and Neve, R.A. 1972. The influence of various factors in the cost of production of hop alpha acid. J. Inst. Brew. 78:156-161.

Zattler, F. and Jehl, J. 1962. On the influence of atmospheric conditions on yield and quality of the hops in the Hallertau in the period 1926-1961. Hopfen-Rundschau 13(5):64-64.

Tables

Table 1. Mean values of alpha acid contents in 'Saaz' aroma variety in Brozany in the period of 1981-2006.

Year	Alpha (% w/w)	Year	Alpha (% w/w)	Year	Alpha (% w/w)
1981	5,2	1991	3,8	2001	4,1
1982	4,9	1992	3,2	2002	2,9
1983	3,6	1993	4,0	2003	3,0
1984	5,1	1994	2,1	2004	3,4
1985	4,0	1995	3,3	2005	3,5
1986	4,2	1996	4,5	2006	1,9
1987	4,1	1997	3,9	2007	2,9
1988	4,6	1998	3,2	2008	-
1989	3,8	1999	3,1	2009	-
1990	3,5	2000	3,8	2010	-

Table 2. Actual and predicted alpha acid contents in 'Saaz' aroma variety in Brozany in the period of 1981-2006

Year	Alpha (% w/w)		Year	Alpha (% w/w)	
	Actual	predicted		Actual	Predicted
1981	5,2	4,9	1996	4,5	4,6
1982	4,9	4,1	1997	3,9	4,3
1983	3,6	3,2	1998	3,2	3,7
1984	5,1	5,2	1999	3,1	3,3
1985	4,0	4,1	2000	3,8	3,7
1986	4,2	4,2	2001	4,1	3,9
1987	4,1	4,2	2002	2,9	3,2
1988	4,6	4,4	2003	3,0	2,7
1989	3,8	4,0	2004	3,4	3,6
1990	3,5	3,3	2005	3,5	3,9
1991	3,8	3,7	2006	1,9	2,6
1992	3,2	3,1	2007	**2,9**	**3,0**
1993	4,0	3,8	2008	-	-
1994	2,1	2,6	2009	-	-
1995	3,3	3,0	2010	-	-

Figures

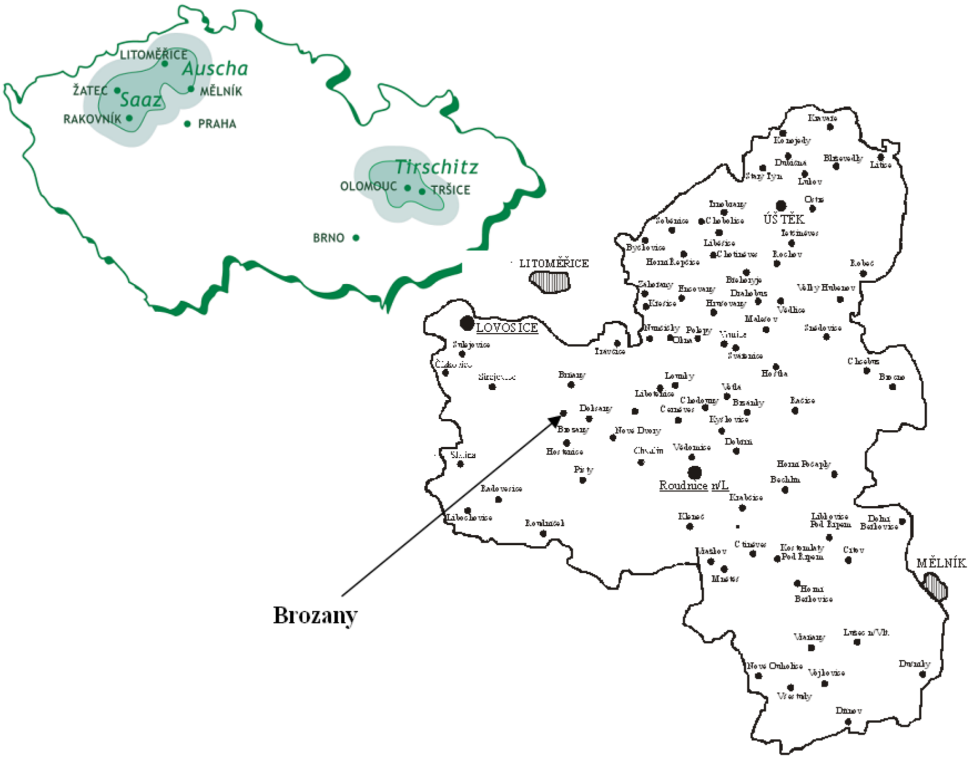

Fig. 1. Hop growing regions in Czech Republic, location of Brozany farm.

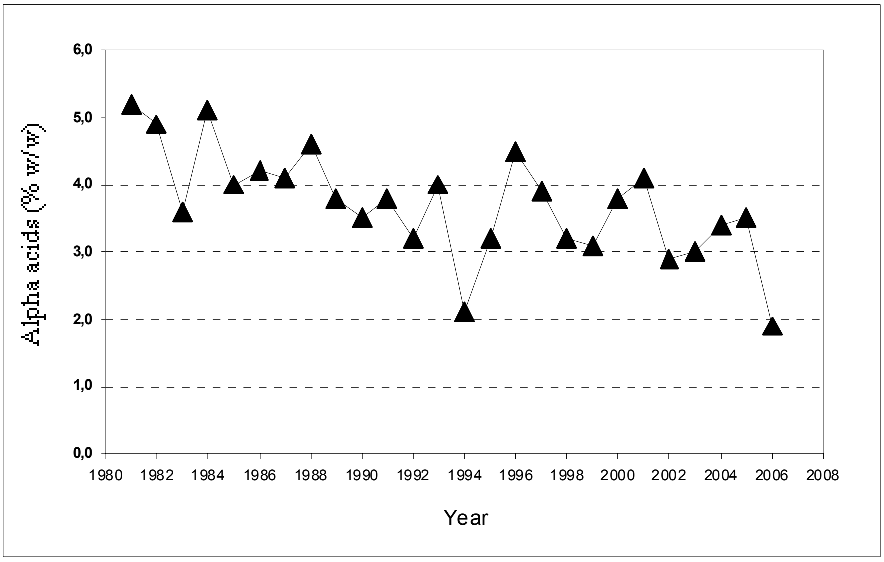

Fig. 2. Alpha acid contents in ‘Saaz’ aroma variety in Brozany in the period 1981-2006.

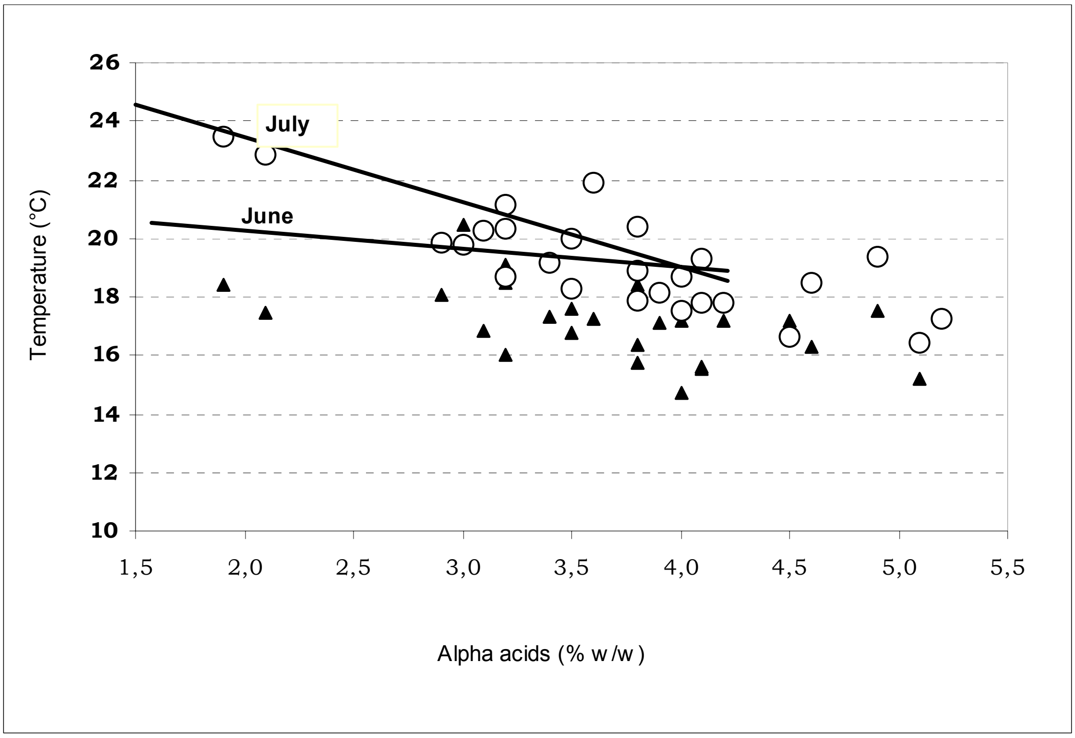

Fig. 3. The effect of mean temperatures in June and July on alpha acid content in 'Saaz' aroma variety (Brozany, 1981-2006).

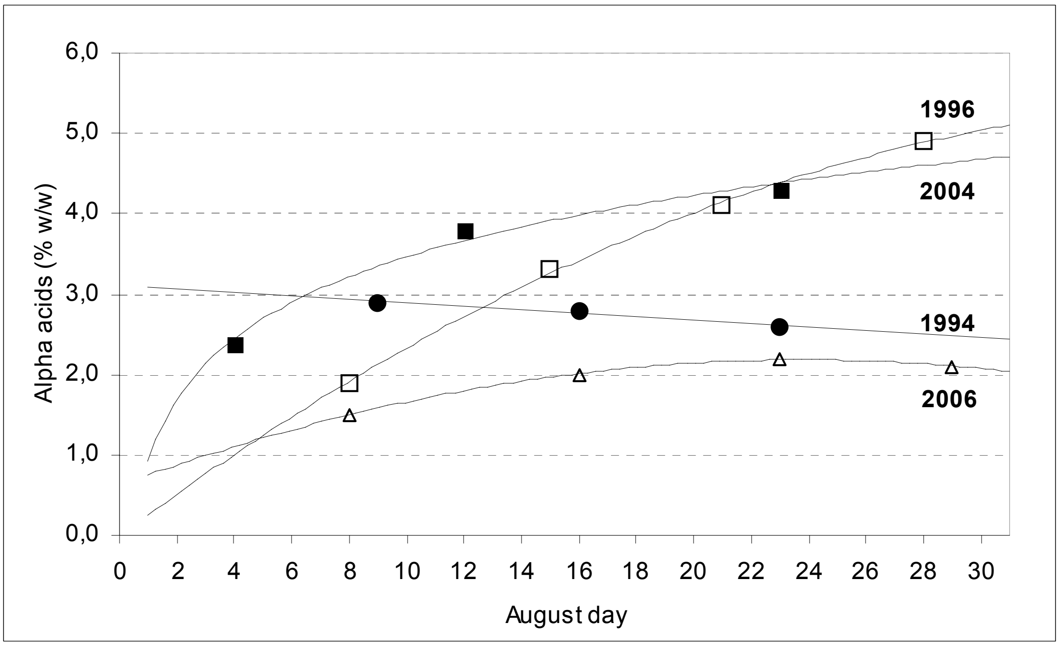

Fig. 4. Development of alpha acid contents in 'Saaz' aroma variety during preharvest period (August).

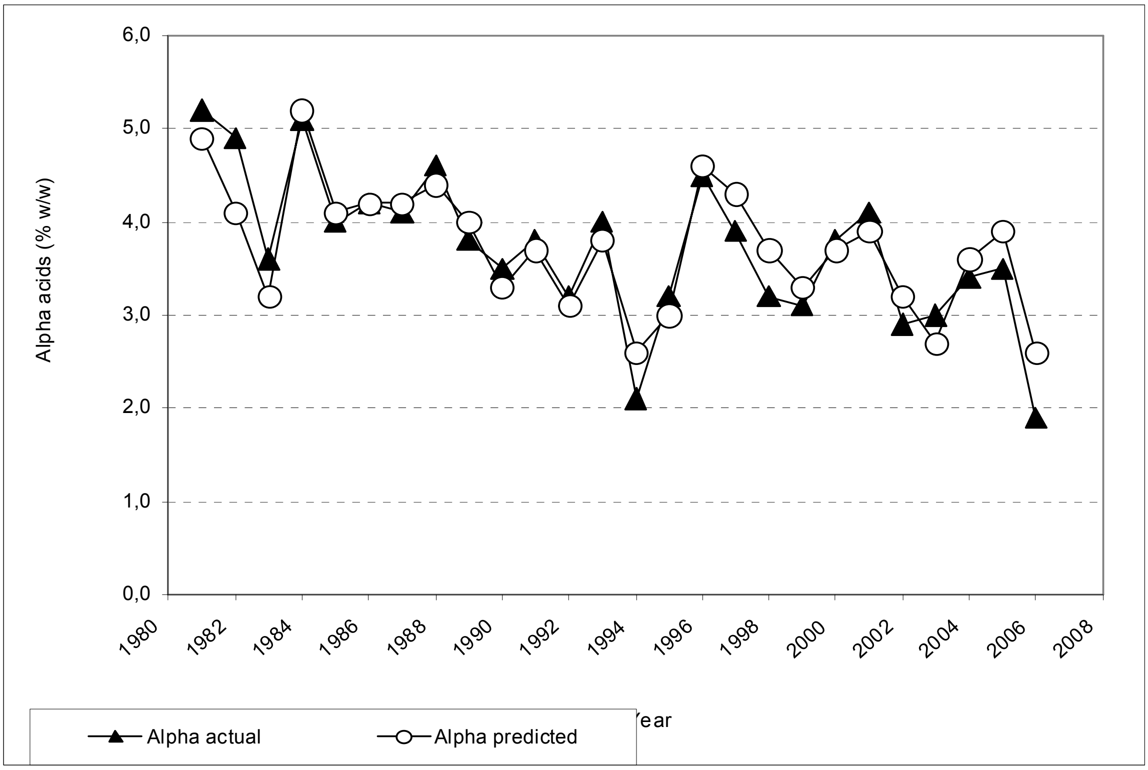

Fig. 5. Actual and predicted alpha acid contents in 'Saaz' aroma variety in Brozany in the period 1981-2006.

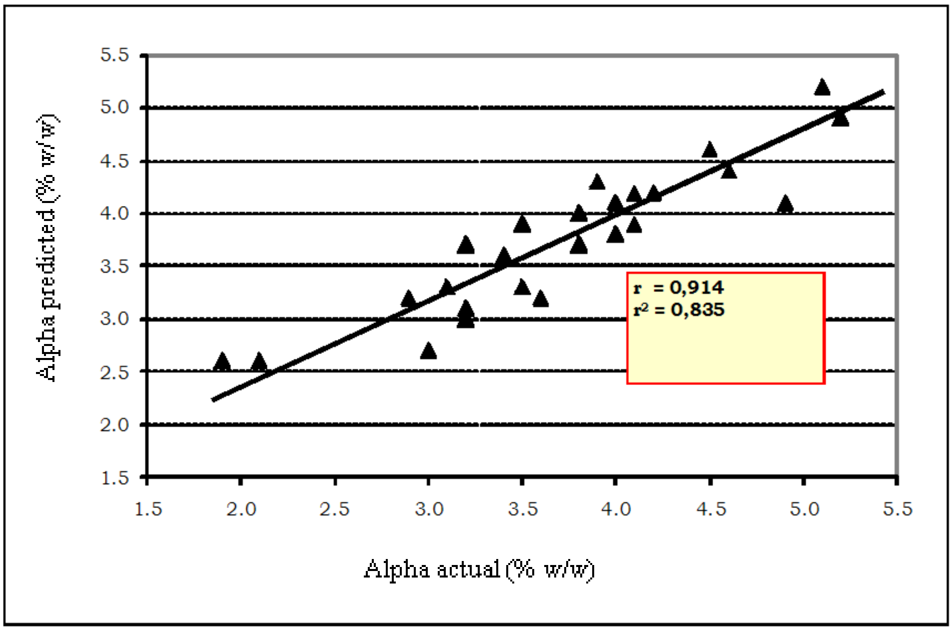

Fig. 6. Correlation between actual and predicted alpha acid content in 'Saaz' variety in Brozany in the period 1981-2006.