Modelling of Quality Prediction for Hops (*Humulus lupulus* L.) in Relation to Meteorological Variables

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Abstract

Hops are vital for brewing industry since they provide their certain bitterness (alpha-acids), specific aroma and beer stability as well as a tranquillizing effect. Correlation analysis among meteorological variables and chosen quality parameters (alpha-acid contents) in hops in time period 1994-2008 showed, that Slovenian hop varieties react with resemblance on weather conditions. Impacts of air temperature, precipitation quantity and day length on alpha-acid content in hop cones were investigated. The included meteorological variables point out in certain phenological phases of hop plants from moderate to high level of dependency with alpha-acid content of varieties analysed. Based on correlation analysis between alpha-acid values in various hop varieties and meteorological variables, a model concept for early prediction of hop alpha-acid content was formulated to support additionally hop growers' and hop merchants' business decisions. The results validate the application of the model for further research.

Key words: hops, alpha-acid content, weather data, modelling, draught management

Introduction

Brewing industry accompanied with a production of raw material sources i.e. field crops used in beer production supports a wealth of direct and indirect jobs across Europe, in particular in the agricultural and hospitality sector. Beer brewing is an intricate process that encompasses elaboration of four essential raw materials counting brewing water, barley malt, hops and yeast. Hops, in particular its aroma components and its bitter substances (alpha-acids), determine to great extent typical beer qualities such as bitter taste, flavour and foam stability (Anon., 2002).

Hop plants grow mainly up to 7 m high being supported with a wirework trellis. Their main commercial product represent female blossoms, i.e. hop cones. An important market quality parameter of hops are alpha-acids content in hop cones, which may range from 2-8 % by finest aroma hop varieties till 12-18 % by super-alpha hop varieties. Furthermore, alpha-acids from hops have been considered by the brewing industry – and consequently also by hop merchants – as one of the most important quality parameters within a hop industry business circle. Furthermore, in statistics of the International hop growers' convention (www.ihgc.org), alpha-acid values represent an important global hop balance parameter in crop predictions, stock estimations and contract market initiatives (Pavlovič, 2009). Precise and updated alpha-acid estimations are very important information for growers and hop merchants, who bind a hop price level in their sales contracts also with various hop quality parameters.

Decisive meteorological parameters that influence an alpha-acid level formation are daylight, air temperatures and water availability during the growing period. Hops require during the whole season an amount of 1700^{o}C of effective temperatures. They have a humid character, since they require 500 to 600 mm of rainfall properly disposed in a growth season. Direct sunlight and long day length (15 hours or more) is also needed. A shortage of daylight can influence significantly a crop level. As a consequence of day length and season length, hop production is limited to latitudes between 35 and 55 degrees.

The research contribution is a part of an international project entitled Drought management in South East Europe (DMCSEE, 2009-2012), where a model for early prediction of alpha-acid content for Slovenian hops was formulated. The impact of the research is estimated to enhance capability of the hop industry sector research community, raw material producers in agriculture as well as the brewing industry as its end user. The results validate the application of the model for further research.

Concept of a model hop quality prediction

Analysis of weather circumstances influence on alpha-acid level was carried out on hop varieties such as Aurora, Bobek, Celeia, Savinjski golding and Hallertauer Magnum that represent over 95% of the total national hop area.

Samples of hops

Samples from hop cones analysed represent an average national alpha-acid values of chosen hop varieties. Sampling and analysis were carried out at the Slovenian Institute of Hop Research and Brewing in Žalec. Alpha-acid values were obtained by the accredited method cited in Analytica EBC 1998, revision 2000, 7.4. Over 2000 chemical analyses of alpha-acids for all the hop varieties included in a research were performed.

Figure 1. Hop plant and hop cones

Meteorological data used as model variables

Meteorological data were obtained from the Environmental Agency of the Republic of Slovenia that performs expert, analytical, regulatory and administrative tasks related to the environment at the national level. These data relate on areas of Celje, Šmartno pri Slovenj Gradcu, Velenje and Starše pri Mariboru in a time period from 1994 till 2008. Average meteorological values were calculated from all four stations, since hop areas are widespread within these mentioned regions.

Hop plants warmth requirements are included within a variable total amount of average daily temperatures (^{o}C) in a growing season in the time period analysed. Water requirements of hop plants are demonstrated within the variable total rainfall amount (mm/m^2) with presumption that no irrigation was implemented. Plants daylight necessity is included within the variable sunshine hours (h) in analysed production areas. In modelling activities also average relative air moisture was considered.

Model formation

Based on preliminary results from correlation analysis of variables analysed, a test model for early prediction of alpha-acids in Slovenian hop varieties was formulated. For the model dependant variable VIRTUAL (virtual hop variety), average weighted values of alpha-acid contents of hop varieties Aurora, Bobek and Savinjski golding were determined. In this way a model was generalised to be used for an average alpha-acid content of all included hop varieties.

Furthermore, the model did base on a presumption that different meteorological parameters enabled in various plant growing periods also diverse effects. That is why as independent variables – segmented meteorological parameters were selected and adequately pondered. A multiple linear

regression was implemented and based on experiences some independent variables were chosen. Model accuracy was tested by a method “leave-one-out” (Han et al., 2008).

Results

Interacting similarity of hop varieties’ response towards meteorological parameters was studied with a correlation analysis. Preliminary results pointed out that all included varieties in general reacted in a rather similar way. Hop varieties were divided into 2 groups. Aurora, Bobek and Savinjski golding did show a very high interacting correlation ($r=0.9$; $p<0.001$) in alpha-acid values. The other varieties Celeia in Hallertauer Magnum pointed out lower correlation compared to varieties from the first group.

Increase of effective daily temperatures amount caused a reduction of alpha-acid values by all studied hop varieties at a risk level $\alpha<0.05$. For the varieties of a first group this certainty is even higher (99.9 %). Similar results had been obtained also by other authors. Total hours of sunshine in the experiment were inversely proportional to the alpha-acid level as also stated in previous results (Krofta et al. 2009; Srečec et al. 2008). On the contrary the rainfall amount resulted as the only variable that was directly proportional to the alpha-acid amounts at a risk level $\alpha<0.01$. Similar results were cited also previously (Zatler et al. 1962; Park, 1988). The results demonstrate that a rainfall distribution during a growing period was even more important – especially in the hop plant phenophases F_6 and F_7.

With a hop variety and growing region input parameters, model coefficients i.e. correction constants for each variety and production region were determined. Based on such a test model – a tryout prediction of alpha-acid values for all three tested hop varieties can be made four to six weeks before the hop harvest. The values for all varieties and all included production regions can be calculated with a help of the following equation:

$$\textit{Alpha-acid values for a hop variety in a production region} = \textit{model prediction} \times \boldsymbol{K}_{\textit{hop variety}} \times \boldsymbol{K}_{\textit{growing region}} \qquad /1/$$

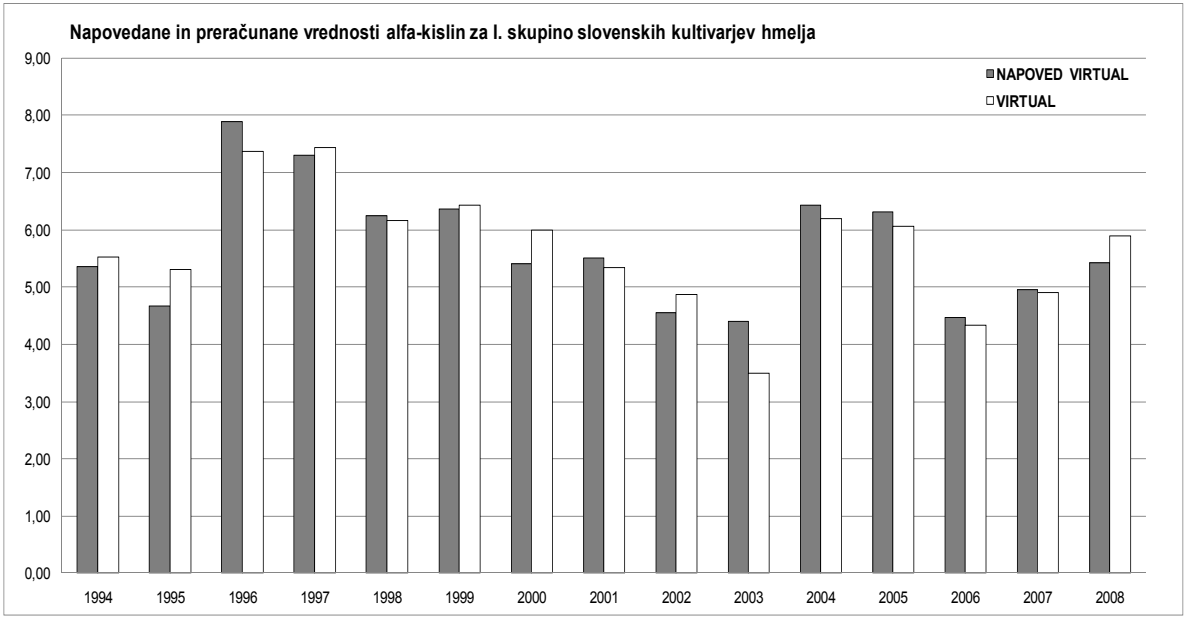

Figure 1. Predicted (dark) and calculated (clear) values of independent variable alpha-acid content for the first group of hop varieties analysed

Analysis of model accuracy did show that its predictions have an average error at a level of 7 %. Results will be demonstrated in detail during the conference presentation.

Correlation coefficient values between predicted and measured out values of alpha-acids in analysed hop varieties are very high ($r=0.9$ pri $p<0.001$). This shows a high level of model prediction reliability. Less reliable prediction was made only for the unusually extremely dry year 2003. In that year the model predicted value was 4.4 while the measured one was 3.5.

Conclusion

Rainfall amount in a growing period of blossom and cone formation is essential for the alpha-acid content in hops. Water availability should be as much as possible evenly distributed. Sunshine hours positively stimulate alpha-acid formation, but also dry soil and thus negatively affect a plant development. Increase of effective daily temperatures causes a reduction of alpha-acid values.

Correlation analysis between meteorological variables and a quality parameter (alpha-acid content) in hops from 1994 till 2008 illustrate that Slovenian hop varieties react with resemblance on weather circumstances. Tests of air temperature, rainfall and day length impacts on alpha-acid content in hop cones were carried out. The included meteorological variables point out in certain phenological phases of hop plants from moderate to high level of dependency with alpha-acid values of varieties analysed. A comparison of correlation coefficients between included meteorological variables and alpha-acid values of the Slovenian hop varieties demonstrated that Aurora, Bobek and Savinjski golding react very equally on relevant weather conditions.

This enabled to formulate a universal model for early prediction of hop alpha-acids. Based on correlation analysis between alpha-acid values in hop varieties and meteorological variables, a model concept for early prediction of hop alpha-acid values was formulated to support additionally hop growers' and hop merchants' business decisions. In the test model pondered meteorological data were used as independent variables. Thus it enables a prediction of alpha-acid values for the 3 main Slovenian hop varieties within the 3 main growing regions. The results validate the application of the model for further research.

Preliminary assessment of hop varieties' alpha-acid values about four to six weeks before a harvest is very valuable for growers and merchants. It may offer important business information related to alpha-acid supply quantities and furthermore to hop sales activities – especially whether a part of price for hops is variable and linked to alpha-acid amounts. In that way model results will improve a decision making process within a hop industry business circle.

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