Empiric mathematical model for predicting the content of alpha-acids in hop (Humulus lupulus L.) cv. Aurora

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Abstract

The aim of this research is to find a simple mathematical model due to sum of effective temperatures and rainfalls from second germination after spring pruning till the technological maturity of hop cones, in order to achieve reliable prognosis of alpha-acids content in hop cv. Aurora. After mathematical analyses of experimental data by Eurequa Formulize 0.96 Beta software 17 equations were offered, and after substituting the values of dependent and independent variables in all equations only one equation was chosen with \( p = 0.034 \) (\( p < 0.05 \)). This equation is not reliable in extremely drought year if crop evapotranspiration \( ET_0 \) in July is higher than 4.5, primarily because of negative influence on formation and development of hop glandular trichomes. Considering achieved results it is possible to suggest following general equation for alpha-acids accumulation in hop:

\[
y = \left( k_1 w - k_2 - \frac{k_3 w^2}{x} \right) \div (-10) \leftrightarrow ET_0, July \leq 4.5.
\]

Where \( y \) is alpha acids content in dry matter (%), \( x \) = sum of effective temperatures and \( w \) = sum of rainfalls, both from second germination after spring pruning till technological maturity of hop cones. Coefficients \( k_1, k_2 \) and \( k_3 \) are determined for cultivar Aurora (53.8, 453 and 1.33, respectively).

Keywords: Hop, Humulus lupulus L, Alpha-acids, Accumulation of alpha-acids, Empiric mathematical model, Eurequa software

Introduction

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 biosynthesis of hop secondary metabolites is divided into three biosynthetic pathways A, B and C, and biosynthesis of humulone or alpha-acids is the final step of C pathway (Nagel et al. 2008; Wang et al. 2008). Accumulation of alpha acids is most intensive in third and fourth week after hop flowering (Wang et al. 2008). Mozny et al. (2009) found a positive impact of rainfall and a negative effect of temperature on alpha-acids accumulation in Czech Saaz hop cultivar, as well as Srečec et al. 2008 in Aurora hop cultivar. On the other hand, Kučera and Krofta (2009) found that the strongest impact on the alpha-acid content was exerted by air temperatures in July and rainfall had significant effects during the period from May to July, while in August the impact of a rainfall was negligible. Pavlović et al. (2012) found that 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 blooming by the mid July (week 28). These results stays in line with results of Srečec et al. (2008) who found significant decrease of alpha-acids accumulation if average daily reference crop evapotranspiration in June is higher or equal to 4.5. Srečec et al. (2008) on the basis of results of linear and multiple correlations suggested a following functional equation for accumulation of alpha acids (equation 1).
\[ A = f(T; R; I) \rightarrow A[7.41; 12.35] = f\left( T\left( \sum_{F3} 1601.74; 2000 \right); \right), \\
\quad R\left( \sum_{F9} 212.1; 391.8 \right); \\
\quad I\left( \sum_{F3} 1027.23; 1229.61 \right) \right. \rightarrow \quad ET_{0(VI)} \leq 4.5 \]

(1)

where:

- \( A \) – content of alpha-acids in dry matter (\%)
- \( T \) – sum of effective temperatures from second germination to hop harvest (°C)
- \( I \) – total hours of sun shining from second germination to hop harvest
- \( F3 \) – second germination after pruning
- \( F9 \) – technological maturity of hop cones (harvest time)
- \( ET_{0(VI)} \) – average daily reference crop evapotranspiration in July (mm day\(^{-1}\))

This equation, based on significant analytical data, unfortunately does not allow reliable prognosis of alpha-acids accumulation in technological maturity of hop cones.

However, nowadays because of very high hop supply, prognosis of alpha-acids accumulation become very important in order to estimate the commodities. Thus, the aim of this research is to find a simple mathematical model due to sum of effective temperatures and rainfall from second germination after spring pruning till the technological maturity of hop cones, in order to achieve reliable prognosis of alpha-acids accumulation in hop cv. Aurora.

**Materials and methods**

Research was carried out on hop cv. Aurora planted in hop garden in Croatia, near the village of Gregurovec (close to Križevci), during the six vegetation years (2001 – 2006, Srečec et al. 2008). The soil type of examined hop garden is an eutric pseudogley or eutric podzoluvisol. Content of physiological active phosphorus and potash, analysed by the AL-method, was medium. Average content of P\(_2\)O\(_5\) and K\(_2\)O during the all six

![Figure 1](http://www.springerplus.com/content/2/1/59)
Table 1 Reliability of mathematical model for accumulation of alpha-acids in hop cultivar Aurora in location of Gregurovec, Croatia during the six vegetation periods (2001-2006)

| Crop year | Sum of effective temperatures (°C) | Sum of total rainfalls (mm) | ET₀ in July | Calculated content of alpha-acids (%) in dry matter | Analysed content of alpha-acids (%) in dry matter (mean) | Difference (alpha calc. – alpha analysed) |
|-----------|-----------------------------------|-----------------------------|-------------|------------------------------------------------------|----------------------------------------------------------|------------------------------------------|
| 2001      | 1698.4                            | 393.7                       | 4.26        | 10.9                                                 | 11.6                                                     | 0.7                                      |
| 2002      | 1932.1                            | 425.8                       | 4.20        | 11.3                                                 | 11.1                                                     | 0.2                                      |
| 2003      | 1994.4                            | 175.2                       | 5.5         | 2.5                                                  | 6.7                                                      | - 4.2 (v/r)                             |
| 2004      | 1856.7                            | 398.5                       | 4.28        | 10.2                                                 | 10.0                                                     | 0.2                                      |
| 2005      | 1920.8                            | 403.3                       | 4.38        | 10.1                                                 | 9.7                                                      | 0.5                                      |
| 2006      | 1872.1                            | 382.0                       | 4.42        | 9.2                                                  | 9.3                                                      | 0.1                                      |

* previous functional equation for accumulation of alpha acids based on the results of linear and multiple correlations between weather conditions and accumulation of alpha acids described by Srečec et al. 2008 n/r – not reliable.

Table 2 Reliability of mathematical model for accumulation of alpha-acids in hop cultivar Aurora in location of Žalec, Slovenia in 2012

| Crop year | Sum of effective temperatures (°C) | Sum of total rainfalls (mm) | ET₀ in July | Calculated content of alpha-acids (%) in dry matter (mean) | Detected content of alpha-acids (%) in dry matter (mean) | Difference (alpha calc. – alpha detect.) |
|-----------|-----------------------------------|-----------------------------|-------------|-------------------------------------------------------------|----------------------------------------------------------|------------------------------------------|
| 2012      | 1766.2                            | 400.4                       | 4.2         | 10.8                                                         | 10.2                                                     | 0.6                                      |
Results and discussion

After mathematical analyses of experimental data by Eureqa Formulize 0.96 Beta software 17 equations were offered (Figure 1).

After substituting the values of dependent and independent variables in all equations only one equation was chosen with $p = 0.034 \,(p<0.05)$ (equation 3).

$$y = \frac{53.8w - 453 - 1.33w^2}{x}$$ \hspace{1cm} (3)

Where:

- $y$ – alpha-acids content in dry matter (%)
- $x$ – sum of effective temperatures (°C) from second germination after the spring pruning till technological maturity
- $w$ – sum of total rainfalls (mm) for the same period

However, that equation had to be refined by the authors, due to the negative results obtained and shifting the decimal point one space to the left (equation 4), because fraction must be divided by $-10$ in order to achieve reliable values.

$$y = \frac{53.8w - 453 - 1.33w^2}{x} \div (-10)$$ \hspace{1cm} (4)

Reliability of equation (4) was checked by inserting the values for the dependent and independent variables for the ten-year period for Croatian agro-ecological conditions (Table 1).

The results were tested also in agro-ecological conditions of Žalec, Slovenia during the 2012 (Table 2).

It is obvious that the differences between calculated and detected content of alpha-acids varied from 0.1 to 0.7, which is within boarders of repeatability ($R_{95} = 0.2$) and reproducibility ($R_{95} = 1$) for EBC 7.4 method (Anon 1998). However, this equation is not reliable in extremely drought year, like the year of 2003 was. That confirms results of Srečec et al. (2008) who found a negative correlation, determined by Spearman’s rank correlation, during the phonological phase of hop cones formation, between average daily reference crop evapotranspiration (ET0) in July and yield of hop cones, $r_s = -0.75 \,(p<0.05)$, as well as between ET0 and yield of alpha-acids in the same period, $r_s = -0.88 \,(p<0.05)$. This is also possible to explain with results of Pavlović et al. (2012), according to them, rainfall quantity from June 18 to July 22 shows the highest correlation with alpha-acid contents and impact of rainfall begins to decline after July 29. However, in time after July 29, the formation of glandular trichomes starts and the positive Spearman’s rank correlations were found between the average number of glandular trichomes and the content of alpha-acids ($r_s = 0.90; \, p<0.05$) and also between the average volume of glandular trichomes and content of alpha-acids ($r_s = 0.97; \, p<0.05$) (Srečec et al. 2011).

Finally, considering these results it is possible to suggest following general equation for alpha-acids accumulation in hop cv. Aurora (equation 5):

$$y = \frac{(k_1w) - k_2 - (k_3 \, w^2)}{x} \div (-10) \leftrightarrow ET_{0(b)} \leq 4.5$$ \hspace{1cm} (5)

In case of Aurora hop cultivar coefficients $k_1$, $k_2$ and $k_3$ are determined, which have to be determined for the other hop cultivars.

Conclusion

Achieved results confirms the results of Srečec et al. (2008) and using the Eureqa Formulize 0.96 Beta software allows reliable mathematical analyses but only if linear and multiple correlations of experimental data are previously provided. However, these results as well as results of previous authors show that weather conditions, during the hop vegetation have a stronger influence on accumulation of alpha-acids in technological maturity of hop cones than soil conditions.

Competing interests

The authors declare that they have no competing interests.

Authors’ contribution

SS conducted the research and led the writing, BC checked equation (4) in Slovenia during hop growing year of 2012, TSC assisted in research, AFR coordinated the field work in Slovenia during hop growing year of 2012. All authors read and approved the final manuscript.

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