Influence of Climatic Conditions on Accumulation of α-acids in Hop Cones

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Summary

The influence of climatic conditions on accumulation of α-acids was determined during the six years (2001 – 2006) of stationary experiment in hop cultivar Aurora. The research results show that increasing sum of effective temperatures during the technological maturity stay in negative correlation with accumulation of α-acids in hop cones (r = - 0.39*), whereas total rainfalls stays in positive one (r = 0.46*) At the same time sum of hours of sun shining stay in not significant negative correlation with the accumulation of α-acids (r = - 0.38). The results of factorial analysis show significant positive multiple correlation between sum of effective temperatures and total rainfalls with α-acids accumulation (multiple r = 0.6232**) and at the same time show a significant positive multiple correlation between total rainfalls and sunshine hours with α-acids accumulation (multiple r = 0.5492*). However, there was a very strong negative influence of reference crop evapotranspiration during the phenological phase of hop cones formation on yield of hop cones and of α-acids (r_s = - 0.75* and – 0.88*, respectively).

The total rainfalls during the hop vegetation in interval of [212.1; 391.8] mm and also the sum of effective temperature in interval of [1601.74; 2000] °C caused the α-acids accumulation in hop cones of cultivar Aurora in interval of [7.41; 12.35] % in dry matter. It is important to point out that the level of provided tillage, plant protection measures and fertilization was the same in all six experimental years, which excluded their effects on accumulation of α-acids.

These results could possibly contribute in creating a model of predication of α-acids accumulation and beginning of hop harvest.

Key words

α-acids, effective temperatures, total rainfalls, reference crop evapotranspiration, correlations

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Introduction

Share of α-acids is one of the most important parameters of hop quality and strictly corresponds with the growing conditions during the crop year (Srečec et al., 2004; Engelhardt, 2003; Srečec et al., 2001; Forster 2001). Dynamic of α-acids accumulation is not a represented by the linear curve in observed time during the technological ripeness of hop cones (Howard and Tatchell, 1956) but corresponds with the growing conditions during the crop year (Srečec, 2004; Majer, 1997; Majer, 1995; Knapić and Oset, 1995; Hacin, 1987).

It is well known that hop growing demands moderate climatic conditions, which means the sum of temperatures from the beginning of vegetation to technological maturity among 2400 to 2500 °C and average rainfalls of 470 mm (Kralj, 1962). Minimal temperature required for beginning of hop vegetation is 5 °C (Zmrzlak, 1991; Zmrzlak and Kajfež-Bogataj, 1996). However recent climatic changes known as global warming cause no deficit of temperatures but cause the deficit of the rainfalls during the vegetation which cause the changes in plant phenology and consequently, the wide fluctuations in yield and quality of hop (Engelhardt, 2003; Anon., 2007a; Anon., 2007b).

Therefore, the moment of hop harvest become the most critical operation in hop production for two reasons: determination of the right time of the beginning of hop harvest and the provision of the best labour organization in order to 'catch' the time of the highest accumulation of α-acids in hop cones. Early harvest can decrease the share of α-acids in hop cones for 20 % and the late one for 10 % (Virant and Majer, 2003).

There were many researches of hop photoperiodism provided during the seventies of the last century (Kišgeci et al., 1984), but there isn't any literature source about the influence of number of hours of sun shining on hop quality.

Thus, the aim of provided research were to determine the influence of climatic conditions, such as: sum of effective temperatures, total rainfalls, number of hours of sun shinning and reference crop evapotranspiration on accumulation of α-acids in hop cones of cultivar Aurora to predict the share of α-acids in hop cones in hop harvest.

Materials and methods

Research was carried out on hop cv. Aurora (Super Styrians) planted in hop garden near the village of Gregurovec (close to Križevci), during the six vegetation years (2001- 2006).

Hop cones were sampled from the same plants every third day during the phenological phase of technological maturity (F_9) in every experimental year and the samples were treated as depended samples.

Soil type on which the hop garden was placed is an eutric pseudogley (Škorić et al., 1985) or eutric podzoluvisol (FAO classification, 1990a; 1990b). On the basis of analysis of soil texture in Na-pyrophosphate, soil texture was classified as loam in all horizons (Ap – 0-24 cm, Eg – 24-33 cm, Btg I – 24-67 cm and Btg II – 67-100 cm). Supply level of physiological active phosphorus and potash, analyzed by the AL-method, was medium. Average content of P_2O_5 and K_2O during the all five experimental years was 19.1 and 15.4 mg per 100 grams of soil, respectively. Content of humus in soil was very low, only 1.48 %. Fertilizing was provided on the basis of balance accounts of needed and disposable plant nutrients for hop (Kišgeci et al., 1984) and it was uniform in all five experimental years.

Meteorological data were collected at the Field Agro Meteorology Station in Križevci, which is five kilometres from hop garden location.

Sums of effective temperatures, during the hop vegetation, for every experimental year, was calculated by the following equation:

$$\Sigma_{\text{effective temperatures}} = \left(\frac{D\min.T + D\max.T}{2} - 5\ ^{\circ}\text{C}\right),$$

where:

$D_{min.}T$, mean daily minimal temperature,

$D_{max.}T$, mean daily maximal temperature and 5°C is minimal temperature required for beginning of hop vegetation.

Data for referent crop evapotranspiration (Doorenbos and Pruitt, 1975) was calculated using the CROPWAT software (Allen et al., 1998).

The content of α-acids was determined by the method of lead conductance value of hops, powder and pellets prescribed by Analytica - EBC 7.4 (Anon., 1998) and dry matter content by the method of moisture content of hops and hop products prescribed by Analytica - EBC 7.2 (Anon., 1998). The boarder of repeatability (r_{95}) for method of lead conductance value was 0.2 and the boarder for reproducibility (R_{95}) was 1. During the six research years the 210 samples of hop cones were hand picked and analyzed from the same 35 plants, randomly chosen and marked in the first research year (2001) in the same hop garden, which means five control plots with seven plants per each plot within the same hop garden. The total number of provided chemical analyses (during the six research years) was 420 (including parallel control analyses), provided on hand mixed average samples of hop cones per plot of 7 plants.

After analyses of lead conductance value in all research years, there were only 27 analytical results with higher difference of analytical value than 1 % ($R_{95} = 1$) of α-acids, which were further statistically analyzed.

Statistical analysis of experimental results was provided by descriptive statistics, linear and multiple correlations. Factorial analyses between sum of effective temperatures, total rainfalls, hours of sun shining (as independent variables) and α-acids (as dependent variable) were determined by linear and multiple correlations. Correlation between reference crop evapotranspiration and α-acids share in hop content was determined by Spearman's coefficient of rank correlation (Vasilj, 2000; Little and Hills, 1978). All calculations were provided by using the STATISTICA 7.0 software.

Results and discussion

Comparisons of differences of plant nutrients supply of soil, such as P_2O_5, K_2O and nitrogen content, from the beginning to the end of hop vegetation, were not significant between and within the all six experimental years, thus all the differences in α-acids accumulation were explained as the influence of climatic conditions in different crop years.

Linear correlation analyses of meteorological data and analytical values of α-acids in dry matter of hop cones from second germination after the hop pruning (F_3) to the stage of technological maturity (F_9), showed the medium correlation between the total rainfalls and α-acids in hop cones, r = 0.46*, $t_{exp.(r)} = 2.5$; $t_{tab.(P=5\%)} = 2.06$ (Table 1). This result stays in line with Hacin's results (1987), who found a strong positive correlation between total rainfalls and α-acids content in cultivar Aurora.

On the other hand, sum of effective temperatures stays in negative correlation with accumulation of α-acids, r=-0.39*, $t_{exp.(r)} = 2.166$; $t_{tab.(P=5\%)} = 2.06$ (Table 1), which confirms the results of previous research (Srečec et al. 2004), in which the sum of effective temperatures has negative impact on the accumulation of α-acids in hop cones of cultivar Aurora ($r_s = -0.6$, $F_{exp.} = 4.4$; $F_{tab.(P=10\%)} = 3.10$).

Such phenomena could be explained by the negative correlation, determined by Spearman's rank of coefficients, during the phenological phase of hop cones formation F8, between reference crop evapotranspiration (ET_O) and yield of hop cones, rs = - 0.75* (p<0.05) as well as between ET_O and yield of α-acids in the same period, rs = - 0.88* (p<0.05) (Figure 1).

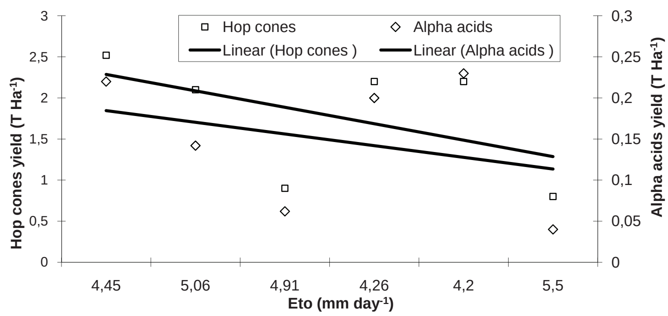

Figure 1. Influence of reference crop evapotranspiration (ET_O) during phenological phase of hop cones formation (July of 2001 - 2006) on yield of hop cones, $r_s = -0.75$* and yield of α-acids $r_s = -0.88$* ($p < 0.05$)

The beginning of phenological phase of hop cones formation (F_8) is usually in first decade of July and sometimes continues to the end of first week of August. Usually in that period high temperatures are very often and naturally cause increasing of evapotranspiration. That period of high temperatures and high daily reference crop evapotranspiration can cause not only decrease of α-acids yield, but even decrease of yield of hop cones, because of complete positive correlation between yield of hop cones and yield of α-acids, $r_s = 0.89$* ($p < 0.05$) (Figure 2). These results are possible explanation of Majer's results (1997) who obtained that water stress during July and beginning

Table 1. Variability and influence of climatic factors on α-acids accumulation in hop cones cv. Aurora

Statistical parameter	Sum of effective temperatures (°C)	Total rainfalls (mm)	Sunshine hours (insolation)	α-acids (%) (y – variable)
$\bar{x}$	1800.2	301.95	1128.42	9.88
$s_{(n-1)}$	198.26	89.85	101.19	2.47
$\bar{x} \pm s$	[1601.74;2000]	[212.1;391.8]	[7.41;12.35]	[7.41;12.35]
$S\bar{x}$	38.15	17.29	19.47	0.47
$\mu_{(\bar{x} \pm s\bar{x})}$	[1762.05 ; 1838.35]	[284.66 ; 319.24]	[1108.95 ; 1147.89]	[9.41 ;10.35]
r	- 0.39*	0.46*	- 0.38NS	-
S_r	0.18	0.1778	0.185	
$t_{exp.}(r)$	2.166	2.5	2.05	-
$t_{tab.(P=5\%)}$	2.06	2.06	2.06	-
$t_{tab.(P=1\%)}$	2.79	2.79	2.79	

(In linear correlation analysis content of α-acids was treated as dependent variable in comparisons with each climatic factor)

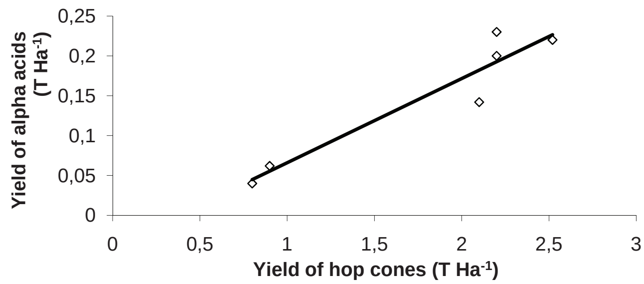

Figure 2. Correlation between yield of hop cones and yield of α-acids, $r_s = 0.89^*$ ($p < 0.05$)

of August cause a significantly reduction of: stomatal conductivity, net photosynthesis, weight of green mass, cones and roots and finally yield of hop cones.

However, medium multiple correlation was obtained, multiple r = 0.62** (p = 0.0027, n = 27), between sum of effective temperatures and total rainfalls as independent variables and share of α-acids (dependent variable), and also medium multiple correlation, multiple r = 0.55* (p = 0.0135, n = 27), between rainfalls and hours of sunshine as independent variables and share of α-acids (dependent variable) from second germination of hops after pruning (F_3) till technological maturity of hop cones (F_9) (Figure 3 and 4).

Comparing the experimental data it was obvious that total rainfalls during the hop vegetation in interval of [212.1; 391.8] mm and also the sum of effective temperature in interval of [1601.74; 2000] °C cause the α-acids accumulation in hop cones of cultivar Aurora in interval of [7.41;12.35] % in dry matter (Fig. 3). However, because of significant multiple correlation of total rainfalls and hours of sunshine on accumulation of α-acids (multiple r = 0.55*, p = 0.0135, n = 27) it is facultative possible to accept the fact that hours of sunshine in interval of [1027.23; 1229.61] hours can cause α-acids accumulation in hop cones of cultivar Aurora in interval of [7.41;12.35] % in dry matter (Fig. 4).

On the basis of that, it is possible to suggest following equation:

$$A = f(T;R;I) \rightarrow A_{[7.41;12.35]} = f\left(T_{\left(\sum_{F3}^{F9}[1601.74;2000]\right)}; R_{\left(\sum_{F3}^{F9}[212.1;391.8]\right)}; I_{\left(\sum_{F3}^{F9}[1027.23;1229.61]\right)}\right) \leftrightarrow ET_{o(VII)} \leq 4.5$$

where:

A, mean a content of α-acids in % of dry matter

T, mean a sum of effective temperatures (°C) from second germination to hop harvest

R, mean a total rainfalls (mm) from second germination to hop harvest

I, mean hours of sun shining from second germination to hop harvest

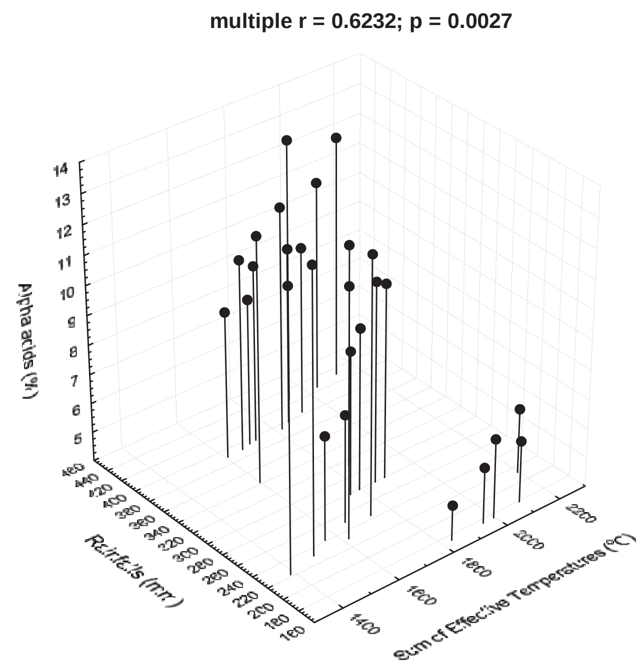

Figure 3. Interaction between effective temperatures and total rainfalls on α-acids accumulation in hop cones (from second germination of hops F_3 till technological maturity of hop cones F_9 during the research years 2001 – 2006)

F_3, mean second germination after pruning

F_9, mean technological maturity (harvest time)

$ET_{o(VII)}$, mean average daily reference crop evapotranspiration in July (mm day^{-1})

These results stays in line with Kralj's results (1962) with some exceptions; firstly, Kralj provided her experiment with cultivar Savinjski Golding that has a shorter vegetation in the comparison with cultivar Aurora and secondly the experimental period in Kralj's research was beginning of hops vegetation, which consist F_1 phenological phase.

However from practical view, sometimes is completely useless to consider the effects of climatic conditions on hop yield and quality from F_1 to F_9 phenological phase, because of possibly excessive rainfalls during the March and April that cause water saturation in soil and impossibility of tillage and spring hop pruning. From that reason we chose the second germination of hop after the spring pruning or F_2 as more important phenological phase for commercial hop production.

It is very important to point out that the most critical vegetation period for hop yield and quality determination

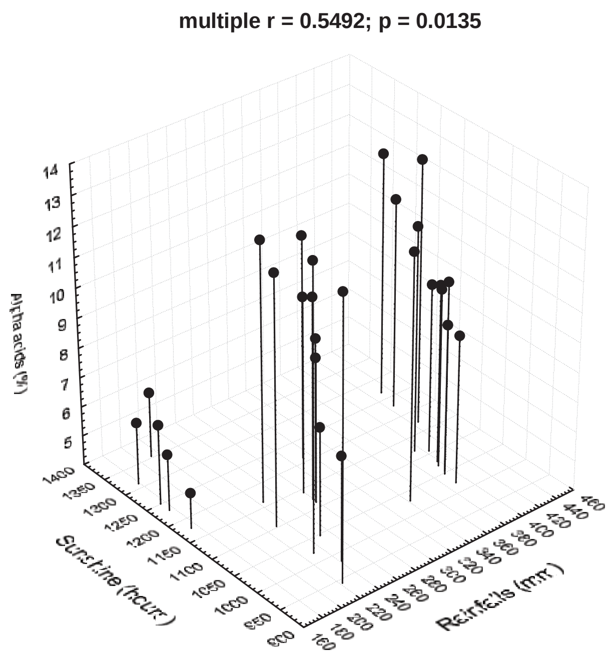

Figure 4. Interaction between total rainfalls and sunshine hours on α-acids accumulation in hop cones (from second germination of hops F_3 till technological maturity of hop cones F_9 during the research years 2001 – 2006)

is F_7 phenological phase or hop cones formation and that means the time of July. In the case of high evapotranspiration, which means the higher average values of ET_O than 4.5 mm day^{-1} the yields of hop cones and α-acids would significantly decrease (Fig. 1), which confirm the results of Forster's (2001) and Engelhardt's (2003) researches.

However, these researches were provided only on hop cultivar Aurora and the results are probably not valid for the other hop cultivars depending on their needs for weather condition during the vegetation.

Conclusion

The results of influence of climatic conditions on accumulation of α-acids in hop cones from second germination after the hop pruning (F_3) to the stage of technological maturity (F_9) shows that it is possible to predict the final content of α-acids in hop cones, because of achieved correlations between meteorological conditions during the vegetation year and share of α-acids in dry matter of hop cones.

Comparing the experimental data it is obvious that total rainfalls during the hop vegetation in interval of [380; 440] mm and also the sum of effective temperature in interval of [1700; 2000] °C cause the α-acids accumulation in hop cones of cultivar Aurora in interval of [8.3; 10.0] % in dry matter. Because of significant multiple correlation of total rainfalls and hours of sunshine on accumulation of α-acids (multiple r = 0.55*, p = 0.0135) it is facultatively possible to accept the fact that hours of sunshine are in interval of [1100; 1300] hours.

However, it is very easy and even simple to estimate the future yield of α-acids only by simple measuring the daily values of minimal and maximal temperatures, calculating the effective temperatures per day, measuring daily rainfalls and/or facultative hours of sunshine and finally summarizing the obtained values.

This might be of a practical value for every hop producer and/or hop merchant, primarily because of poor supply in the comparison with demand of α-acids at the world hop market.

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