TOOLS FOR TERROIR CLASSIFICATION FOR THE GRAPE VARIETY KÉKFRANKOS

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ABSTRACT

A 3-year study was carried out in order to evaluate the ecophysiology, yield and quality characteristics of *Vitis vinifera* L. cv. Kékfrankos (syn. Limberger) at Eger-Nagyeged hill (steep slope) and at Eger-Kőlyuktető (flat) vineyard sites located in the Eger wine region, Hungary. The aim of this paper was to analyse the effect of 'vintage' and 'terroir' on the seasonal changes of Kékfrankos ecophysiology and its possible relationship with yield and wine composition.

Grapevine physiological responses (midday- and pre-dawn water potential, pressure–volume analysis and gas-exchange), yield and wine composition of each vineyard were studied. Lower grapevine water supply was detected at Eger-Nagyeged hill in each season due to its steep slope and soil characteristics. Stomatal conductance, transpiration rate and photosynthetic production per unit leaf area were affected by water availability. Lower yield in Eger-Nagyeged hill was partly associated with decreased photosynthetic production of the canopy. Improved wine quality of Eger-Nagyeged hill was due to moderate water stress which induced higher concentration of anthocyanins and phenolics in the berries. There was a close relationship between environmental conditions, Kékfrankos gas exchange, water relations, yield and wine composition. Water deficit plays an important role in creating a terroir effect, resulting in decreased yield, better sun exposure of leaves and clusters and thus higher concentration of phenolics and anthocyanins. Although quality is mainly influenced by vintage differences, vineyard characteristics are able to buffer unfavourable vintage effects even within a small wine region. Stomatal conductance, pre-dawn water potential and climatic data may be reliable parameters for terroir classification, although variety–terroir interactions must always be considered.

Data of Geographycal Information System (GIS) performed in this study may serve as part of the data base, that we are engaged in the Eger wine district in Hungary.

KEYWORDS:

Climate-grapevine-photosynthesis-terroir-water relations-water deficit-wine composition, yield

INTRODUCTION

Grape and wine qualities are determined by many factors including variety, environmental conditions where the grapevine is grown and the impacts of human activities. Natural factors depend on the prevailing climatic system, the types of soil of the given region and geographical characteristics (Königer et al. 2003, van Leeuwen and Seguin 2006). All of the elements of a given vineyard will have a combined effect on yield and quality. Generally, in a given area, the soil type and viticultural practices do not change significantly from year to year and, therefore, climate is the most dominant factor in determining grape quality (Tonietto and Carbonneau 2004, Downey et al. 2006).

Within a wine region, mesoclimatic variability could be essential in the so-called 'terroir effect' (van Leeuwen and Seguin 2006). Daily temperature plays a determinant role (Coombe

1987, Downey et al. 2006) especially during the ripening period, although night minima are also reported as a very important factor (Tonietto and Carbonneau 2004). Water deficit also has a great impact on fruit and wine quality with a positive effect at a moderate level of stress (Bravdo and Hepner 1987, Carbonneau 1998), which results in larger relative skin mass in the berries (Roby and Matthews 2004) and thus higher concentration of phenolics and anthocyanins (Kennedy et al. 2002, Ojeda et al. 2002, Sivilotti et al. 2005). Environmental conditions also influence the physiological status of the grapevine. Measurement of the relevant parameters could be a rapid and reliable tool for assessment of the interactions between the plant and its environment, although responses of individual cultivars could be very different (Düring 1984, Choné et al. 2001, Flexas et al. 2002, Medrano et al. 2003, Schultz 2003).

The present study compares two growing sites with very similar climatology in three climatically-different years with regard to *Vitis vinifera* L. cv. Kékfrankos within the Eger wine region of Hungary close to the northern limits of the grapevine cultivation zone. Our hypothesis was that vineyard/terroir characteristics may buffer unfavourable "vintage effect" year by year. Therefore, the aim of this paper was to analyse the effect of the 'vintage' and 'terroir' on the seasonal changes of Kékfrankos ecophysiology and its possible relationships with yield and wine composition. Our results present scientific evidence for the importance of a terroir-selection strategy based on a complex approach in terms of climate-ecophysiology-yield-quality interactions.

MATERIALS AND METHODS

Eger-Kőlyuktető: This was a flat commercial vineyard with brown soil formed on rhyolite tuff. The clay content was 39-42 %, increasing towards to the deeper layers. The water-holding capacity of the soil was 36-38% and the wilting point was at 24-27%; pH was slightly acid. The sand fraction was 23-38 %, decreasing downwards. Slope: 5-12%, exposition: NE-E, elevation: 190 m (Photo 1. and Fig. 1.).

Eger-Nagyeged hill: This was a steep-sloped, commercial vineyard with a Southern exposure resulting in rapid precipitation runoff and high radiation loads, and thus generally water deficit in the soil during the growing season. The brown soil was formed on marine limestone. Clay content was 21-24 %. The silt fraction (40-55 %) was dominant. Water-holding capacity was 25-27%, wilting point was at 12-14% and the pH was neutral. Slope:17-25%, elevation: 310-335 m (Photo 2. and Fig.2.).

Based on GPS coordinates, the distance between the two vineyards is 6.97 kilometres. Three blocks were selected randomly within each 0.5 hectare vineyard, each block including 40 plants. Marginal rows were not included. The vines at both vineyards were cordon trained, with N-S row orientation with 3 m x 1.2 m row and vine spacing, at the same pruning level (6 buds/m^2) on Teleki 5C (Berlandieri x Riparia) rootstocks.

Climatic data were gathered, grape and wine analysis for the experiments were done according to Zsófi et al. (2009). Ortho photos were generated by the National Institute of Geodesy, Cartography and Remote Sensing, Hungary (FÖMI). The digitized slope, exposition and elevation maps are based on the scale of 1:10000 topographical maps. The georeferenced maps were digitized (contour lines) in ESRI ArcGIS, the TIN models created by 3D Analysis.

RESULTS AND DISCUSSION

Water relations

Preliminary pre-dawn water potential measurements were taken in 2003 and 2004. In 2005, Ψ_p was monitored during the growing season more frequently and in parallel with Ψ_m. In

2003, Ψ_p values indicated a higher water deficit at Eger-Nagyeged hill with values between -0.3 and -0.35 MPa in contrast with Eger-Kőlyuktető having -0.1 to -0.15 MPa pre-dawn water potentials. A slight decrease was observed in both vineyards during the ripening period (from the end of July to 10^{th} of October), however, the difference in water supply between the

Photos 1 and 2: Ortho photos of the 2 examined growing sites. No. 1. on the photo indicates Eger-Kőlyuktető, No. 2. indicates Eger-Nagyeged hill.

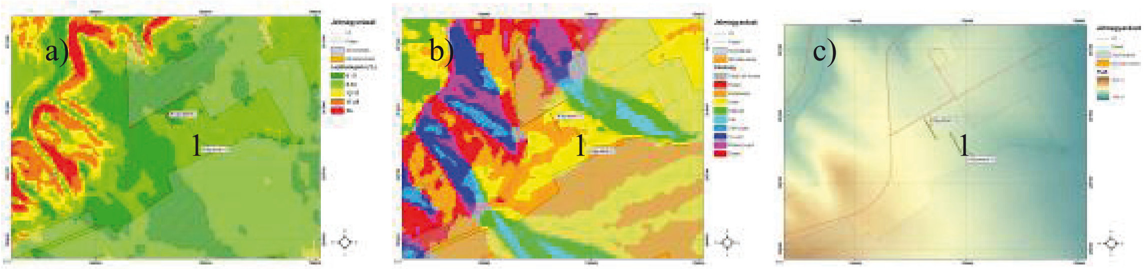

Fig. 1.a, b and c.: Digitized maps of Eger-Kőlyuktető growing site (1): a) slope, b) exposition, c) elevation maps

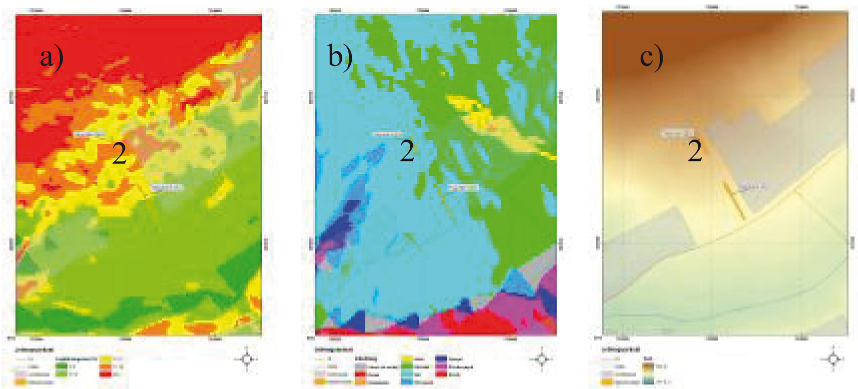

Fig. 2.a, b, and c.: Digitized maps of Eger-Nagyeged hill growing site (2): a) slope, b) exposition, c) elevation maps

experimental sites remained constant. In the next two years, Ψ_p was a slightly higher at both vineyards. There were Ψ_p fluctuations during the growing season at each experimental site, however, Eger-Nagyeged hill was regularly prone to water deficit. Although differences were smaller between the vineyards in these years than in 2003, values indicated a significant increase in the intensity of late seasonal water deficit at the steep-sloped site in each year. In most cases, there were no differences in midday leaf water potential between the experimental sites. The range of Ψ_m was from -1.2 to -0.6 MPa. The lowest values were measured in 2003 with values between -0.95 and -1.2 MPa. In 2004 and 2005, more positive Ψ_m values were measured during the growing season. Although significant differences occurred between the experimental sites during the ripening period (2004: from the middle of August to 3rd of November; 2005: from the middle of August to 26th of October) for some leaf Ψ_m in each year, the range of values did not indicate stress conditions in any case (Fig. 3).

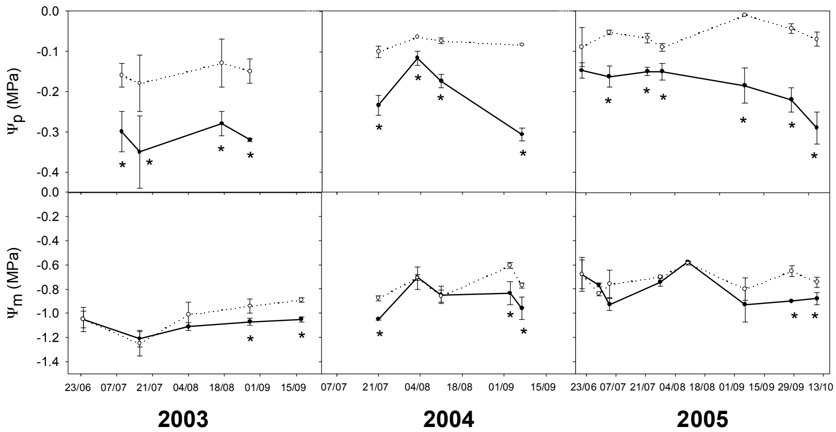

Fig. 3. Seasonal changes of predawn (Ψ_p) and midday (Ψ_m) water potentials during the growing seasons of 2003, 2004 and 2005 at Eger-Kőlyuktető (dotted line with open symbols) and at Eger-Nagyeged hill (solid line with filled symbols). Each Ψ_p symbol represents the average ± standard errors (SE) of 9-12 replicates. Ψ_m symbols represent 4-6 replicates as measured during early afternoon. Within each seasonal period average ± SE values marked by asterisk are significantly different from the values at the other site ($p<0.05$) according to Duncan's test.

Gas-exchange

Stomatal conductance, assimilation rate and transpiration rate were monitored during the growing seasons in each year. There were differences in many cases between the sites with respect to gas-exchange parameters, especially during the ripening periods. At Eger-Kőlyuktető g_s, P_n, and E were higher during the experimental periods than at Eger-Nagyeged hill, although seasonal fluctuations were observed due to heavy local rains (2003: the end of July and the beginning of August; 2005: the end of July) at both experimental sites. Stomatal conductance at Eger-Nagyeged hill was lower than at Eger-Kőlyuktető. This caused a reduced rate of assimilation and transpiration. Generally g_s values fluctuated between about 0.06 and 0.23 mol m^{-2} sec^{-1} during ripening, indicating a moderate water stress at Eger-Nagyeged hill. Stomatal conductance values higher than 0.23 mol m^{-2} sec^{-1} were measured after heavy rains at Eger-Nagyeged hill (Fig. 4).

DISCUSSION

Although the annual rainfall of the vineyards exceeded the amount which is characteristic for this geographical region (500-600 mm) in each year, there were differences in soil water availability between the terroirs due to the low soil water-holding capacity and the steep slope of Eger-Nagyeged hill. Pre-dawn leaf water potentials indicated greater differences in grapevine water supply between the vineyards than midday water potentials. Differences in Ψ_m were not significant through most of the growing season, although they became significant during the ripening period. The range of Ψ_m was between 0.6 - 1.2 MPa which indicates nil stress according to the findings of Hsiao (1973), in spite of the apparent water deficit (low Ψ_p, g_s, and soil matric potential) in this vineyard (Eger-Nagyeged hill).

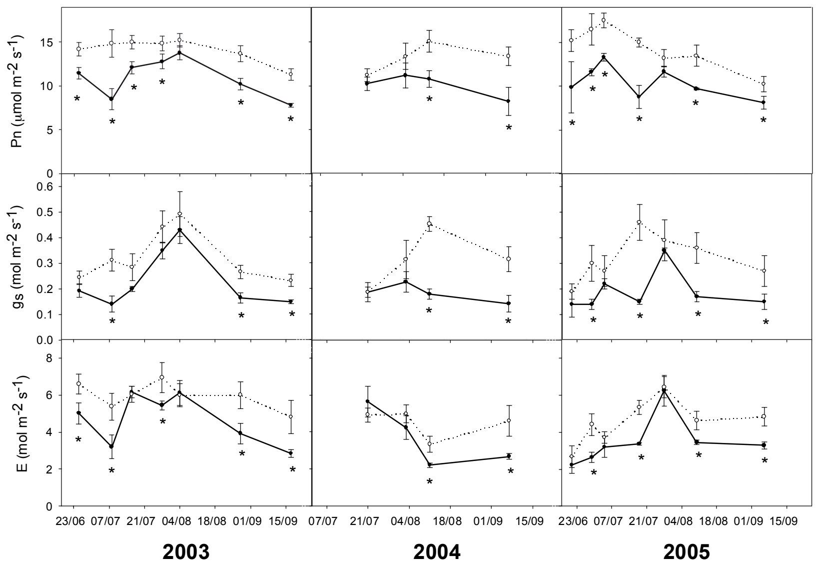

Fig. 4. Midday net CO_2 assimilation rate (P_n), stomatal conductance (g_s), and transpiration rate (E) at Eger-Kőlyuktető (dotted line with open symbols) and at Eger-Nagyeged hill (solid line with filled symbols) during the growing seasons. Each symbol represents the average ± SE of 5-10 replicates from early afternoon. Within each seasonal period average ± SE values marked by asterisk are significantly different from the values at the other site ($p<0.05$) according to Duncan's test.

This result suggests that Kékfrankos has a close to isohydric behaviour under the described climatic conditions, as was reported in the case of Grenache vines (Schultz, 2003). This stress avoidance strategy is due to stomatal regulation caused by ABA signals from the roots in response to the drying soil (Loveys and Düring, 1984; Correia et al., 1995) and to the high VPD in leaves (Soar et al., 2006b). Stomata may also close in response to the occurrence of embolisms in the xylem under high evaporation demand and the resulting decreased conductance capacity of stems and petioles (Schultz, 2003).

Stomatal regulation occured at Eger-Nagyeged hill causing reduced carbon uptake and water loss of the canopy. Additionally, the generally smaller g_s characteristic of the stressed vineyard (Eger-Nagyeged hill) was accompanied by a slight upward shift in WUEi (data not presented here). Based on the relationship between P_n and g_s, it can be concluded that there were two main ranges of stomatal conductance detected during the three years of the experiment. These ranges match the findings of Cifre et al. (2005) in which the g_s value was used as an integrative parameter for determination of the degree of water deficit. The first range (about 0.06-0.23 mol m^{-2} s^{-1}) was typical of the Eger-Nagyeged hill slope indicating moderate and in some cases mild water deficit during the growing season. The second range (about 0.23-0.7 mol m^{-2} s^{-1}) demonstrates mild or a lack of water stress at Eger-Kőlyuktető with values close to the upper limit of g_s. Summing up the physiological results, gas exchange parameters and pre-dawn water potentials indicated significant differences between the terroirs during the ripening period when water deficit may have a favourable impact on wine quality (Hepner et al., 1985). It seems that stomatal conductance (and pre-dawn water potential) is a reliable tool for determining the degree of water stress and thus, in this case, vineyard/terroir water status.

Yield and average cluster weight in the water stressed terroir (Eger-Nagyeged hill) were consistently lower during the experimental period (Figure 3). Berry weight was also smaller by 20–30% at Eger-Nagyeged hill than at Eger- Kőlyuktető , as a result of water deficit (measured only in 2004 and 2005, data not shown).

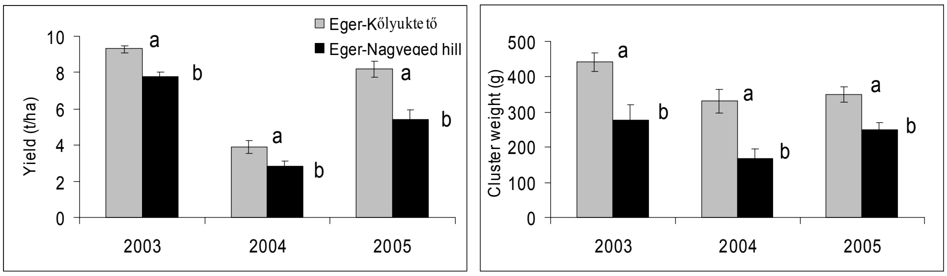

Fig. 3. Yield and cluster weight from the two experimental sites. Each graph bar represents the average ± SE of 12-15 clusters from each block of both vineyards. Significant differences between the vineyards are marked by different subscript letters in a given year according to Fisher's LSD comparison test (p<0.05).

Table 1. Results of the experimental wine analysis from the vineyards in each year**.** Each value is the average of three winemaking replicates. In a given year the different subscript letters between the rows indicate significant differences in wine composition between the vineyards (p<0.05).

Vineyard	Year	Catechin (mg/L)	Total polyphenol (mg/L)	Anthocyanin (mg/L)	Total tannin (g/L)
Eger-Nagyeged hill	**2003**	491.3[a]	828.6[a]	208.4[a]	1.64[a]
	2004	768.5[a]	1478.5[a]	213.4[a]	2.23[a]
	2005	565.4[a]	857.2[a]	212.2[a]	1.6[a]
Eger-Kőlyuktető	**2003**	428.2[b]	802.1[a]	121.9[b]	0.96[b]
	2004	379.3[b]	871.3[b]	138.4[b]	0.82[b]
	2005	415.2[b]	656.5[b]	122.7[b]	1.37[b]

Juice sugar concentration (except 2005) and titratable acidity were slightly higher at Eger-Nagyeged hill, although the difference was not significant (data not shown). Wines from the stressed vineyard (Eger-Nagyeged hill) had higher total polyphenols, total tannins, anthocyanins and catechin concentrations compared with the unstressed terroir (Eger-Kőlyuktető) in each year (Table 1). Anthocyanin and total tannin concentrations were almost twofold higher in the wines from Eger-Nagyeged hill than the other site, especially in 2003 and 2004.

CONCLUSION

Environmental conditions caused important and significant differences in Kékfrankos ecophysiology, yield and wine quality. These differences are linked to the effect of several factors, in which water deficit plays an important role in creating a terroir effect, resulting in decreased berry weight/size, better sun exposure of leaves and clusters and thus higher concentration of phenolics and anthocyanins. However, in our study, the described level of water deficit at Eger-Nagyeged hill was due to the combined effect of low soil water holding capacity and precipitation runoff. On the other hand, vineyard exposure (slope and aspect) can determine temperature characteristics with respect to diurnal range and minimum values at night. Therefore, slope, aspect and soil type of the vineyards may strongly modify the ripening process, leading to profound differences in wine composition. Terroir selection is a reliable tool for buffering unfavourable vintage effects, and thus improving and/or sustaining wine quality. *In situ* physiological measurements (g_s and Ψ_p) and meteorological data (night minima) may be useful methods for terroir selection and classification. However, the terroir–variety interaction must always be considered in respect of strategies against abiotic stresses and ripening dynamics of the given cultivars.

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