The effect of two terroirs with different water supply on the water relation, production and thermal stability of photosynthesis of the Kékfrankos (*Vitis vinifera* L.) grapevine

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1. INTRODUCTION

In wine regions with a cool climate, the climatic conditions increase the cost of vine growing compared to the Mediterranean and other arid vine growing regions. The main vulnerability of cool climate areas is that the seasonal dynamics of the combined climatic factors may be different year to year, resulting in the so-called "vintage effects". Global warming may result in a positive effect on viticulture close to the northern/southern limit of the vine growing zone; however, some scenarios predict increased climate change effects in these regions, resulting in more frequent, extreme weather events.

In countries with a long tradition of wine making terroir selection is one of the main tools to improve wine quality. The concept of terroir originated from France and it is a complex approach to 'vitiviniculture'. According to Seguin (1988) the terroir is "…an interactive ecosystem in a given place including climate, soil and the grapevine". In this context the key point is to find the optimal 'terroir-variety' combination. Therefore, it is essential to know the ecophysiological responses and the ripening dynamics of a given variety under different environmental conditions. The dissertation deals with this segment of the terroir concept. The necessity to describe terroir-variety interaction is also supported the fact that climate change may result in extremely dry growing seasons. Therefore, the ecophysiological assessment of a given variety and monitoring of physiological parameters of the vines during the growing season could be a reliable tool to optimize viticultural practices (i.e. irrigation).

Experiments were carried out on the Kékfrankos variety (*Vitis vinifera* L. cv. Kékfrankos), which is the main component of Egri Bikavér. Because this variety is cultivated on a large scale only in the Central European region and because of its typical character (besides the terroir effect) this cultivar is suitable for making unique and high quality wines.

2. AIMS

Two growing sites (Eger-Kőlyuktető – flat; Eger - Nagyeged hill – steep slope) with different water supply were compared in three climatically different years with regard to *Vitis vinifera* L. cv. Kékfrankos within the Eger wine region of Hungary. The experiments were designed to answer the following questions:

1) How do the mesoclimate, grapevine physiological responses and production change on the two terroirs in different vintages?

2) How do the gas-exchange and water relation parameters of the Kékfrankos variety change during the growing season on the terroirs? What are the main physiological responses to water deficit of this variety? Is it possible to characterize terroirs by physiological and climatic parameters?

3) Is there any effect of terroir and vintage on starting dates and the duration of phenological stages?

4) Is there any effect of terroirs on vegetative growth and canopy structure? Is there any relationship between canopy structure and yield sugar concentration?

5) How do the terroir and vintage characteristics influence the heat sensitivity of Kékfrankos photosynthesis? Are there any seasonal changes of thermal stability of grapevine leaf photosynthesis?

3. METHODS AND MATERIALS

In the Eger wine region two terroirs close to each other (Eger-Kőlyuktető – flat, 26 years old; Eger-Nagyeged hill – steep slope, 29 years old), with different water supply were studied. The vines (*Vitis vinifera* L. cv. Kékfrankos) at both vineyards were umbrella trained, with south-north row orientation, with the same row and vine spacing and pruning level on Teleki 5C (Berlandieri x Riparia) rootstocks.

The following tools and devices were used during the experiment:

1) Climatic data were collected by automatic weather stations (Boreas Ltd., Budapest, HU).

2) Pre-dawn (Ψ_p) and midday (Ψ_m) water potential were monitored with a Scholander-pressure chamber (PMS, Albany, OR, USA). Pressure–volume curves were applied in order to describe the acclimation mechanisms against water stress on tissue level (osmotic and/or elastic adjustment).

3) Gas-exchange parameters were measured with a CIRAS 1 and an ADC 4 portable infrared gas analyser (PP System, Hitchin, UK; ADC Bio Scientific Ltd, Herts, UK.).

4) Canopy measurements were carried out using the point quadrate method. Individual leaf area was determined by a CI – 202 Area Meter (Cid INC. USA).

5) Yield components and quality parameters (sugar concentration and wine phenolic compounds, spectrophotometer: Hewlett-Packard, Waldbronn, Germany) were determined.

6) *In vivo* chlorophyll *a* fluorescence was measured in dark-adapted leaves with pulse amplitude modulation fluorometers (PAM 101-103 and PAM 2000 Walz, Effeltrich, Germany) during linear heating (25-60 ^{o}C). Thermal stability of basic fluorescence parameters (F_v/F_m – optimal quantum yield; $\Delta F/F_{m'}$ – effective quantum yield; NPQ – non-photochemical quenching), the breakpoints (T_c) of the initial (F_0) and "steady–state" (1200 µmol $m^{-2}s^{-1}$) (F_s) fluorescence were determined.

7) Xanthophyll cycle components were determined by means of HPLC (Perkin Elmer Series 200 HPLC System, Waltham, MA, USA). Chlorophylls and total carotenoids were measured by spectrophotometer.

4. RESULTS

I. TERROIR AND VINTAGE EFFECTS ON WATER RELATIONS, GAS-EXCHANGE, PHENOLOGICAL STAGES, CANOPY STRUCTURE, YIELD COMPONENTS AND QUALITY PARAMETERS OF THE KÉKFRANKOS GRAPEVINE (*VITIS VINIFERA* L.)

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 mild to moderate water deficit plays an important role in creating a terroir effect. Pre-dawn leaf water potentials (Ψ_p) and stomatal conductance (g_s) indicated mild to moderate water deficit at the hilly site. No water deficit was observed at Eger-Kőlyuktető. Ψ_p showed greater differences in grapevine water supply between the vineyards than midday water potentials (Ψ_m). 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 indicates nil stress at both vineyards in spite of the apparent water deficit (low Ψ_p, g_s) at Eger-Nagyeged hill. This result suggests that Kékfrankos has a close to isohydric behaviour under the described climatic conditions. This variety is much more sensitive to vapour pressure deficit of the air (VPD) than to water deficit in the soil. At both vineyards more negative Ψ_m values were measured due to higher VPD without any difference between the terroirs. Pressure-volume analysis indicated a lack of osmoregulation in this cultivar at this level of water stress. At Eger-Kőlyuktető (no water stress) more negative osmotic potentials were measured in the leaves probably due to a higher assimilation rate.

Water deficit resulted in reduced yield and vegetative growth, consequently in better sun exposure of leaves and clusters and thus a higher concentration of phenolics and anthocyanins. Furthermore, vineyard exposure (slope and aspect) can determine temperature characteristics such as minimum values at night. At the steep slope terroir night minimum temperatures were higher by 4-6 ^{o}C that at the flat vineyard. Therefore slope, aspect and soil type of the vineyards may strongly modify the ripening process, leading to profound differences in wine composition.

II. RELATIONSHIPS BETWEEN THE TERROIR, VEGETATIVE GROWTH, LEAF AREA, GAS-EXCHANGE AND YIELD SUGAR CONCENTRATION

At the water-stressed terroir there was a lower assimilation rate per unit leaf area than at the flat vineyard, however yield sugar concentration was higher. Water deficit decreased yield and individual leaf area, and furthermore it resulted in changes in berry size/weight ratio inside the clusters. Better light conditions were detected in the canopies at Eger-Nagyeged hill than at Eger-Kőlyuktető due to lower individual leaf areas and reduced vegetative growth. Terroir has an obvious effect on sink-source relations between the yield and the canopy and between sunlit and shaded leaves inside the canopy.

Therefore an intensive vegetative growth and a dense canopy compete with grape bunches for photosynthetic sugar produced by sunlit leaves.

III. TERROIR AND VINTAGE EFFECTS ON PHOTOSYNTHETIC THERMAL STABILITY OF KÉKFRANKOS GRAPEVINE LEAVES

Under field-grown conditions abiotic stress factors co-occur frequently, therefore thermal stability of Kékfrankos grapevine leaf photosynthesis was also studied in a warm and a cooler vintage in the two terroirs. We aimed to test (1) how the seasonal changes and mesoclimatic/topoclimatic characteristics influence the thermal stability of basic chlorophyll fluorescence parameters in grapevine leaves and photosynthetic pigment (*Chl a+b* and xanthophylls) concentrations ('terroir effect'); and (2) how the climatic characteristics of the given year may modify these basic parameters in each vineyard ('vintage effect').

2007 was drier and warmer with higher vapour pressure deficit (VPD) than 2005. Pre-dawn water potential measurements indicated mild water deficit at the steep-sloped vineyard. In July 2005 a mild water deficit enhanced the thermostability of grapevine photosynthesis, as reflected in the temperature dependence of optimal quantum yield (F_v/F_m) and in the critical temperature of initial fluorescence (F_0T_c). Decreased F_v/F_m and actual quantum yield ($\Delta F/F_m$') were recorded at most temperatures in September at the water-stressed site. This time F_0T_cs were also lower due to early leaf senescence. In September 2007 the heat sensitivity of F_v/F_m was similar to 2005, and $\Delta F/F_{m'}$ indicated higher thermostability at both sites, while keeping the consistent difference between the two vineyards. The critical points of steady-state fluorescence (F_sT_c) were higher by 3-6°C at both vineyards in 2007 than in 2005. Although in September thermolabile F_0 signals were measured at the stressed vineyard, the heat sensitivity was not decreased in the light adapted state, assumingly as a result of enhanced xanthophyll cycle pigment pool size. The higher xanthophyll pigment pool size (V+A+Z) in 2007 at the unstressed vineyard suggests (compared to 2005) that high temperature and VPD play a role in changing (V+A+Z)/(Chl_{a+b}), and thus results in higher thermostability under high light conditions.

5. NEW SCIENTIFIC RESULTS

1) Mild to moderate water deficit at Eger-Nagyeged hill was due to the combined effect of low soil water holding capacity and precipitation runoff in each year. Mild and moderate water deficit have a favourable impact on wine quality, therefore terroir selection is a reliable tool for buffering unfavourable vintage effects, and thus improving and/or sustaining wine quality. This relationship was shown by a complex approach to climate-ecophysiology-yield-quality interactions.

2) Pressure-volume curves indicated that there was no osmotic adjustment in the leaves of this variety. Higher osmotic concentration was measured at turgor loss and full turgor in the leaves of the unstressed vineyard (Eger-Kőlyuktető) presumably due to higher photosynthetic activity. Water deficit resulted in only slightly increased cell wall rigidity. Therefore, water relation of this variety is regulated by stomatal regulation and the relatively high osmotic concentration. Kékfrankos has a close to isohydric behaviour under the described climatic conditions. However, this variety is much more sensitive to vapour pressure deficit of the air. *In situ* physiological measurements (stomatal conductance and pre-dawn water potential) and meteorological data (night minima) may be useful methods for terroir selection and classification.

3) The starting dates and the duration of the phenological stages of the terroirs were only affected to a minor extent by their slope and exposure. On the other hand, growing stages were influences by vintage temperature characteristics.

4) Both terroirs made a complex effect on Kékfrankos ecophysiology, vegetative growth, yield and wine quality. Mild to moderate water deficit had a positive effect on the ratio of yield and vegetative parts of the grapevine. Increased light interception occurred due to lower individual leaf area and decreased vegetative growth.

5) Heat sensitivity of grapevine leaf chlorophyll fluorescence is highly determined by mesoclimatic ('terroir effect') and macroclimatic ('vintage effect') conditions. Water deficit, higher temperature (degree days) and higher VPD induced an enhanced heat tolerance in grapevine leaves. However, leaf senescence, as a result of a long term mild water deficit, may lead to incorrect interpretation of F_0T_c breakpoints in terms of PSII thermostability. At the water-stressed site under high-light conditions increased thermal stability is probably due to higher xanthophyll pool size. Furthermore, the increased xanthophyll pigments pool size in 2007 compared to 2005 at the unstressed vineyard suggests that high temperature and VPD also play a role in changing (V+A+Z)/(*Chl a*+*b*), and thus results in higher thermal stability under high-light conditions.

6. CONCLUSIONS AND PROPOSALS

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 a higher concentration of phenolics and anthocyanins. Mild to moderate water deficit had a positive effect on the ratio of yield and vegetative parts of the grapevine and increased light interception occurred due to lower individual leaf area and decreased vegetative growth. Therefore, precise canopy management may help to obtain an optimal maturity of the yield under unfavourable environmental conditions. In different vintages grapevine responses of the given terroir were very similar year by year in terms of ecophysiology and quality parameters. Therefore, terroir selection is a reliable tool for buffering unfavourable vintage effects, and thus improving and/or sustaining wine quality. *In situ* physiological measurements (stomatal conductance and pre-dawn water potential) and meteorological data (night minima) may be useful methods for terroir selection and classification and may help to create an optimal terroir-variety combination. In endangered terroirs (steep slopes and/with low soil water holding capacity) water restriction and water supply technologies are suggested.

Water deficit, higher temperature (degree days) and higher VPD induced an enhanced heat tolerance in grapevine leaves. However, leaf senescence, as a result of a long term mild water deficit, may lead to incorrect interpretation of F_v/F_m and F_0T_c breakpoints in terms of PSII thermostability. Light induced biochemical changes relatively increased the thermal stability of senescence leaves at the water-stressed terroir. Indeed, F_sT_c breakpoints were higher at Eger-Nagyeged hill, probably as a result of enhanced xanthophyll cycle pigment pool size. Therefore, thermal stability of photosynthesis should be studied in a complex way, taking into account the acclimation ability of the system.

7. PUBLICATIONS

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