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TEMPRANILLO PHYSIOLOGICAL AND AGRONOMICAL RESPONSES TO HEAT AND DROUGHT STRESS – PERSPECTIVES ON ITS VULNERABILITY UNDER CLIMATE CHANGE SCENARIOS

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ABSTRACT

With the aim to characterize the ability of Tempranillo grapevines, one of the most widely used varieties in Spain and Portugal, to withstand drought and heat stress, ecophysiological and agronomical data from irrigation experiments conducted in the hot and dry region of Alentejo, south of Portugal, are presented.

The impact of different irrigation treatments on physiological parameters (leaf water potential, photosynthesis, and stomatal conductance) and water use efficiency are showed. Leaf senescence observed in non-irrigated and deficit irrigated plants and its consequences on cluster exposure and berry temperature are compared with those of fully irrigated plants. The consequences on berry ripening and juice composition are discussed in order to evaluate the vulnerability of Tempranillo to the expected global climatic change.

Keywords: grapevine, water stress, vegetative growth, berry composition, climate change.

1- Introduction

Nowadays deficit irrigation strategies applied to grapevines are common practices used for managing grapevine growth, improving fruit quality and water use efficiency, while maintaining yields (McCarthy, 2000; Santos *et al*, 2003). However, when exposed to severe heat stress, as observed in recent years in the European Mediterranean regions like Spain and Portugal, the mild stressed vines are vulnerable to leaf burning. This occurs due to the restriction in stomatal conductance leading to a decreased ability to energy dissipation.

In some situations the fraction of burnt leaves can be very high and, depending on the variety and the ripening phase, it can have strong effects on berry ripening and also on vine longevity. The resultant increase in cluster sun exposure can lead to burning of the berries and/or lead to abnormal ripening, originating reduced yield, juice with high low titratable acidity and a loss of aromatic compounds. In warm regions, the high temperature that the fully exposed berries can achieve may also affect anthocyanin concentration either through degradation, inhibition of synthesis, or, more likely, both (Kliewer and Torres, 1972; Haselgrove *et al*., 2000; Spayd *et al*., 2002).

The incidence of drought have increased in recent years and predictions from simulation models on global change suggest an increase in the likelihood of extended summer droughts coupled to a substantial increase in temperature in the future (Jones *et al*., 2005). Therefore information on the capacity of the varieties to withstand water and heat stress is needed in order to predict their behavior in the near future. Tempranillo, one of the most widely used red varieties in Spain and Portugal, is quite sensitive to water and heat stress, being one of the first varieties to show symptoms from those abiotic stresses.

Using ecophysiological and agronomical data from an irrigation experiment conducted in the hot and dry region of Alentejo, south of Portugal, this paper discuss the ability of Tempranillo to withstand drought and heat stress.

2- Material and Methods

The field trial was carried out in 1999 at a commercial vineyard located in Évora, Southern of Portugal. The fourteen-year-old grapevines of the red variety 'Aragonez' syn. 'Tempranillo', grafted on 1103P rootstock, were spaced 2.5 m between and 1.1 m along North-South oriented rows and trained on a vertical trellis. The soil is an Antrossoil with an ApCR profile derived from granite with 75% of sand and high percentage of gross elements.

The experiment was set up in a randomized block design with four replicates per treatment. Four drip irrigation intensities, established according to the crop evapotranspiration (ETc): (DIv - 50% ETc witheld after veraison, DIh - 50% ETc supplied until harvest, FIv - 100% ETc witheld after veraison and FIh - 100% ETc supplied until harvest), were tested against a non-irrigated control (NI). Irrigation began at the end of May (10 days after full bloom) when the available soil water was around 60% and was cut-off at the end of July (full veraison) for the DIv and FIv treatments and one week before harvest (end of August) for DIh and FIh ones. In the deficit irrigation treatments a total of 144 and 216 mm was applied once a week in DIv and DIh respectively. In the full irrigation ones a total of 270 and 431 mm were applied twice a week in the FIv and FIh respectively.

Predawn and midday leaf water potential were measured at the two central blocks in 6 fully mature and well-exposed leaves per treatment, on the day before irrigation, using a pressure chamber (PMS Instrument Co, USA). Photosynthesis was measured with a portable IRGA (LI-6400, Li-Cor Inc., USA) in 6 fully mature and well exposed leaves per treatment. Light at the cluster zone was measured on sunny days at midday using a Sunflek Ceptometer (model SF-40, Delta T Devices Ltd, Cambridge, UK) inserted horizontally at the cluster zone along the row. The values of incident photosynthetic photon flux density (PPFD) were expressed in percentage of a reference PPFD, measured over the canopy top.

Berry temperature was determined on NI and FIh vines on clear sunny days using 12 berries per treatment located on each face of three representative cluster locations within the canopy, east-exposed, west-exposed and interior (centre of the canopy) (Fig. 1). Measurements were made continuously using fine-wired (36 American Wire Gauge [AWG]) two-junction thermocouples (type T [copper-constant]) which were manually inserted into the berries and connected to a data logger (Delta-T Devices Ltd, Cambridge, UK).

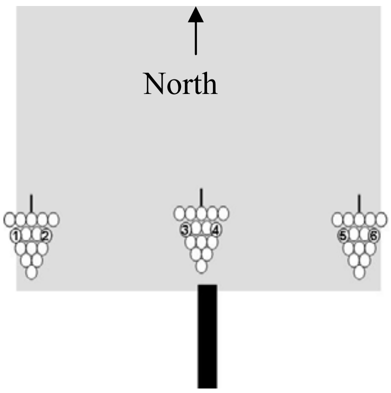

Figure 1. Schematic diagram of canopy cluster zone showing the berry positions where temperature measurements were done during the ripening period (25 August) of 1999 growing season on NI and FIh vines.

3. **RESULTS**

3.1- Response of leaf water potential and photosynthesis to water availability

In NI vines predawn leaf water potential (Ψ_{pd}) showed a decreasing pattern during the summer period attaining –0.6 MPa two weeks before veraison, *ca* -0.9 MPa at veraison (July 20th) and values lower than -1.0 MPa during the ripening period. In the full irrigation treatment Ψ_{pd} presented high values (-0.2 MPa) during the whole season. In the deficit irrigation treatments Ψ_{pd} presented a similar decreasing trend until veraison, DIv showing a steeper decrease after irrigation cut off, attaining at harvest values close to those of NI plants. A marked decrease of Ψ_{pd} of FIv vines was also obtained at harvest (Fig. 2A). The midday leaf water potential (Ψ_m) showed also a decreasing pattern along the season however the relative differences between treatments were not so pronounced as in Ψ_{pd} (Fig. 2B).

The seasonal variation of net assimilation and stomatal conductance showed a similar pattern to that reported for Ψ_{pd}, being the highest values presented by FIh vines and the lowest ones by NI plants. After irrigation suspension on the DIv and FIv treatments both photosynthesis and stomatal conductance showed a strong decline, achieving similar values to those of the NI vines (Fig. 2 C, D).

From June to the middle of July the intrinsic water use efficiency (WUEi) increased in NI and deficit irrigated vines while FIv and FIh presented constant and lower values. From veraison to the end of ripening period the WUEi increased in FIv but declined in NI and DIh treatments, while DIv and FIh showed almost no changes (Fig. 2 E).

Figure 2 F presents the leaf to air temperature difference (ΔT_{leaf}) measured at midday on the same exposed leaves where photosynthesis measurements were done. From bloom to veraison we can observe a clear separation between NI (highest ΔT_{leaf}) and FI (lowest ΔT_{leaf}) with the deficit irrigation vines presenting intermediate values. FI vines always presented the leaf temperature closer to air temperature or even lower. After irrigation cut-off at veraison on DIv and FIv those treatments increased their ΔT_{leaf} attaining at harvest similar values to those of NI.

3.2. Leaf senescence

In NI vines leaf senescence began prematurely (3 weeks before veraison) and, at veraison, 60% of main leaf area had already been lost. At harvest (end of August) while FIh plants showed about 23% of defoliation, NI vines presented 72.5%. Irrigation cut-off at veraison induced also a fast increase in leaf senescence which was more evident in DIv plants than on FIv ones (Fig. 3A).

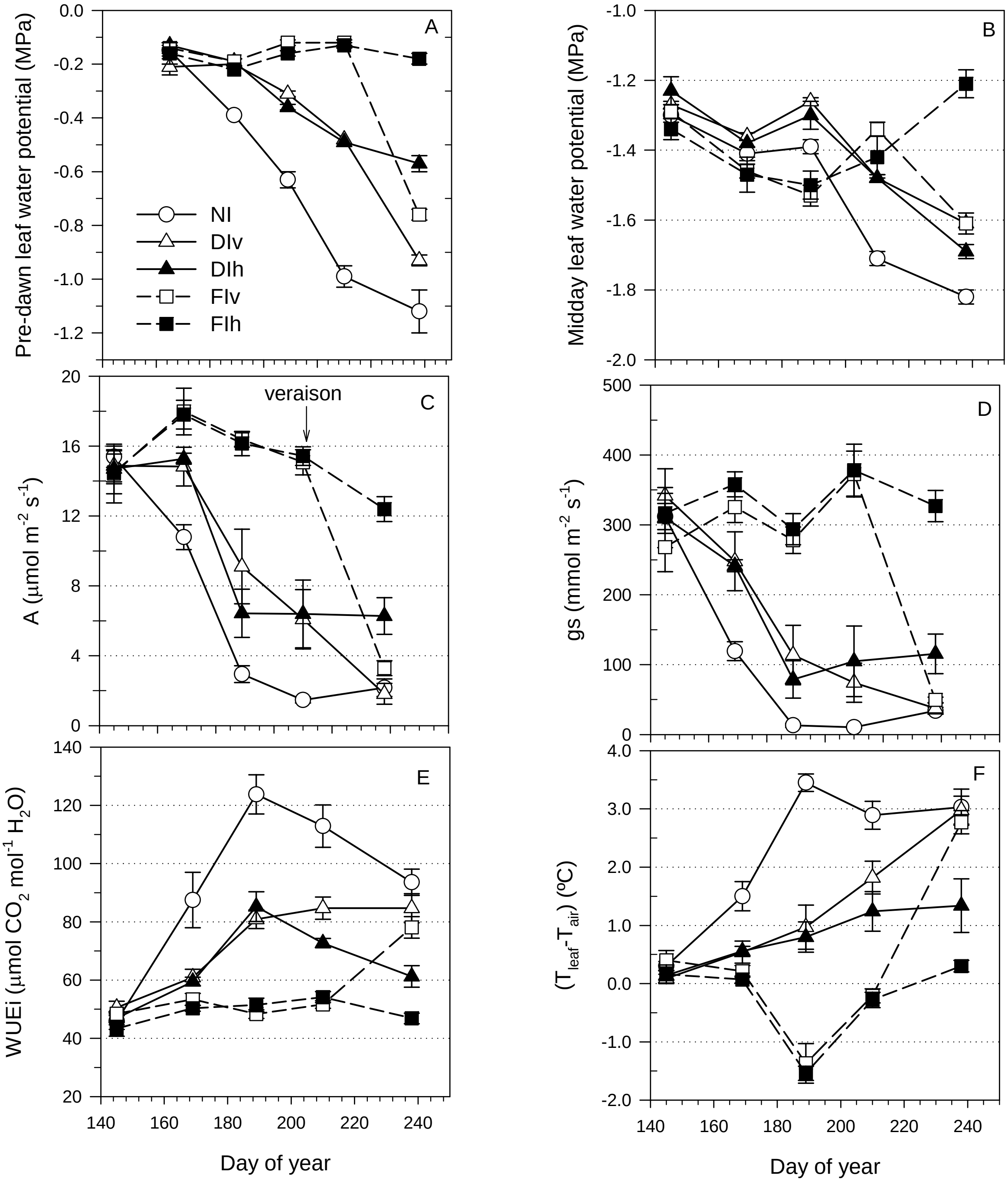

Figure 2. Seasonal pattern of predawn (A) and midday leaf water potential (B); midday photosynthesis (C) midday stomatal conductance (D); intrinsic water use efficiency (WUEi) (E) and midday leaf to air temperature difference (F) of Tempranillo grapevines submitted to different water suply: NI- non-irrigated; DIv - 50% ETc withheld after veraison, DIh - 50% ETc supplied until harvest, FIv -100% ETc withheld after veraison; FIh - 100% ETc supplied until harvest. Average ± standard error of 6 adult exposed leaves.

3.3. Cluster microclimate

The high rate of defoliation observed in NI vines reduced the basal leaf layer number inducing a higher interception of PAR in the cluster zone (Fig. 3B). The irrigation treatments showed similar values of intercepted PAR until 11 august (22 days after veraison); thereafter only FIh presented a slight increase whereas the other irrigation treatments showed a strong increase.

Those differences in canopy density induced important changes on cluster exposure being the highest differences observed between NI and the FIh vines. At the middle of the ripening period, using the point quadratic method (Smart and Robinson, 1991) we measured 77% of exposed clusters on NI vines while FIh presented only 13%. In order to evaluate the impact of cluster exposure on berry temperature we inserted thermocouples within a sample of 12 berries located in 6 different positions on the two control treatments (NI and FIh) at the end of the ripening period (see diagram of Fig. 1). The data obtained show a very high variability related to the 6 different locations of the sampled berries. The highest positive berry to air temperature differences were obtained on the sun-exposed berries of the exterior clusters (berry positions 1 and 6 on Fig.1) in the mid-morning (East canopy side) and mid-afternoon (West) of both treatments which showed similar patterns (data not shown). However, when comparing the interior clusters and interior faces of the exterior clusters (berry positions 2 to 5 on Fig.1) we detected a higher positive berry to air temperature during most part of the day on NI berries when compared to FI ones (Fig. 4).

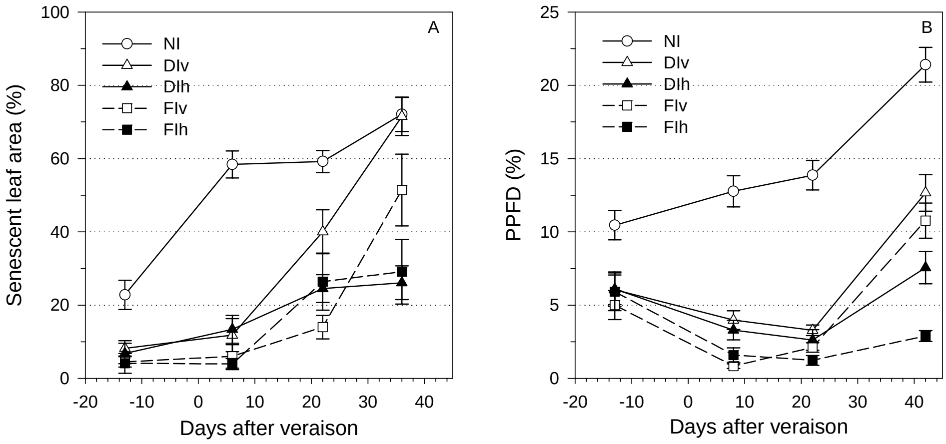

Figure 3. Seasonal pattern of senescent leaf area (A) and photosynthetic photon flux density at the cluster zone expressed as a % of the reference at the top of the canopy (B). Values shown represent the average ± standard error of 16 shoots (A) or 40 measurements (B).

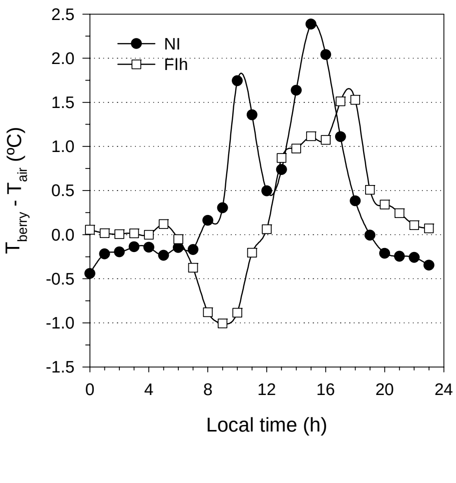

Figure 4. Berry to air temperature differences measured on the non-exposed berries. Values shown represent the mean of 4 representative berry positions (positions 2 to 5 on Fig. 1) measured on 2 representative vines per treatment.

3.4 – **Yield and berry composition**

In NI vines the severe water stress delayed full veraison by two weeks relatively to irrigated ones. Due to a significantly lower berry and cluster weight, NI vines presented a significantly lower yield than irrigated ones, while DIv showed intermediate values. NI vines showed a significantly lower titratable acidity and higher anthocyanins content than irrigated vines, which presented statistically similar values (Table 1).

Table 1. Yield and berry composition of Tempranillo grapevines submitted to different water supply: NI- non-irrigated; DIv - 50% ETc withheld after veraison, DIh - 50% ETc supplied until harvest, FIv -100% ETc withheld after veraison; FIh - 100% ETc supplied until harvest. In each row, different letter suffixes show statistically significant differences at $P<0.05$ by LSD test.

	NI	**DIv**	**DIh**	**FIv**	**FIh**
Yield components					
berry weight (g/100 berries)	112.3 c	163.4 b	178.1 ab	185.5 ab	200.5 a
cluster number/vine	17.0 a	18.9 a	19.8 a	18.4 a	17.9 a
cluster weight (g/cluster)	148.6 c	220.2 b	257.6 a	260.6 a	263.3 a
Yield (kg/vine)	2.6 c	4.1 b	5.1 a	4.8 ab	4.9 ab
Fruit composition					
Total soluble solids (ºBrix)	21.6 a	21.9 a	22.8 a	21.8 a	22.9 a
Tit. acidity (g tartaric acid/L)	4.1 b	4.4 ab	4.4 ab	5.4 a	5.3 a
Skin anthocyanins (mg/berry)	1.3 a	0.9 b	1.0 b	0.9 b	0.9 b

4- Discussion

The very hot and dry season induced a strong and premature decline in available soil water, as indicated by the low predawn leaf water potential, which induced a severe water stress in non-irrigated vines. As a consequence NI vines exhibited premature leaf senescence and very low photosynthetic rates on the remaining leaves which reduced berry growth and increased intercepted light by the cluster.

During the ripening period, in non-irrigated and deficit irrigated plants, the reduction of stomatal conductance, although preventing excessive transpiration losses, leaded to an increase in leaf temperature which attained at midday values about 3ºC higher than air temperature. This high leaf temperature exposed the leaves to burning and may became a problem under heat waves conditions which begun to be very common in Mediterranean regions, like Alentejo.

Basal leaf senescence induced important changes in canopy density. The more open canopy of NI plants increased light penetration in the cluster zone which can be, in most temperate wine regions, beneficial to phenols and anthocyanins accumulation since this process is strongly light dependent (Haselgrove *et al*, 2000). However, as the degree of cluster exposure influences berry temperature, the concomitant increase in berry temperature may also affect the synthesis of anthocyanins or induce their degradation (Kliewer and Torres, 1972; Bergqvist *et al*., 2001, Spayd *et al*., 2002). Defoliated vines like those of NI are much more exposed to berry sunburn and/or negative effects of the high temperature on berry ripening. However, as within a canopy the berries have several locations and, consequently, several expositions, it is not easy to understand the integrated effects on berry composition. Indeed, at harvest, despite the higher proportion of exposed clusters of NI vines, when compared to FI ones, the former showed a significantly higher anthocyanins concentration per berry than that of the irrigated plants. Those results indicate that temperature attained is not yet supraoptimal for berry colour formation.

In this "terroir" the low titratable acidity obtained in NI berries should be taken into consideration when defining the severity and/or period of water stress by deficit irrigation strategies. Indeed, as must acidity decreases with water and heat stress (Williams & Matthews, 1990; Esteban *et al*., l999) the main aim of irrigation should be to maintain good levels of juice acidity which is known to lack in this variety.

Our results show that this variety has a higher leaf sensitivity to heat and drought but seems to present a berry colour metabolism highly resistant to high temperatures. More research is needed in order to better understand the effects of drought, light and temperature under field conditions in other varieties.

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