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Pedoclimatic abiotic stress tolerance observed on twenty-eight Sardinian autochthonous grape accessions and their resilience to climate change

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Abstract. The climate change imposes rising physiological stress on grapevine. The difference on abiotic stress tolerance of 28 Sardinian autochthonous grape accessions (SAGAs) were studied, to search for resilience differences among them, during a three-year trial. Two-way factorial experimental design and analysis were implemented considering the SAGA and the phenological stage as variability factor, whereas random factors were the year and plant replicates. Net photosynthesis, stomatal conductance, transpiration rate and midday stem water potential (mSWP) were measured from fruit set until harvest. GLM-ANOVA and HSD Tukey test were performed to analyse data and discriminate averages. The mSWP measured on all SAGAs allowed for distinguishing significantly the cultivars according to four water stress thresholds. No mSWP and leaf gas exchange difference were observed among groups when SAGAs were classified according to berry colour (white vs red). To better understand the stress tolerance differences among SAGAs, they were classified according to a resilience index, mSWP based. SAGAs were separated in a declining order according to a climate resilience index (CRI). The trial permitted to classify SAGAs on the base of the stress level induced by pedoclimatic environment, and to distinguish some autochthonous rarer accessions potentially much climate-resilient such as Tintillu, Moscatello, Remungiau di Serri and Muristellu, than others most diffuse accessions or cultivars such as Cagnulari and Vermentino.

1 Introduction

Climate change is the recent great challenge in viticulture. Temperature increases in most grape regions worldwide, together with prolonged drought lead to grapevine physiological adaptation as shortening of phenological timing and advances in harvest dates [1]. Genetic diversity of *Vitis* spp. is one of the main strength of vine adaptive capacity under different environments. According to Gashu et al. [2], different grapevine cultivars exhibit varying sensibility to temperatures. They reported that small differences in seasonal mean daily temperature (+ 1.5 °C) induces slower vegetative development and ripening of the berries, which are more intense in red cultivars (CVS) than in white ones. Many authors suggest to shift grapevine cultivation to northern latitude or upper elevation in order to reduce the negative impact of the warmer and dryer conditions [3]. Moreover, there is a third way, consenting grape to stay in the same vineyards, just introducing resistant or resilient cultivars. Frioni et al. [4] evaluated fruit ripening course of 16 local minor CVS versus the locally most common variety and they found that local germplasm could hide relevant potentialities in terms of adaptation of viticulture to climate change.

Lovicu [5] reported the possibility to find accessions in the very large Sardinian germplasm, probably suitable for combating climate change. Several authors [6-8] evidence earlier harvest at the beginning of August because of the growing of temperature and the lack of rainfall affecting especially the hot spot Mediterranean climate-type region [9]. Figure 1 shows the last ten years faster maximum temperature increasing trend: +1.0 °C in 1000 days and progressive decrease in the number of the rainy days recorded in Sardinia in the same trial site.

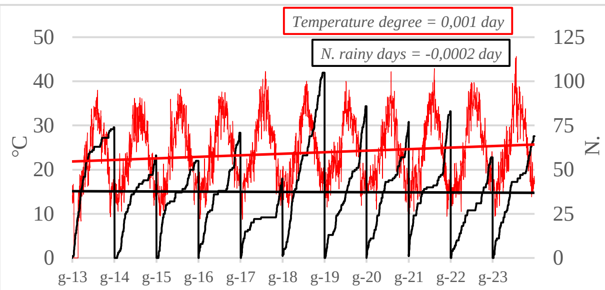

Figure. 1. Maximum daily temperature (°C) and number of rainy days (N. counted if rainfall is ≥ 0.8 mm) last ten years' trends.

Nevertheless, climate change effects on Sardinian viticulture are amplified because the rain-fed cultivation still prevails. Therefore, increase of temperatures and droughts induces further adaptive stress to the vineyard areas not assisted by irrigation. In Sardinia, where the irrigation is applied, supplemental irrigation strategy

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prevails, and re-watering supplies are applied when visible plant water stress visual symptoms are observed by the farmer, which are often not enough to prevent severe drought and heat stress damages. Therefore, a survey has been carried out on twenty-eight Sardinian autochthonous grapevine accessions (SAGA) of the Agris Sardegna variety collection vineyard [5], grown on homogeneous soil and under same cropping conditions, to explore variety physiological adaptation to inter-annual weather variation and to discriminate their potential resilience to extreme events under Mediterranean climate.

2 Materials and methods

2.1 Experimental field

The three years' study (2013, 2014 and 2015) was carried out in an autochthonous germplasm collection vineyard in the Agris Sardegna experimental farm in Sardinia, Italy (39° 24' 44''N; 9° 06' 27''E, 130 m a. s. l.), where 202 white and red SAGAs are cultivated [5]. Vines were grafted onto 1103P rootstock and planted, in 2005,on an alkaline clay-sandy soil, with an active calcareous fraction near the 10%, a sufficient organic matter fraction (near 2%) and a good K, Mg, Ca and P content [5].The vines were spaced 2.4 x 1 m, the rows were directed along the maximum slope (about 10 %) assuming a Northwest-Southeast orientation, and the shoots were trained to a VSP system Guyot pruned with about 10 nodes on the horizontal cane and two more buds on a spur left for annual cane renewal [5].

Table 1. The trial selected 15 white and 13 red SAGAs included in the collection ITA376 [10].

White-skinned SAGAs (names and abbreviations).	
Monica bianca (MNCB)	Malvasia di Sardegna (MLV)
Remungiau di Serri (RER)	Moscatello (MSC)
Caddiu bianco (CDB)	Semidano (SMI)
Vernaccia di Oristano (VRS)	Nasco (NSC)
Cannonau bianco (CNNB)	Vermentino (VRM)
Argu Mannu/AAA* (AGA)	Alvarega/Gregu biancu (GEB)
Vernaccia bidri Villasor (VRB)	Nuragus (NRA)
Cranaccia arussa (CAA)	-
Red-skinned SAGAs(names and abbreviations).	
Girò (GRO)	Gregu nieddu (GEN)
Caricagiola (CRC)	Pascale di Cagliari (PSC)
Carignano (CRG)	Bovaleddu antigu (BLV)
Cagnulari (CGN)	Monica (MNC)
Cannonau (CNN)	Barbera sarda (BRS)
Tintillu (TNT)	Bovali mannu (BVM)
Muristellu (MRI)	-

* = AAA = Aghina de Anghelos di Abbasanta.

The experiment was conducted on two vines per genotype, randomly selected within the available ones ranging from 7 to 140 plants per accession, preliminary excluding those with visible symptoms of vegetative dieback. During the three years' irrigation seasons the vineyard was supplementary irrigated with one or two watering per month according to the yearly rainfall trend (fig.2); fertilization, disease and pest management were uniformly applied across the whole vineyard.

2.2 Meteorological data

Meteorological data were recorded by a SIAP DA7000 Agris Sardegna weather station, located at about 700 meters away from the vineyard, and provided with sensors which measure hourly several parameters including air temperature (°C) and rainfall (mm). In figure 1 and figure. 2the daily maximum temperatures and the number of rainy days in the last ten years, and the daily maximum temperatures and the amount of rainfall of the three years of trial, are shown.

2.3 Plant Ecophysiology

Eco-physiological parameters such as midday stem water potential (mSWP), and leaf gas exchange, i.e. net photosynthesis (PN), transpiration rate (EVAP) and stomatal conductance (GS)were measured by using the Scholander pressure bomb pump-up model (PMS Instrument Company 1725 Geary Street SE Albany, OR 97322 USA) form SWP, and the gas analyzer Ciras 2 (PP Systems 110 Haverhill Road, Suite 301 Amesbury, MA 01913 USA) for the leaf gas exchange. Data are shown in table 2 and in figures 3, 4 and 5. All measures were taken in June, July, August and September, at mid-morning, once per month corresponding to the phenological stages of fruit set, bunch development, veraison and grape ripening, respectively.

2.4 Experimental design, data statistical analysis and modelling

Two-way factorial experimental design and analysis were implemented, considering the 28 SAGAs or their subdivision according to the colour of the berries and the phenological stage or the stress threshold range, as controlled variability factor, whereas random variables were the year (n = 3) and the single plant (n = 2) which were combined and considered as replicates(n = 6).Repeated measures of each parameter (PN, GS, EVAP and mSWP), taken at different dates each year(n = 4), were analysed with the Repeated Measure General Linear Model analysis of variance (GLM-ANOVA).The comparison among accessions was performed by using the HSD Tukey test at $p \leq 0.05$. Data were analysed by using Centurion 18 statistical software (© 2023 Statgraphics Technologies, Inc., The Plains, Virginia).

Calculating the ratio (1) to evaluate the three years mSWP variability in each SAGA, considering as a pedoclimatic resilience index (PRI) the following expression:

$$PRI = (SS\ mSWP - AS\ mSWP) / (AS\ mSWP) \quad (1)$$

where SS represents high stress (mSWP < - 1.2 MPa) and AS represents no stress conditions (mSWP > - 0.8 MPa). Intra SAGAs anisohydric degree (SAD) was expressed by the following equation:

$$SAD = [(highest\ SAGA\ GS - single\ SAGA\ GS) / (highest\ SAGA\ GS)] + [(highest\ SAGA\ mSWP - single\ SAGA\ mSWP) / (highest\ SAGA\ mSWP)] \quad (2)$$

By combining PRI and SAD, it was possible to calculate an index for estimating climate resilience of the grapevine varieties (CRI):

$$CRI = (PRI + SAD) \tag{3}$$

which allows to classify all the 28 SAGAs in order of their declining sensitivity to the stressing conditions experienced during the trial (fig.5). CRI data in fig. 5 were normalized applying the equation:

$$Xnorm = (X-Xmin) / (Xmax-Xmin) \tag{4}$$

were Xnorm is normalized CRI for a given SAGA as in formula (3); Xmin and Xmax are respectively the minimum and maximum CRI of the 28 SAGA population.

3 RESULTS

During the three years, the thermo-pluviometry trend (fig. 2) was particularly variable, especially from June to September. In these months, the average maximum daily temperatures were higher in 2014 (30,6 °C) and much higher in 2015 (31,3 °C) than in 2013 (30,1 °C). This last year was drier than the following two, had earlier summer conditions (June and July), and was wetter during berry ripening (end of August and September):the effects on vines were highlighted by the mSWP values detected on all the SAGAs (fig. 3) and defined "year effect" according to Lovicu [5].

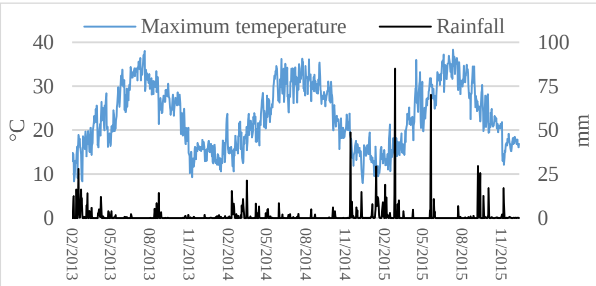

Figure. 2. Daily maximum temperature and rainfall between the 20/02/2013 and the 31/12/2015.

Based on all SAGAs mSWP, it was possible to distinguish four stress threshold ranges one per each main phenological stage:
- AS = No Stress, mSWP > - 0.8 MPa at fruit set (June);
- LS = Low Stress, - 0.8 MPa <mSWP< - 1.0 MPa at bunch closure(July);
- MS = Medium Stress, - 1.0 MPa <mSWP< - 1.2 MPa at veraison (August);
- SS = High stress, mSWP< - 1.2 MPa at berry ripening (September).

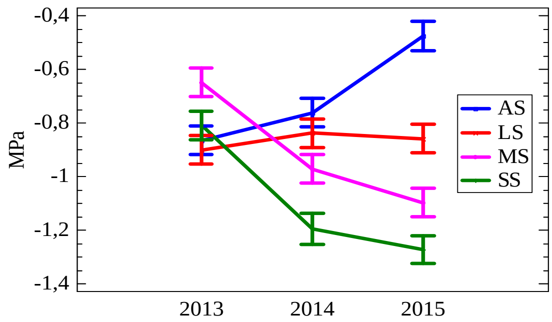

Figure. 3. The monthly mSWP averages for the period of stress (from June to September each year) and HSD Tukey's intervals, at 95% confidence levels, observed on all SAGAs and the related stress thresholds estimated (expressed in MPa).

The abnormal weather conditions recorded in 2013 compared to those of the following two years, induced unexpected mSWP values, while the 2014 and 2015 mSWP values confirmed the normal trends of the local Mediterranean climate and were considered as AS, LS, MS and SS stress threshold clusters (fig. 3 and tab. 2).

Table 2. The three-year averages of mSWP, GS, PN and EVAP observed in AS, LS, MS and SS (MF, main factor) on SAGAs divided on the base of berry colour (BC, sub factor).

MF	SF	mSWP	GS	PN	EVAP
ST	BC	MPa	mmol $m^{-2}sec^{-1}$	µmol $m^{-2}sec^{-1}$	mmol $m^{-2}sec^{-1}$
AS	W	-0.7 a	275.6 ab	8.8 b	2.71 aB
	R	-0.7 a	267.9 ab	8.1 b	2.73 aA
LS	W	-0.9 b	213.4 a	7.9 b	3.57 bB
	R	-0.8 b	225.7 a	8.6 b	3.77 bA
MS	W	-0.9 c	242.6 ab	5.1 a	3.67 bB
	R	-0.9 c	281.2 ab	4.8 a	4.15 bA
SS	W	-1.1 d	301.0 b	5.5 a	3.39 bB
	R	-1.1 d	268.2 b	5.3 a	3.72 bA

Different small letters mean significant differences due to main factor (MF); different capital letters indicate significant differences induced by sub factor (SF). ST = stress threshold; BC = berry colour; W = white; R = red.

Moving from the lower to the upper stress level (tab. 2) significantly different levels of mSWP were detected, confirming the correct subdivision of the stress threshold clusters described above. Dividing the 28 SAGAs into white-grape and red-grape type (tab. 1), the mSWP observed in AS, LS, MS and SS conditions did not show significant differences according to berry colour, not even during the ripening phase, in conditions of greater water scarcity (SS).PN, GS and EVAP (tab.2) showed significant differences related to the stress threshold ranges at the corresponding phenological stage, and confirmed the absence of differences related to the berry colour. However, red SAGAs showed a tendency for a higher GS (+16%) than the white ones at MS conditions (during veraison), while the white ones showed the same tendency in SS conditions (during ripening), although the differences among the two groups were not statistically significant. As shown in table 2 a similar value of EVAP was observed in LS, MS or SS and significantly higher than in AS conditions, reflecting the vine evaporative response to the higher evaporative demand of the dryer and hotter season. Nevertheless, during this season, the SAGAs were able to perform high levels of net photosynthesis in AS, not different from those observed in LS and significantly greater than those observed in MS and SS. Only the EVAP resulted significantly influenced by berry skin colour and was higher in red grapes than in white grapes.

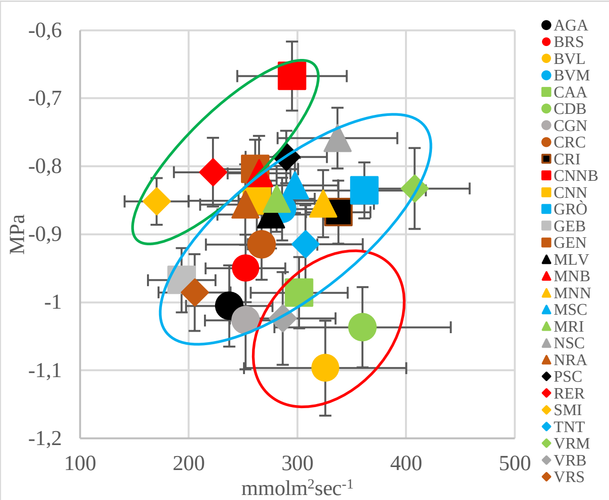

Figure. 4. SAGAs behaviour: near-isohydrics: green line; near-anisohydrics: red line; intermediate behaviour: blue line. GS (X) vs mSWP (Y) graph: X/Y average and standard error.

As far as the isohydric and anisohydric behaviours of the SAGAs is concerned, the relationship between the average GS and mSWP values in fig. 4 shows three groups with different stomatal regulation in response to changes in mSWP. Among varieties within the red oval line, BVL, CDB, CAA and VRB showed higher stomatal aperture under medium to high water stress conditions (MS< mSWP< SS), while the varieties within the green oval line, SMI, RER and CNNB kept a stronger stomatal closure even under low to mild water deficit (AS<mSWP<LS). Furthermore, an important variability in GS was observed among varieties within the light blue oval line, under mild to moderate water stress conditions (LS<mSWP<MS), which demonstrates that the stomatal responses to water deficit along the irrigation season of each variety can be strongly influenced by other environmental factors, including their adaptation to soil, temperature and other weather conditions.

By analysing the mSWP values observed on all 28 SAGAs, both the mean value, but, above all, the seasonal variability, take on a significant differentiation among SAGAs, that can be translated into a resilience model of the different ability of each accession to adapt to climatic conditions and soil water availability as resulted in table 2.

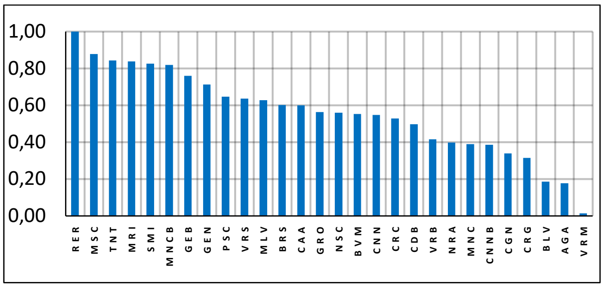

Figure. 5. The dropping off order scale of the 28 SAGAs resulting by using normalized data of the Climate Resilience Index (CRI).

Following the order in figure 5, RER, MSC, TNT, MRI, SMI and MNCB accessions were found having a CRM>0.8, being practically indifferent to the growing stress conditions from AS to SS; therefore, they are potentially the most resilient to climate change. On the other hand, VRM, AGA, and BLV, with CRI < 0.2, and CRG, CGN, CNNB, MNC, NRA and VRB, with 0.2 < CRI < 0.41, that are respectively the largest and the larger mSWP variation between SS and AS conditions, resulted the most sensitive SAGAs to pedoclimatic condition changes over the three years' trial, and potentially the least resilient to climate change. All the other SAGAs, especially BRS, MLV, VRS, PSC, GEN and GEB, with a recorded 0.6 < CRI ≤ 0.8, followed by CBD, CRC, CNN, BVM, NSC, GRO, and CAA, with 0.41<CRI<0.6, tend to be potentially tolerant to the climate change.

4. CONCLUSIONS

Contrary to what was expected, the 28 SAGAs main physiological parameters did not respond differently to the three-year weather variations recorded in this trial, if grouped on the basis of the berry skin colour. Therefore, the pigmentation of the berry skin was not correlated with variations in the physiological parameters that were detected and cannot be considered an index of different adaptation or resilience to climate change in the 28 SAGAs. In conditions of no stress (AS) all SAGAs, but especially on Nuragus, Nasco among the white-skinned accession, and Monica and Carignano among the red-skinned ones, recorded a high transpiration and a correspondingly high net photosynthesis. On the other hand, in conditions of high stress (SS), accessions or varieties such as Caddiu bianco, Vernaccia bidri di Villasor and Vermentino among the "whites", and Carignano, Bovaleddu antigu, Girò and Cagnulari among the "reds", in the face of lower mSWP values, showed a higher GS, typical of the near-anisohydric behaviour. To avoid water waste and increase photosynthetic efficiency, with those accessions or varieties it is advisable to adopt deficit irrigation strategies, which induce a moderate reduction in water availability after fruit set, followed by a more intense reduction after veraison, without inducing excessive water stress that can affect a significant yield drop, as evidenced on Vermentino and Cagnulari in Mameli *et al.* [11]. On the other hand, based on previous studies, the SAGAs that have shown a stronger stomatal control of transpiration, such as Semidano, Remungiau di Serri and Cannonau bianco (fig. 4) probably tend to perform less from a yield point of view [12-14], although they are more efficient in photosynthesis rate. The other SAGAs showed intermediate behaviour in terms of resilience to draught and heat stress. In fact, according to the CRI, 13SAGAs showed an intermediate condition but are still potentially able to withstand drought and heat stress. Remungiau di Serri, Moscatello, Tintillu, Muristellu, Semidano and Monica bianca, turned out to be the most resilient. On the contrary, Vernaccia bidri, Monica, Cannonau bianco, Cagnulari, Carignano, Bovaleddu, Aghina de Anghelos, and especially the Vermentino were found potentially less resilient. Finally, the study carried out allowed to observe that some of the 28 SAGAs, not commonly cultivated, as Tintillu and Muristellu among red grapes and Moscatello and Remungiau di Serri among "whites", were probably capable of coping more efficiently with the abiotic stress differences among years of trial as compared to others diffusely cultivated, as for instance Vermentino and Cagnulari. These cultivars showed a good ability to adapt to the variation of the three-years climatic conditions, in terms of temperatures and soil water availability, as they could be potentially suitable genotypes for better adapting viticulture in Sardinia to the on-going changes of climate.

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