Influence of drought stress on shoot, leaf growth, leaf water potential, stomatal resistance in wine grape genotypes (*Vitis vinifera* L.) [1]

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Summary: Most physiological and morphological tests suggested in the literature for drought resistance are too sophisticated, time-consuming and sometimes unreliable. Quantitative data have indicated that plant growth is very sensitive to water stress. Therefore the elongation rate of shoot and leaf characters (petiole, lamina), which are simple parameters to measure, and leaf water potential and stomatal resistance were determined on 5 sampling dates under water stress and non-stress conditions in different wine grape varieties (*Vitis vinifera*). The leaf water potential and stomatal resistance show very little variability as well as low correlation in the wine grape varieties considered. On the contrary, the weekly elongation rate of shoot and leaf characters (petiole, lamina) shows high variability and highly significant correlations. Thus some of these morphological characters (lamina and shoot elongation) might be used as test in the early phase (at seedling stage) of a breeding selection program for drought resistance in *Vitis*.

Key words: drought, resistance, shoot, leaf, growth, hydration, analysis, statistics, test, selection, variety of vine, Italy.

Introduction

The literature on drought resistance in plants indicates that almost any parameter of the plant can be changed by water stress since plants are integrated organisms which present different control mechanisms to adjust other processes for counterbalancing the water stress disturbances. In *Vitis*, morphological characters, such as the degree of leaf succulence (Düring and Scienza 1980; Scienza 1983), the stomatal number (Fregoni *et al.* 1978; Düring and Scienza 1980; Zamboni *et al.* 1985), root/shoot ratio (Scienza 1983), and physiological characters, such as leaf water potential and stomatal resistance (Smart 1974; Fregoni *et al.* 1978; Düring and Scienza 1980; Giulivo and Ramina 1981), leaf osmotic potential (Düring 1984), abscisic acid (Loveys and Kriedemann 1973; Fregoni *et al.* 1978; Zamboni *et al.* 1985), have been considered as test methods for drought resistance.

Most of the tests, suggested for annual or perennial species, are too sophisticated and time-consuming. In addition, too few cultivars are used for evaluation of the tests and they are not randomly selected, making these methods unreliable in application. Hsiao and Acevedo (1974) reviewed from literature on the sensitivity of plant processes to water stress; they list cell growth (defined as cell expansion) as the most sensitive parameter to water deficit. Therefore, young leaves and shoots, which present a high metabolic activity for the cell expansion, have been taken into consideration and their growth rate determined as well as the leaf water potential and stomatal resistance in different wine grape cultivars (*V. vinifera*) under water stress and non-stress conditions. This research was carried out to study the variation and covariation among these parameters to determine if some of them (the simplest to measure) are suitable for testing drought resistance in the early phase (at seedling stage) of a grape breeding selection program.

Materials and methods

The study was conducted on 2-year rooted cuttings of 16 wine grape cultivars (*V. vinifera*) of different origin. Each genotype was grown as a single shoot in a large container (1 x 1 x 1 m) used to

[1]) Grant M.P.I. 40 %.

develop drought under more natural conditions; containers were protected from incidental precipitation by a special plastic covering. All varieties were subject to water stressed and non-stressed treatments. The stressed treatment was imposed by withholding irrigation from June 1 throughout the summer. The non-stressed plants were irrigated weekly to field capacity. A completely randomized split plot design (with 4 replications for each variety and treatment) was

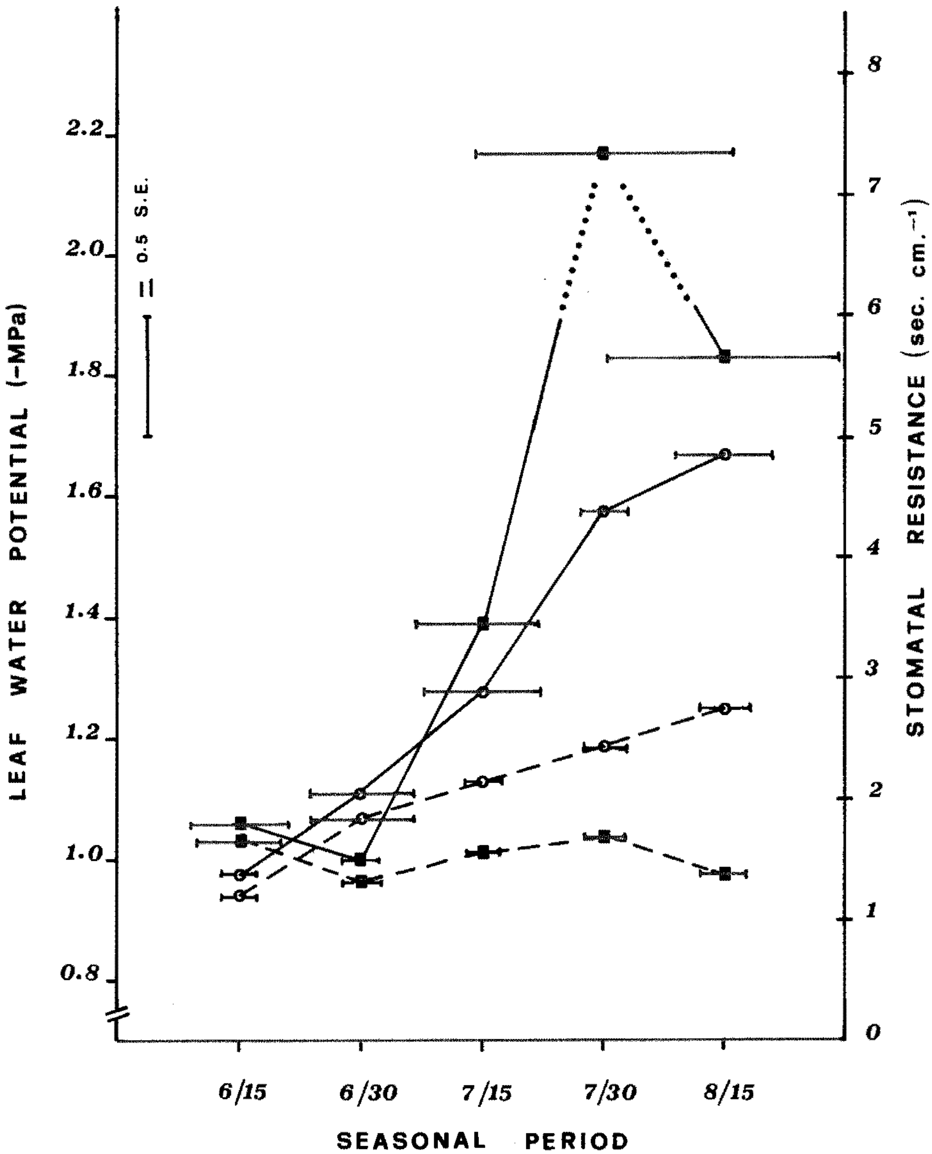

Fig. 1: Leaf water potential (o) and stomatal resistance (■) for midday observations at 5 seasonal sampling dates under water stress (—) and non-stress (---) treatments. Values are means of 16 wine grape cultivars. Horizontal bars are S. E.

applied. The leaf water potential (LWP), determinaed by a Scholander pressure chamber, was taken from fully expanded young leaves in the upper third of the shoot; the stomatal resistance (Rs) was measured with a steady state autoporometer on the abaxial surface of the same leaf and

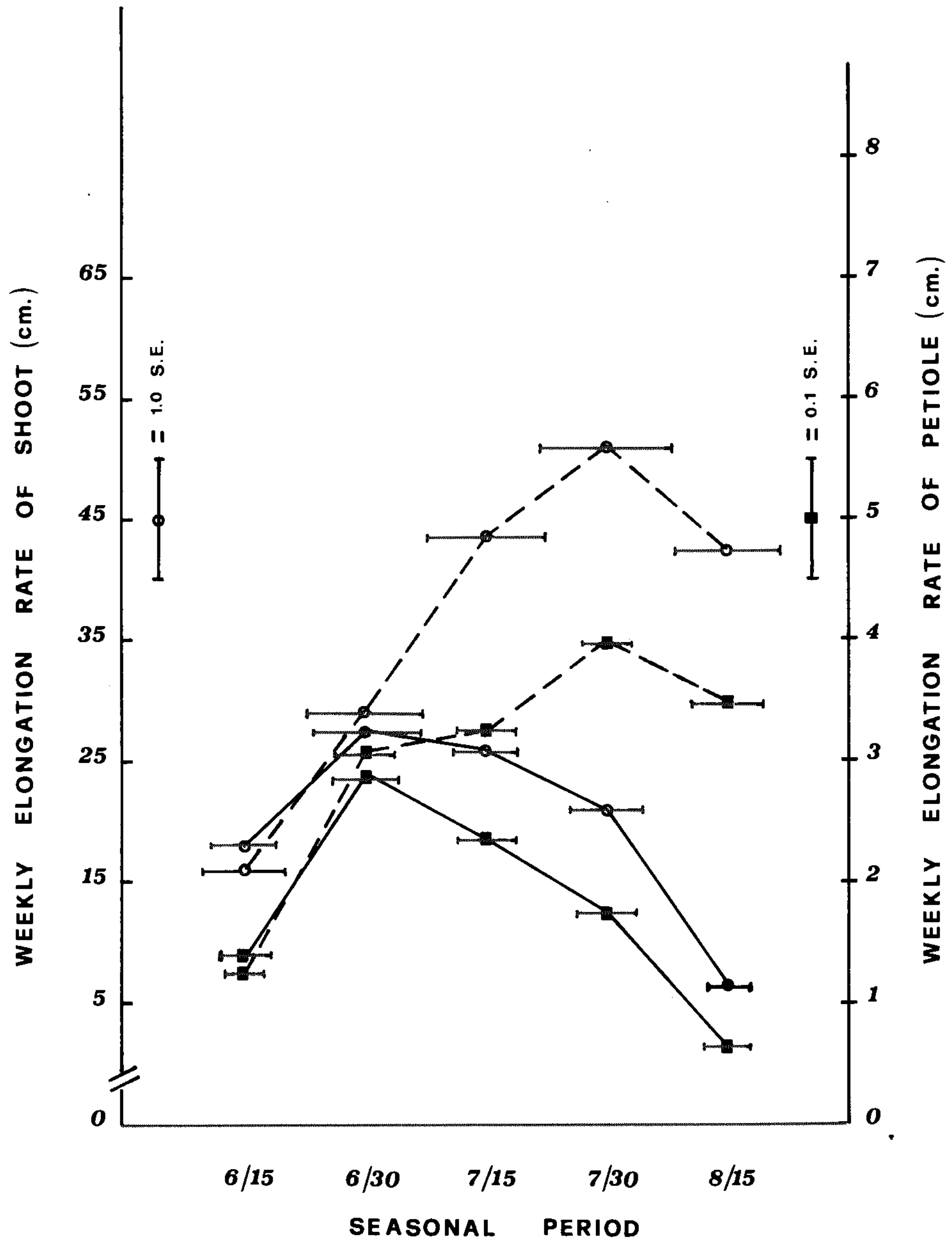

Fig. 2: Growth rate (weekly increase in cm) of shoot (o) and petiole length (■) at 5 seasonal sampling dates under water stress (—) and non-stress (---) treatments. Values are means of 16 wine grape cultivars. Horizontal bars are S. E.

repeated on all replications. Both measurements were recorded at midday on 5 sampling dates (June 15 and 30, July 15 and 30, August 15) for both stressed and non-stressed plants.

The variations of the soil water potential were followed through the gravimetric method and through the previously drawn soil moisture release curve for the estimation of the corresponding values of the matrix potential.

The soil water potential of the non-stressed containers remained at about -0.05 MPa. The soil water potential of the stress treatment continued to decline from June 1 without any interruption and reached the value of about -1.0, -1.1 MPa on August 15. Young leaves (the second from the shoot tip) were utilized to measure the weekly rate of growth of the lamina length (ΔL), lamina width (ΔW), petiole length (ΔP) in the 5 mentioned sampling dates; the weekly rate of shoot elongation (ΔS) was also measured. All data were subject to the analysis of variance and Duncan test for the 5 sampling dates, even though the results are reported only for some periods (Tables 1-4). Correlation coefficients between all physiological and morphological parameters were also determined for stressed and non-stressed treatments. The log transformations of LWP data were used for a more homogeneous variance.

Results and discussion

Quantitative data (Hsiao 1973; Hsiao and Acevedo 1974) clearly established that growth is extremely sensitive to water deficit and any reduction in tissue water potential reduces cell expansion in plants. In this work the variation and covariation of the elongation rate of shoots and young leaves, as well as the leaf water potential and stomatal resistance, were studied in several wine grape cultivars grown under water stress and non-stress conditions.

Fig. 1 indicates that the mean leaf water potential of the 16 cultivars increases (more negative) during the seasonal periods considered, in particular under stress condition, where it reaches about -1.7 MPa after 2.5 months from beginning of the stress. The stomatal resistance also tends to increase under stress condition while it shows little seasonal variation under non-stress condition due to the fact that the stomata are not very sensitive to optimal water conditions (Hsiao 1974). Figs. 2 and 3 show that the weekly elongation rate of shoot and leaf characters (petiole, lamina) increases in the first period of stress and then it decreases, while under non-stress condition it increases except in the last observation periods. The graphs show the mean seasonal variation of the cultivars considered for all the physiological and morphological parameters under water stress and non-stress conditions but they do not indicate the difference among varieties. The analysis of variance, reported only for two representative periods, shows no significant differences among varieties and between treatments for all characters at 1 month of stress (Table 1), while significant differences were detected after that period (Table 2) for the same characters, except for the leaf water potential, which presents also low coefficient of variability (about 4 %) both under stress and non-stress conditions. The stomatal resistance (Rs) shows some variability (CV = 10 % S and 6 % NS) but large variation was also detected among replications. In contrast, the weekly growth rate of shoot and leaf characters presents a larger variability, in particular during the last period of stress (Table 2, the CV was over 20 %). As significant differences among varieties were detected in the last periods of stress (Table 2) a Duncan test was performed for these data even though it is only reported for the last date (August 15) (Tables 3-4). Table 3 shows that there is little difference among varieties in the leaf water potential for midday observations under stress and non-stress conditions on the last sampling date but also the same trend appears in the other periods.

As far as the stomatal resistance is concerned, the difference among varieties was not tested (Table 3) because of high variability among replications, which might be due to sampling error attributable to circumstances external to the operator (leaf shading, leaf orientation etc.).

The elongation rate of shoot and leaf characters differs among varieties not only in the last period of stress (Table 4) but also in other periods. Thus the study of the variability of our wine grape population suggests that the morphological characters are better parameters to discriminate varieties under stress conditions. Correlation coefficients were also computed to study the relationships among the physiological and morphological characters in order to choose those which can be used as an index for drought resistance in *Vitis*. Table 5 shows that there is not a very high correlation (r = 0.35) between leaf water potential and stomatal resistance under water stress and no correlation (r = 0.01) under non-stress conditions. It has been shown (HSIAO and ACEVEDO 1974; WEST and GAFF 1976; SYVERTSEN 1987) that stomata remain unaffected until the leaf water

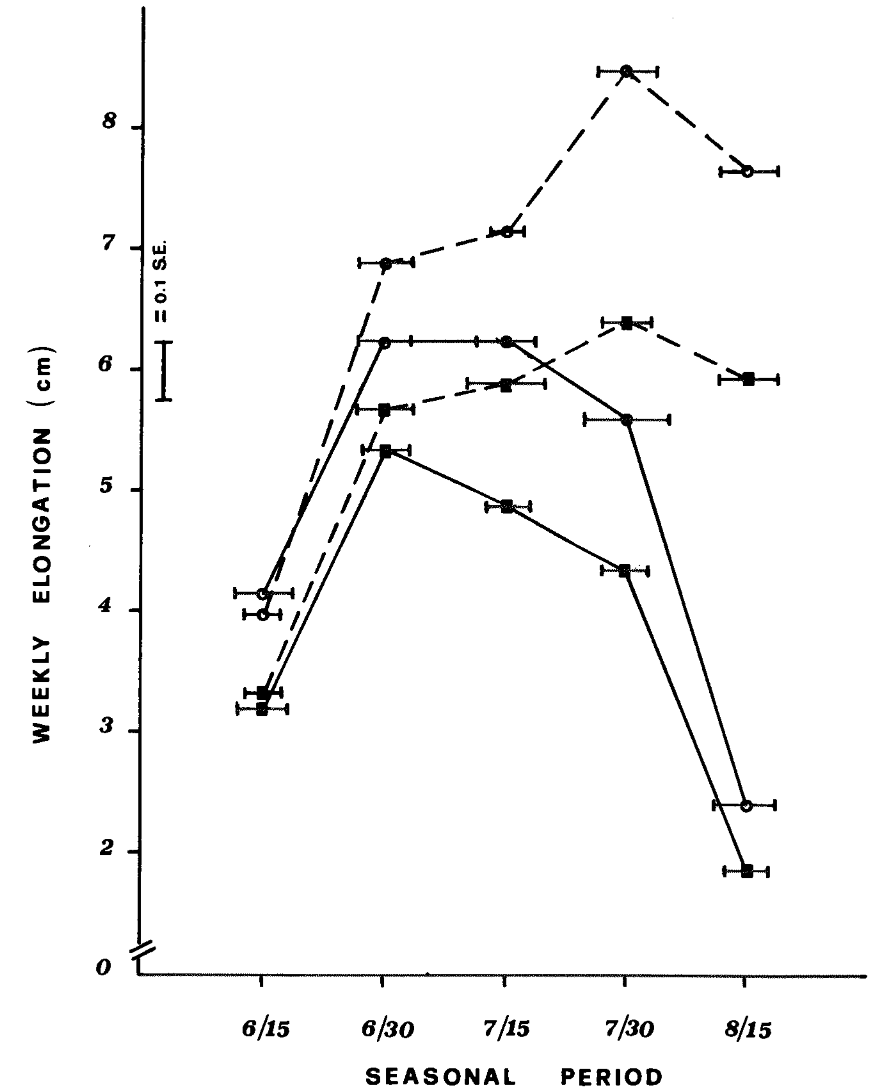

Fig. 3: Growth rate (weekly increase in cm) of lamina length (■) and lamina width (o) at 5 seasonal sampling dates under water stress (—) and non-stress (- - -) treatments. Values are means of 16 wine grape cultivars. Horzontal bars are S. E.

potential drops to a critical value and that the mechanism of stomata closure induced by water deficit is not a simple loss of turgor from the leaf but rather a complex mechanism.

Low correlations were found among the physiological parameters (leaf water potential, stomatal resistance) and morphological ones (elongation rate of shoot and leaf characters) under stress condition, while no correlations were shown under non-stress condition. A lack of correlation between leaf water potential and fruit growth has been found in citrus and other species

Table 1: Descriptive statistics for midday leaf water potential (LWP), stomatal resistance (Rs), and the growth rate (weekly increase) of shoots (ΔS), leaf characters (petiole length (ΔP), lamina length (ΔL), lamina width (ΔW)) at 1 month water stress (S) and non-stress treatments (NS) in 16 wine grapes

Variables	Treatments+	Mean	S E	Range	CV
LWP	S	1.10	0.01	1.05-1.25	4.1
(-MPa)	NS	1.07	0.03	1.05-1.10	2.2
Rs	S	1.4	0.4	1.1- 1.9	6
(sec.cm^{-1})	NS	1.4	0.5	1.1- 1.6	6
ΔS	S	26	1.0	13 -49	17
(cm.)	NS	28	0.8	16 -59	16
ΔP	S	2.8	0.07	1.9- 4.2	13
(cm.)	NS	3.0	0.05	2.0- 5.3	12
ΔL	S	5.3	0.1	4.5- 6.8	11
(cm.)	NS	5.6	0.1	3.7- 8.3	11
ΔW	S	6.5	0.8	5.3- 8.2	10
(cm.)	NS	6.8	1.1	4.0- 9.2	11

+ No significant differences were detected by analysis of variance (F test) for treatments, varieties x treatments, varieties.

Table 2: Descriptive statistics for midday leaf water potential (LWP), stomatal resistance (Rs), and the growth rate (weekly increase) of shoots (ΔS), leaf characters (petiole length (ΔP), lamina length (ΔL), lamina width (ΔW)) at 2.5 months water stress (S) and non-stress treatments (NS) in 16 wine grapes

Variables	Treatments+	Mean	S E	Range	CV	V+	VxT+
LWP	S 128**	1.7	0.07	1.6-1.7	4.0	0.01 n.s	0.1**
(- MPa)	NS	1.25	0.08	1.2-1.3	3.0		
RS	S 440**	5.7	1.2	3.4- 8.1	10	0.04 n.s	3.1**
($sec.cm^{-1}$)	NS	1.4	0.6	1.0- 1.9	6		
ΔS	S 326**	5.6	0.8	2.0-11	23	240**	262**
(cm.)	NS	42.5	1.0	23 -73	18		
ΔP	S 207**	0.6	0.02	0.1- 1.3	29	0.7**	1.3**
(cm.)	NS	3.5	0.06	2.2- 5.5	11		
ΔL	S 414**	1.8	0.1	0.5- 2.8	25	2.4**	3.5**
(cm.)	NS	5.9	0.1	3.7- 8.2	11		
ΔW	S 642**	2.4	0.7	1.3- 3.8	22	3.4**	5.8**
(cm.)	NS	1.4	0.2	4.7- 9.8	10		

+ Variances and statistical significance by analysis of variance for treatments, varieties (V), varieties x treatments (VxT) at .01 P level (**).

(ELFVING and KAUFMANN 1972). This might be due to the fact that the physiological or physical mechanisms that control cell growth, water balance and stomata closure in the plants are independent processes. In contrast, very high correlations were shown among the morphological characters. This suggests that some of these parameters might be used as selection indices for drought resistance. In particular, the elongation rate of the lamina or of the shoot, which are simple

Table 3: Cultivar means for midday leaf water potential (LWP) and stomatal resistance (Rs) at 2.5 months water stress (S) and non-stress (NS) treatments

Cultivars	Variables treatments	LWP (-MPa)		Rs (sec.cm^{-1})	
		S	NS	S	NS
Teroldego		1.75a*	1.30a	4.5+	1.4
Sangiovese		1.70a	1.30a	4.5	1.3
French Colomb.		1.70a	1.25ab	6.4	1.1
Peverella		1.70a	1.25ab	5.1	1.9
Montepulciano		1.70a	1.30a	6.7	1.4
Verdeca		1.70a	1.25ab	4.6	1.6
Sangiovese C.		1.70a	1.25ab	7.2	1.6
Aleatico		1.70a	1.25ab	4.6	1.1
Greco		1.65ab	1.25ab	6.7	1.5
Barbera		1.65ab	1.20b	4.1	1.3
Trebbiano		1.65ab	1.20b	4.4	1.1
Malvasia Candia		1.65ab	1.20b	8.1	1.4
Malvasia Nera		1.65ab	1.30a	7.5	1.1
Negro Amaro		1.65ab	1.20b	4.6	1.4
Bombino b.		1.65ab	1.20b	7.8	1.7
Rubired		1.60b	1.25ab	4.1	1.3

* Numbers in the same column followed by the same letter are not different at .01 P level as determined by Duncan test.

+ The significant difference (Duncan test) are not reported because of the high sampling error within each genotype.

parameters to measure, might represent an easy and non destructive test method to be used in the early phase (at seedling stage) of a breeding selection program for drought resistance in *Vitis*.

However, further studies are needed to apply this selection test for mature grapevines.

Table 4: Cultivar means for the growth rate (weekly increase) of shoots (Δ S), leaf characters (lamina length (ΔL), lamina width (ΔW), petiole length (Δ P)) under 2.5 months water stress (S) and non-stress (NS) treatments

Cultivars	Variables / Treatments	ΔS S	ΔS NS	ΔL S	ΔL NS	ΔW S	ΔW NS	ΔP S	ΔP NS
Teroldego		2.3 e*	38 g	0.5 h	4.6 f	1.3 f	6.1 f	0.1 i	3.1 ef
Sangiovese		8.6 ab	49 c	2.8 a	5.6 e	3.2 b	7.3 d	1.1 a	3.4 cde
French Colom.		2.3 e	55 b	1.3 cd	7.9 a	1.8 e	9.8 a	0.6 cdef	5.2 a
Peverella		2.3 e	47 cd	0.8 g	5.8 de	2.2 d	8.0 c	0.2 hi	3.2 def
Montepulciano		6.3 d	34 g	2.6 c	6.6 c	3.1 b	8.2 c	0.8 bcd	3.7 bc
Verdeca		3.0 e	44 de	1.7 c	6.8 bc	2.1 d	9.2 b	0.4 fghi	3.6 bc
Sangiovese C.		7.0 cd	70 a	1.6 c	7.0 b	1.5 ef	9.0 b	0.5 defg	3.9 b
Aleatico		9.0 ab	41 ef	2.7 a	5.7 de	3.8 a	7.9 c	0.7 cde	3.2 ef
Greco		6.3 d	67 a	1.2 ef	6.0 d	1.7 e	8.9 b	0.5 defg	3.9 b
Barbera		4.0 e	43 def	0.9 fg	5.5 e	1.5 ef	6.4 ef	0.2 hi	3.2 ef
Trebbiano		8.0 bc	39 f	2.6 a	5.6 e	3.7 a	7.4 d	0.8 abc	2.9 fg
Malvasia Candia		3.0 e	26 h	1.1 ef	3.7 g	1.4 f	4.7 h	0.3 ghi	2.6 gh
Malvasia Nera		7.0 cd	34 g	2.0 b	8.2 a	2.7 c	8.9 a	0.8 bcd	5.0 a
Negro Amaro		10.0 a	32 g	2.7 a	5.9 de	3.3 b	6.6 e	1.0 ab	3.6 bc
Bombino		8.0 bc	32 g	2.6 a	5.9 de	3.1 b	7.5 d	1.1 a	4.0 b
Rubired		7.0 cd	32 g	1.5 cd	4.6 f	2.8 c	5.3 g	0.8 bcd	2.4 h

* Numbers in the same column followed by the same letter are not different at .01 P level as determined by Duncan test.

Table 5: Correlation coefficients of leaf water potential (LWP), stomatal resistance (Rs), and weekly growth rate of shoot length (ΔS), lamina length (ΔL), lamina width (ΔW) and petiole length (ΔP) under water stress (above) and non-stress (below) treatments

Variables	Rs	ΔS	ΔL	ΔW	ΔP
LWP	0.35** 0.01	0.31** 0.03	0.36** 0.05	0.32** 0.04	0.33** 0.02
Rs		-0.29** -0.05	-0.33** -0.03	-0.32** -0.04	-0.31** -0.02
ΔS			0.85** 0.76**	0.76** 0.72**	0.73** 0.62**
ΔL				0.93** 0.90**	0.91* 0.87*
ΔW					0.87* 0.86*

* $P \leq 0.05$
** $P \leq 0.01$

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