© 2011 Triveni Enterprises
Vikas Nagar, Lucknow, INDIA
editor@jeb.co.in
Full paper available on: www.jeb.co.in

J. Environ. Biol.
32, 543-549 (2011)
ISSN: 0254-8704
CODEN: JEBIDP

Evaluation of drought tolerance of new grapevine rootstock hybrids

Author Details

Pavel Pavlousek (*Corresponding author*)
Mendel University Brno, Faculty of Horticulture, Department of Viticulture and Oenology, Valtická 337, Lednice na Morave, CZ-691 44, Czech Republic
e-mail: pavel.pavlousek@mendelu.cz

Publication Data

Paper received:
22 January 2010

Revised received:
17 August 2010

Accepted:
24 September 2010

Abstract

The drought tolerance is a very important property of grapevine rootstocks. For that reason the breeding and selection of new rootstock varieties is focused also on the evaluation of their drought tolerance. In this experiment, altogether 20 new hybrids and 4 existing rootstock varieties were compared and evaluated. The experimental scheme involved 3 variants of water supply. Evaluated were the following properties: growth intensity of annual shoots, CCI (chlorophyll content index) and visual characteristics of plants. The most resistant were hybrids from the pedigree groups C (*Binova x Börner*), D */Binova x /(Binova x Teleki 5C/) x Börner/*, and F (*Teleki 5 C x Börner*). The following hybrids were classified as drought-tolerant: 17-1-6 (C); 17-1-9 (C); 17-6-2 (C); 17-6-9 (C); 17-8-2 (D) and 9-20-1 (F). Based on obtained experimental results and also on correlations existing between individual traits it can be concluded that practically all traits under study may be used when evaluating the resistance of plants to drought. The obtained results indicated that the Börner rootstock (and thus also the species *Vitis cinerea*) can be used as a suitable genetic resource for the purpose of the breeding grapevine rootstocks for tolerance to drought.

Key words

Drought, Grapevine, Hybrid, Rootstock, Tolerance, *Vitis* spp.

Introduction

In recent years, it is possible to observe global climatic changes. The numbers of warm years and longer periods of drought are increasing. In the course of its phylogenetic development, grapevine (*Vitis vinifera*) has developed various physiological and morphological mechanisms enabling plants to survive under conditions of water deficits (Kondouras *et al.*, 2008). One of the possibilities how to adapt viticulture to climatic changes (especially as far as the longer periods of drought are concerned), is to breeding and selection rootstock with an increased tolerance to drought (Vandeleur et al. 2009, Comas et al., 2010, Flexas et al., 2010). It is acknowledged that the timing and intensity of the response to soil and atmospheric water deficits, namely in what concerns stomatal control, depends greatly on genotype (Chaves et al., 2010).

Although grapevine (*Vitis vinifera* L.) is considered to be a species that is relatively well adapted to drought stress, the combined effects of intensive illumination, high temperatures and low atmospheric water pressure tension could presumably act as major constraints for leaf photosynthesis, particularly under conditions of severe soil water deficits that are usually encountered by this crop (Flexas *et al.*, 1998).

Because of differences in the architecture of root system, the drought tolerance of plants is significantly influenced by rootstocks.

The capability of grapevine to uptake water and nutrients from soil is dependent not only on the size of the root system but also on its horizontal and vertical arrangement (Smart *et al.*, 2006).

A good resistance of grapevine to stress situations results from deep of root system and physiological mechanism of drought-avoidance (Chaves et al., 2010).

Satisha *et al.* (2006) mentioned that as far as the drought tolerance was concerned, the physiological mechanisms of individual genotypes were rather different.

In plants, and thus also in the grapevine, the drought tolerance can be evaluated on the basis of many physiological indicators.

Monitoring of changes in the growth of annual shoots is a very sensitive indicator of the lack of water and can help to reveal the water stress even before it is possible to detect changes in the water potential of leaves (Grimplet *et al.*, 2007). The morphological adaptability of plants may be one of mechanisms of their adaptation to arid conditions and drought tolerance (Pire et al., 2007). Cregg (2004) mentioned that the following properties may be used when comparing the relative tolerance of individual genotypes to drought: potential for survival, growth capacity, and water use efficiency on the basis of morphological and physiological adaptations that might occur within the plant.

Sommer (2009) observed very interesting differences in drought tolerance of grapevine rootstocks; so, for example the rootstocks 101-14 and Schwarzmann showed a low resistance while in Lider 116-60, Ramsey, 1103 Paulsen, 140 Ruggeri and Kober 5 BB this characteristic was better. Yuejin *et al.* (2004) evaluated 8 Chinese wild species of grapevine (*Vitis spp.*) and 10 hybrids of *V. yeshanesis x V. riparia.* Flexas *et al.* (2009) observed a very good drought tolerance in the rootstock Richter 110 (*V. berlandieri x V. rupestris*). Ramteke and Karibasapa (2005) evaluated 7 varieties, 11 rootstocks and 2 wild species of the genus *Vitis spp.* and classified the following rootstocks as drought-tolerant: 110 R, 1103 P, SO 4, Teleki 5A, and 1613 C.

The aims of this study is to evaluate the drought tolerance of 20 new and four already registered rootstock hybrids to drought stress.

Materials and Methods

The drought tolerance of rootstock varieties already registered in the Czech Republic (*viz.* Kober 5 BB, Craciunel 2, Teleki 5C and SO 4) and 20 new rootstock hybrids Table 1 were evaluated.

One-year-old wood was cut and rooted in a glasshouse in January 2006. It was established in containers with a volume of 4 lit and each of the experimental containers was container room of the Faculty of Horticulture, Mendel University of the Agriculture and Forestry Brno, in Lednice na Morave under drip irrigation. Pots contained the Klassman substrate with conditions: pH = 5.2; N = 210 mg l^{-1}; P_2O_5 = 240 mg l^{-1}; K_2O = 270 mg l^{-1} and Mg = 120 mg l^{-1} and experiment was established as per the method of Guan *et al.* (2004). Altogether 3 experimental variants with 5 replications were evaluated. Using the drip irrigation, the control variant (C) was irrigated to obtain a relative water content (RWC) of 80-85%. Variants V1 and V2 were irrigated at the level of a moderate (RWC 40-45%) and severe (30-35% RWC) drought stress, respectively. All variants were placed into a plastic foil tunnel, which protected experimental plants against precipitation. The evaluation was performed 120 days after the onset of bud burst of experimental plants. Length of annual shoots, chlorophyll content index (CCI) and visual symptoms of draught resistance were evaluated according to IPGRI (1997).

The visual symptoms were indexed as value 1 represents very high drought tolerance (leaves green), value 5 medium drought tolerance (leaves yellow) and value 9 as very low drought tolerance (leaves necrotic or leaf drop).

The statistical evaluation presents average values with their standard deviations. Results are evaluated also by means of variance analysis (ANOVA) and Tukey test at the significance level $p<0.01$. Correlations were calculated using Pearson's method.

Results and Discussion

Drought is the major biotic factor that influences the growth of grapevine plants (Kondouras *et al.*, 2008). For that reason it is very important to evaluate individual factors (*i.e.* treatment and variety) with regard to dependent variables of rootstock hybrids and varieties under this study.

The performed variance analysis indicated that all traits under study (i.e. length of annual shoots, CCI and visual symptoms) were highly significantly influenced not only by the treatment and variety but also by their mutual combination. Detailed results of variance analysis are presented in Table 2. A significant effect of the variety on the drought tolerance was corroborated also by Satisha *et al.* (2006), who mentioned that the physiological mechanism related to drought tolerance vary from genotype to genotype.

Length of annual shoot: The length of annual shoots is one of the traits that are evaluated in individual variants when evaluating the drought resistance of rootstocks. In the variant V2, a marked shortening of annual shoots was recorded in hybrids 16-2-5 and 16-1-6. An inhibition of shoot growth was observed also in rootstock varieties SO 4 and Teleki 5C. On the contrary, however, a very good growth of annual shoots under stress conditions was observed in hybrids from the group C, especially in 17-1-6, 17-1-9, 17-2-10, 17-6-2, and 17-6-9. Detailed results are presented in Table 3.

Cramer *et al.* (2007), has well observed that under conditions of a relatively moderate water deficit the growth of grapevine shoots was reduced. The drought effect was evaluated also with regard to the pedigree of individual hybrids and varieties under study. Detailed results of this evaluation as well as statistical data, differences in shoot length and average values of individual pedigree groups are presented in percent in Table 3. The lowest percentage decrease in shoot length was observed in pedigrees F (96.60%); D (95.32%) H (93.63%) and C (93.54%). The statistical analysis revealed that the pedigree C was highly significantly different from all other groups except H in Variant V2. The shortest shoots were recorded in groups A and G, which were highly significantly different from all other pedigree groups in Variant V2. Detailed statistical differences shown in Table 3. This analysis demonstrated a highly significant effect of drought stress on the length of annual shoots. Similarly as Stevens *et al.* (1995) and Dry *et al.* (2000) it is possible to conclude that an inhibition of growth intensity of annual shoots may be considered as one of symptoms of water deficit in grapevine plants. An inhibition of growth of annual shoots is usually more intensive than that of roots.

This fact was corroborated also by Patil *et al.* (1995) who mentioned the fact that a decreased availability of water resulted in a reduced length of annual shoots of grapevine plants.

In accordance with Pellegrinno *et al.* (2005) and Lebon *et al.* (2006) it is possible to conclude that the growth of annual shoots represents a sensitive indicator of water regime in grapevine plants.

Chlorophyll content index (CCI): The increasing drought stress also highly significantly influenced the necrotisation of leaf area of vines and, therefore, also changes in chlorophyll content in leaf tissue.

Sivilotti *et al.* (2005) mentioned that a combination of drought stress, intensive radiation and high temperatures may inhibit the photochemical performance. A strong drought stress may cause irreversible changes in the photosynthetic apparatus of grapevine.

Assimilative activities of vines and synthesis of chlorophyll are related to the opinion published by Bourque & Naylor (1971) that the drought stress inhibited chlorophyll synthesis in leaves. Patil *et al.* (2005) used for the evaluation of drought tolerance another important parameter, which relates to the chlorophyll content, *viz.* chlorophyll stability index (CSI).

In this experiment a non-destructive method of evaluation of the chlorophyll content in leaves and chlorophyll content index (CCI) was used. The lowest CCI values were recorded in hybrids 17-2-7 (8.25) and 16-12-6 (8.75) in the variant V2.

On the contrary, the CCI highest values were recorded in hybrids 16-1-7; 17-1-6; 17-2-10; 17-6-2 and 9-20-1 and in rootstock varieties Kober 5 BB and Teleki 5C. Basing on these results it can be concluded that these plants will show a very good resistance to drought. Detailed results are presented in Table 4.

Results obtained in the variant V2 indicate that the pedigree group E was statistically highly significantly different from all other groups. On the other hand, however, pedigree groups A, B, C, D, and F in the variant V2 did not show any significant differences. All of them had *Vitis cinerea* in their pedigree.

The evaluation of chlorophyll content is very important because also Schultz (1996) wrote that the responses of grapevine photosynthesis and water relations to water stress included many physiological processes as parts of stress tolerance strategies that varied within individual genotypes. Similarly, Gomez-Del-Campo *et al.* (2002) mentioned that the water deficit stress caused a reduction in the photosynthetic activity.

Drought tolerance on the base of visual symptoms: Results of the evaluation of resistance to drought on the base of visual symptoms are presented in Table 5. The highest number of hybrids without visible symptoms of drought damage was recorded in group C. In the variant V1, this observation concerned hybrids 17-1-6; 17-1-9; 17-2-10; 17-6-2, 17-6-9, 17-8-2, 9-20-1, Kober 5BB and Craciunel 2. In the variant V2, the most resistant were hybrids 17-1-9, 17-6-9, 17-6-2 and 9-20-1; all of them were highly significantly different from all other hybrids and varieties under study.

These results are significantly corroborated by lower numbers of drought-damaged plants in groups D and F. In the variant V2, the most marked symptoms of drought damage were observed in groups A and E.

Very interesting results were obtained also when estimating correlations existing between individual pairs of traits under this study. The evaluation on the base of visual symptoms revealed that the closest correlation between the CCI value and drought tolerance on the base of visual symptoms was r = - 0.76.

Correlations existing between the length of annual shoots and values of CCI (r = 0.41) as well as between the length of annual shoots and drought tolerance on the base of visual symptoms (r = - 0.63) were less significant.

Basing on these results and correlations existing between individual pairs of traits it can be concluded that all above-discussed parameters are very suitable for the evaluation of drought resistance of grapevine rootstock. Kadam and Tambe (2004) also mentioned that the chlorophyll content is a very good criterion for the evaluation of drought resistance of grapevine rootstocks.

Basing on the evaluation of all traits it is possible to conclude that the highest number of drought-tolerant hybrids originated from

Table - 1: Evaluated varieties, hybrids and their pedigree

Symbol	Pedigree	Hybrids and varieties
A	(*Teleki* 5 C x *Borner*) x /(*Vitis berlandieri* x *Vitis rupestris*) x *Vitis cinerea*)/	16-1-6, 16-1-7, 16-2-5
B	BV-9-20-4 x BV-8-20-6 (*Teleki* 5 C x *Börner*) x /*Peking* 1 x /(*Vitis berlandieri* x *Vitis rupestris*) x *Vitis cinerea*)//	16-10-1, 16-10-3
C	Binova x Börner	17-1-6, 17-1-9, 17-2-3, 17-2-7, 17-2-10, 17-3-1, 17-3-6, 17-6-2, 17-6-7, 17-6-9
D	*Binova* x /(*Binova* x *Teleki* 5C) x *Börner*	17-18-2
E	(*Binova* x *Aurelius*) x /*Peking* 1 x /(*Vitis berlandieri* x *Vitis rupestris*) x *Vitis cinerea*)//	16-12-6
F	*Teleki* 5 C x *Borner*	9-20-1
G	BV-9-21-6 x BV-8-20-6 (*Teleki* 5 C x *Börner*) x /*Peking* 1 x /(*Vitis berlandieri* x *Vitis rupestris*) x *Vitis cinerea*)//	17-12-1, 17-13-10
H	*Vitis berlandieri* x *Vitis riparia*	Kober 5 BB, Craciunel 2, Teleki 5C, SO 4

Table - 2: Results of a two-way ANOVA evaluation of plant characteristics by treatment (T) and variety (V) and their statistical significance** p<0.01

Dependent variables	T (treatment)	V (variety)	TxV
Shoot length	494.27**	178.99**	17.66**
CCI	444.24**	60.75**	8.02**
Drought	261.16**	24.51**	8.43**

the group C, (*i.e. Binova x Börner)* so that there is a very good chance to use the rootstock *Börner* and the species *Vitis cinerea* for further breeding and selection of rootstock resistant to drought stress. This concerns the following hybrids: 17-1-6 (C); 17-1-9 (C); 17-6-2 (C); 17-6-9 (C). Hybrids from groups D and F (*i.e.* 17-8-2 and 9-20-1 from the group D and F, respectively) can be also classified as drought tolerant. In all groups this concerns hybrids of *V. berlandieri, V. riparia* and *V. cinerea.*

As far as the drought tolerance was concerned, also Schmidt *et al.* (2005) published similar conclusions and mentioned very good results with *Vitis cinerea*. This species can provide not only a complete phylloxera resistance but is also capable of having a positive influence on scion performance especially in shallow, gravely and consequently also dry soils. The use of phylloxera resistant *V. cinerea* hybrids should therefore be more frequent in vineyards with generally dry conditions. In dry localities, *V.riparia x V.cinerea* hybrids represent a valuable addition to the range of rootstocks currently used in Germany. Particularly on steep slopes and in seasons with scarce rainfalls these hybrids showed to be superior.

The obtained results indicate hybrids *Vitis.berlandieri x Vitis riparia* showed a good tolerance to drought; this observation was corroborated also by Patil *et al.* (2003). On the other hand Padgett-

Table - 3: Evaluation lengths of annual shoots in rootstock hybrids and registered varieties, average values and standard deviations of individual pedigree groups (in cm). Letters indicate results of statistical evaluation by Tukey test at the significance level of p<0.01.

Hybrid / Variety	Pedigree	Variant C	Variant V1	Variant V2
16-1-6	A	119.50 ± 3.69	106.00 ± 4.54	84.50 ± 3.11
16-1-7	A	111.50 ± 2.38	107.00 ± 2.16	98.75 ± 2.98
16-2-5	A	125.50 ± 5.29	104.50 ± 3.10	83.00 ± 2.58
A		**118.83 ± 6.97 c**	**105.83 ± 3.27ab**	**88.75 ± 7.86 a**
16-10-1	B	134.75 ± 4.11	129.00 ± 4.54	124.25 ± 3.30
16-10-3	B	147.50 ± 3.78	135.75 ± 3.30	113.75 ± 4.78
B		**141.12 ± 7.73 d**	**132.32 ± 5.15 c**	**119.00 ± 6.78 c**
17-1-6	C	111.75 ± 1.26	109.75 ± 1.50	109.25 ± 0.95
17-1-9	C	106.50 ± 1.29	105.00 ± 1.15	104.25 ± 0.96
17-2-3	C	117,00 ± 1.82	111.50 ± 1.00	99.50 ± 1.00
17-2-7	C	110.75 ± 1.50	105.50 ± 0.57	97.50 ± 1.29
17-2-10	C	115.25 ± 2.22	114.25 ± 1.71	111.50 ± 1.00
17-3-1	C	103.50 ± 2.65	99.00 ± 1.15	94.50 ± 0.57
17-3-6	C	116.50 ± 1.29	112.50 ± 1.00	107.25 ± 0.96
17-6-2	C	107.00 ± 1.82	104.75 ± 0.50	102.75 ± 0.50
17-6-7	C	99.25 ± 2.12	97.75 ± 1.70	93.25 ± 3.20
17-6-9	C	112.25 ± 2.21	110.75 ± 1.50	109.00 ± 0.81
C		**109.97 ± 5.84 ab**	**107.07 ± 5.52ab**	**102.87 ± 6.32 b**
17-8-2	D	117.50 ± 2.08	116.00 ± 1.82	112.00 ± 2.45
D		**117.50 ± 2.08 bc**	**116.00 ± 1.82 b**	**112.00 ± 2.45 bc**
16-12-6	E	112.75 ± 2.75	104.50 ± 1.29	94.25 ± 3.86
E		**112.75 ± 2.75 abc**	**104.50 ± 1.29 ab**	**94.25 ± 3.86 ab**
9-20-1	F	110.50 ± 3.11	109.00 ± 3.36	106.75 ± 2.12
F		**110.50 ± 3.11 abc**	**109.00 ± 3.36 ab**	**106.75 ± 2.12 bc**
17-12-1	G	106.50 ± 1.29	99.50 ± 1.91	85.75 ± 0.96
17-13-10	G	100.25 ± 2.63	98.50 ± 2.38	93.50 ± 1.73
G		**103.37 ± 3.85 a**	**99.00 ± 2.07a**	**89.62 ± 4.34 a**
Kober 5 BB	H	121.75 ± 3.30	119.75 ± 2.63	117.50 ± 2.88
SO 4	H	100.25 ± 2.63	89.50 ± 6.40	85.50 ± 6.41
Teleki 5 C	H	95.25 ± 2.50	93.00 ± 2.94	87.75 ± 2.63
Craciunel 2	H	121.00 ± 2.94	119.25 ± 2.21	117.50 ± 2.88
H		**109.56 ± 12.60 ab**	**105.37 ± 15.05 ab**	**102.06 ± 16.36 b**

Table - 4: Evaluation of chlorophyll content index (CCI), values in rootstock hybrids and registered rootstock varieties, average values and standard deviations of individual pedigree groups. Letters indicate results of a statistical evaluation by Tukey test at the significance level of p<0.01

Hybrid / Variety	Pedigree	Variant C	Variant V1	Variant V2
16-1-6	A	22.25 ± 1.70	15.50 ± 1.91	12.75 ± 1.89
16-1-7	A	22.50 ± 1.29	20.50 ± 0.57	19.00 ± 0.81
16-2-5	A	18.50 ± 1.91	15.00 ± 0.81	10.00 ± 0.82
A		**21.08 ± 2.43 b**	**17.00 ± 2.83 b**	**13.92 ± 4.10 bc**
16-10-1	B	18.50 ± 1.29	17.25 ± 0.95	16.50 ± 1.29
16-10-3	B	21.50 ± 1.29	17.25 ± 0.95	13.00 ± 0.81
B		**20.00 ± 2.00 ab**	**17.25 ± 0.89 bc**	**14.75 ± 2.12 bc**
17-1-6	C	19.25 ± 0.96	18.25 ± 0.50	17.50 ± 0.57
17-1-9	C	17.75 ± 0.50	17.50 ± 0.57	15.75 ± 0.50
17-2-3	C	19.25 ± 0.96	15.50 ± 0.58	11.25 ± 0.96
17-2-7	C	15.00 ± 0.82	11.25 ± 0.96	8.25 ± 0.50
17-2-10	C	18.25 ± 1.25	17.25 ± 0.96	16.75 ± 0.96
17-3-1	C	16.75 ± 0.96	14.50 ± 0.58	12.75 ± 0.96
17-3-6	C	21.50 ± 1.29	17.75 ± 0.50	15.00 ± 0.81
17-6-2	C	18.25 ± 0.50	17.50 ± 0.58	16.75 ± 0.50
17-6-7	C	17.00 ± 0.82	15.25 ± 0.50	13.50 ± 0.58
17-6-9	C	17.50 ± 0.58	16.75 ± 0.50	16.00 ± 0.81
C		**18.05 ± 1.85 a**	**16.15 ± 2.11 b**	**14.35 ± 2.88 bc**
17-8-2	D	19.25 ± 0.96	17.75 ± 0.50	15.75 ± 0.50
D		**19.25 ± 0.96 ab**	**17.75 ± 0.50 bc**	**15.75 ± 0.50 bc**
16-12-6	E	16.50 ± 1.29	11.50 ± 1.29	8.75 ± 0.95
E		**16.50 ± 1.29 a**	**11.50 ± 1.29 a**	**8.75 ± 0.95 a**
9-20-1	F	19.00 ± 1.15	18.75 ± 0.95	17.00 ± 1.15
F		**19.00 ± 1.15 ab**	**18.75 ± 0.95 bc**	**17.00 ± 1.15 bc**
17-12-1	G	18.00 ± 0.82	14.75 ± 0.50	10.50 ± 1.29
17-13-10	G	17.00 ± 0.82	16.25 ± 0.50	14.50 ± 0.58
G		**17.50 ± 0.93 a**	**15.50 ± 0.93 b**	**12.50 ± 2.33 ab**
Kober 5 BB	H	22.00 ± 1.82	20.50 ± 2.38	19.75 ± 2.06
SO 4	H	23.50 ± 1.29	19.50 ± 1.00	13.75 ± 0.96
Teleki 5 C	H	23.00 ± 0.82	21.75 ± 0.50	19.00 ± 1.15
Craciunel 2	H	18.25 ± 1.26	17.25 ± 1.26	16.25 ± 1.89
H		**21.69 ± 2.44 b**	**19.75 ± 2.14 c**	**17.19 ± 2.83 c**

Johnson *et al.* (2003) evaluated drought tolerance in 17 *Vitis* species and they classified *Vitis berlandieri, Vitis riparia* and *Vitis cinerea* as species showing a low degree of drought tolerance. On the other hand, however, hybrid of *Vitis berlandieri* and *Vitis rupestris* were classified as combinations showing a very good tolerance to drought. Similar results were published also by Lovisolo *et al.* (2008) who concluded that the rootstocks *Vitis berlandieri x Vitis rupestris* showed a higher level of adaptation to dry conditions than hybrids *Vitis berlandieri x Vitis riparia* (these were sensitive to drought).

Based on the results of the evaluation of all aforementioned traits it can be concluded that the most resistant showed hybrids are from pedigree groups C (*Binova x Börner*), group D /*Binova x / (Binova x Teleki 5C/) x Börner*/ and group F (*Teleki 5 C x Börner*). This means that drought resistant are above all those hybrids that have *Vitis berlandieri, Vitis riparia* and *Vitis cinerea* in their pedigree. However, hybrids with *Vitis rupestris* and *Vitis amurensis* in their pedigrees show only a medium resistance to drought stress. The obtained results indicate that *Vitis cinerea* is a good genetic resource of drought tolerance.

Acknowledgments

My sincere thanks for support belong to the Ministry of Agriculture of the Czech Republic. This publication was written as a part of the research project QF 4141: Grape rootstock breeding with the use of grape genetic resources and modern testing methods.

I also thank Ass. Prof. Ing. Miloš Michlovský, DrSc and his enterprise Vinselekt for the provision of rootstock hybrids originating from their own breeding.

Table - 5: Evaluation of drought tolerance on the base of visual symptoms in rootstock hybrids and in registered rootstock varieties, average values and standard deviations of individual pedigree groups. Letters indicate results of a statistical evaluation by Tukey test at the significance level of p<0.01.

Hybrid / Variety	Pedigree	Variant C	Variant V1	Variant V2
16-1-6	A	1.00	3.50 bcd	6.00 d
16-1-7	A	1.00	2.00 abc	3.00 ab
16-2-5	A	1.00	4.50 d	6.00 d
A			**3.33 ± 1.44 b**	**5.00 ± 1.71 b**
16-10-1	B	1.00	1.50 ab	2.50 ab
16-10-3	B	1.00	2.00 abc	5.50 cd
B			**1.75 ± 1.04 ab**	**4.00 ± 1.85 ab**
17-1-6	C	1.00	1.00 a	1.50 ab
17-1-9	C	1.00	1.00 a	1.00 a
17-2-3	C	1.00	3.00 abcd	6.00 d
17-2-7	C	1.00	4.00 cd	6.50 d
17-2-10	C	1.00	1.00 a	2.00 ab
17-3-1	C	1.00	2.00 abc	3.50 bc
17-3-6	C	1.00	2.00 abc	3.00 ab
17-6-2	C	1.00	1.00 a	1.00 a
17-6-7	C	1.00	1.50 ab	3.50 bc
17-6-9	C	1.00	1.00 a	1.00 a
C			**1.75 ± 1.17 ab**	**2.90 ± 2.07 a**
17-8-2	D	1.00	1.00 a	1.50 ab
D			**1.00 a**	**1.50 a**
16-12-6	E	1.00	3.00 abcd	6.00 d
E			**3.00 ab**	**6.00 b**
9-20-1	F	1.00	1.00 a	1.00 a
F			**1.00 a**	**1.00 a**
17-12-1	G	1.00	3.00 abcd	5.50 cd
17-13-10	G	1.00	1.50 ab	2.00 ab
G			**2.25 ± 1.04 ab**	**3.75 ± 2.12 ab**
Kober 5 BB	H	1.00	1.00 a	1.50 ab
SO 4	H	1.00	3.50 bcd	5.50 cd
Teleki 5 C	H	1.00	1.50 ab	3.50 bc
Craciunel 2	H	1.00	1.00 a	1.50 ab
H			**1.75 ± 1.24**[ab]	**3.00 ± 1.93**[ab]

References

Bourque, D.P. and A.W. Naylor: Large effects of water deficits on chlorophyll accumulation and ribonucleic acid synthesis in etiolated leaves of jackbean (*Canavalia ebsiformis* L.D.C.). *Plant Physiol.*, **47**, 591-594 (1971).

Chaves, M.M., O. Zarrouk, R. Francisco, J.M. Costa, T. Santos, A.P. Regalado, M.L. Rodrigues, C.M. Lopes: Grapevine under deficit irrigation: hints from physiological and molecular data. *Ann. Bot.*, **105**, 661-676 (2010).

Comas, L.H., T.L. Bauerle and D.M. Eissenstat: Biological and enviromental factors controlling roor dynamics and function: Effects of root ageing and soil moisture. *Aus. J. Grape and Wine Res.*, **16**, 131-137 (2010).

Cramer, G.R., A. Ergül, J. Grimplet, R.L. Tillett, E.A.R. Tattersall, M.C. Bohlman, D. Vincent, J. Sonderegger, J. Evans, C. Osborn, D. Quilici, K.A. Schlauch, D.A. Chooley and J.C. Cushman: Transcript and metabolite profiling of grapevines exposed to gradually increasing, long-term water-deficit or isoosmotic salinity. *Funct. Integr. Genomics*, **7**, 111-134 (2007).

Cregg, B.: Improving drought tolerance of trees. Theorethical and practical considerations. *Acta Horticulturae*, **630**, 147-158 (2004)

Dry, P., B.R. Loveys and H. During: Partial drying of the rootzone of grape. I. Transient changes in shoot growth and gas exchange. *Vitis*, **39**, 3-7 (2000).

Flexas. J., J.M. Aescalona and H. Medrano: Down-regulation of photosynthesis in grapevine leaves by drought under field conditions. *Aust. J. Plant Physiol.*, **25**, 893-900 (1998)

Flexas, J., M. Barón, J. Bota, J.M. Ducruet, A. Gallé, J. Galmes, M. Jimenéz, A. Pou, M. Ribas-Carbo, C. Sajnani, M. Tomás and H. Medrano: Photosynthesis limitations during water stress acclimation and recovery in the drought-adapted *Vitis* hybrid Richter-110 (*V. berlandieri x V. rupestris*). *J. Exp. Bot.*, **60**, 2361-2377 (2009).

Flexas, J., J. Galmés, A. Gallé, J. Guilas, A. Pou, M. Ribas-Carbo, M. Tomás and H. Medrano: Improving water use efficiency in grapevines: potential physiological targets for biotechnological improvement. *Aus. J. Grape and Wine Res.*, **16**, 106-121 (2010).

Gomez-Del-Campo, M., C. Ruiz and J.R. Lissarrague: Effect of water stress on leaf area development, photosynthesis, and productivity in Chardonnay and Airén grapevines. *Am. J. Enol. Viticul.*, **53**, 138-143 (2002).

Grimplet, J., L.G. Deluc, G.R. Gramer and J.C. Cushman: Integrating functional genomics with salinity and water deficit stress respones in wine grape – *Vitis vinifera*. *In*: Advances in molecular breeding towards drought and salt tolerant crops (*Ed.*: M.A. Jencks). pp. 643-668 (2007).

Guan, X.Q., S.J. Zhao, D.Q. Li and H.R. Shu: Photoprotective function of photorespiration in several grapevine cultivars under drought stress. *Photosynthetica*, **42**, 31-36 (2004).

IPGRI: Descriptors for grapevine (*Vitis* spp.). International Plant Genetic Resources Institute. p. 62 (1997).

Kadam, J.H. and T.B. Tambe: Investigation on various grape rootstocks for drought tolerance. *In*: Proceedings of XXVIII th World Congress of Vine and Wine, 4-9 July, Wien, Austria. p. 10 (2004).

Koundouras, S., I.T. Tsialtas, E. Zioziou and N. Nikolaou: Rootstock effect on the adaptive strategies of grapevine (*Vitis vinifera* cv. Cabernet – Sauvignon) under contrasting water status: Leaf physiological and structural responses. *Agric., Ecosys. Environ.*, **128**, 86-96 (2008).

Lebon, E., A. Pellegrino, G. Louarn and J. Lecouer: Branch development controls leaf area dynamics in grapevine (*Vitis vinifera*) growing in drying soil. *Annals of Botany*, **98**, 175-185 (2006).

Lovisolo, C., S. Tramontini, J. Flexas and A. Schubert: Mercurial inhibition of root hydraulic conductance in *Vitis* spp. rootstocks under water stress. *Environ. Experimen. Bot.,* **63**, 178-182 (2008).

Padgett-Johnson, M., L.E. Williams, M.A. Walker: Vine water relations, gas exchange and vegetative growth of seventeen *Vitis* species grown under irrigated and non-irrigated conditions in California. *J. Amer. Hort. Sci.*, **128,** 269-276 (2003).

Patil, S.G., B.K. Honrao, S.P. Karkamar and V.P. Patil: Drought tolerance in rootstock of grapes. *Drakshavritta*, **15**, 119-122 (1995)

Patil, S.G., S.P. Karkamkar and M.R. Deshmukh: Evaluation of grape varieties for their drought tolerance. *J. Maharashtra Argic. Univ*., **28**, 250-251 (2003).

Patil, S.G., S.P. Karkamkar and M.R. Deshmukh: Screening of grape varieties for their drought tolerance. *Ind. J. Plant Physiol.*, **10**, 176-178 (2005)

Pellegrino, A., E. Lebon, T. Simmoneau and J. Wery: Towards a simple indicator of water stress in grapevine (*Vitis vinifera* L.) based on the differential sensitivities of vegetative growth component. *Australian J. Grape Wine Res.*, **11**, 306-315 (2005).

Pire, R., A. Pereira, J. Diez and E. Fereres: Drought tolerance assessment of a Venezuelan grape rootstock and possible conditions mechanism. *Agrociencia*, **41**, 435-446 (2007).

Ramteke, S.D. and G.S. Karibasappa: Screening of grape (*Vitis vinifera*) genotypes for drought tolerance. *Ind. J. Agric. Sci.*, **75**, 355-357 (2005).

Satisha, J., G.S. Prakash and R. Venugopalan: Statistical modeling of the effect of physio-biochemical parameters on water use efficiency of grape varieties, rootstocks and their stionic combinations under moisture stress conditions. *Turk. J. Afric. Res*., **30**, 261-271 (2006).

Schmidt, J., F. Manty, L. Huber, M. Porten and E.H. Ruhl: Experience with rootstocks varieties in Germany. Proceedings of the 2005 Rootstocks Symposium – Grapevine Rootstocks: Current Use, Research, and Application. pp. 14-24 (2005).

Schultz, H.R.: Water relations and photosynthesis responses of two grapevine cultivars of different geographical origin during water stress. Proceedings of workshop strategies to optimize wine grape quality. *Acta Horticulturae*, **427**, (1996).

Sivilotti, P., C. Bonetto, M. Paladin and E. Peterlunger: Effect of soil moisture avalability on Merlot: From leaf water potential to grape composition. *American Journal of Enology and Viticulture*, **56**, 9-18 (2005).

Smart, D.R., E. Schwass, A. Lakso, L. Morano: Grapevine rooting patterns: A comprehensive analysis and a review. *Am. J. Enol. Vitic.* , **57**, 89-104 (2006).

Sommer, K.: Spring recovery-resilience of Sultana to drought. *The Vine*, **5**, 32-34 (2009).

Stevens, R.M., G. Harvey and D. Aspinall: Grapevine growth of shoots and fruit linearly correlate with water stress indices based on root-weighted soil matric potential. *Aus. J. Grape and Wine Res.*, **1**, 58-66 (1995).

Vandeleur, R.K., G. Mayo, M.C. Shelden, M. Gilliham, B.N. Kaiser and S.D. Tyerman: The role of plasma membrane intrinsic protein aquaporins in water transport throught roots: Diurnal and drought stress responses reveal different strategies between isohydric and anisohydric cultivars of grapevine. *Plant Physiol*., **149**, 445-460 (2009).

Walker, R. and P. Clingeleffer: Rootstock attributes and selection for Australian viticulture. ASEV Symposium 23-26. June 2009. *Australian Viticulture*, **13**, 70-76 (2009).

Yuejin, W., Y. Yazhou, Z. Jianxia, P. Xuejun and W. Yizhen: Preliminary identification of drought resistance of chinese wild Vitis species and its interspecific hybrids. *Acta Horticul. Sinica*, **34**, 711-714 (2004).