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Effect of rootstocks on morphological and physiological traits of Sultana grapevine under moisture stress conditions

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ABSTRACT

The effects of two Iranian grape rootstocks namely Kaj Anguor Bojnord (KA) and Qare Gandomeh (QG) with scion Sultana were studied in 2015 for drought stress, leaf structural characteristics and gas exchange parameters. Greenhouse grown, grapevines of cv. Sultana (*Vitis vinifera* L.) grafted onto two rootstocks and on own roots, were subjected to three drought stress levels (NS: no-stress, MS: moderate stress and SS: severe stress). The results indicated that under SS, relative water content in KA-grafted was similar to that in un-grafted Sultana under MS. Moreover, leaf area decreased under SS compared MS. Furthermore, KA-grafted exhibited the highest value of leaf fresh mass. The leaf dry mass for un-grafted Sultana was significantly lower than grafted vines and, the values of leaf tissue density for the three rootstocks were lower than control. Under MS, the leaf thickness of Sultana on KA exhibited an increase, while the other rootstocks followed a decreasing trend under SS. Also un-grafted Sultana had a higher specific leaf area compared to grafted vines. The amounts of leaf chlorophyll in Sultana on KA and QG were significantly higher than un-grafted vines. KA-grafted improved photosynthesis rate of Sultana scion compared to the own-rooted plants in all experimental drought conditions. Additionally, the transpiration for Sultana scion leaves had declined compared to un-grafted plants. Significant interactions were observed between stress levels and rootstocks on the water use efficiency. Concluding, in his experiment KA rootstock could be better performance compared to QG and un-grafted Sultana to drought stress.

Key words: *Vitis vinifera*, drought stress, gas exchange.

INTRODUCTION

Grapevine (*Vitis* spp.) is one of the most widely grown fruit crop in the world. Historically, at the turn of 1900's grapevine rootstocks were crossed from American *Vitis* species in order to diminish losses caused by phylloxera (Serra *et al.,* 23). Hence, rootstocks were selected mainly for their resistance to phylloxera, as well as for other fundamental requirements such as suitability for grafting and they were found to regulate the size of the scion, to contribute to fruit quality, to affect fruit development/ripening and moreover they can vary specific situation of postharvest fruit quality of a scion (Marguerit *et al.*, 18). In general, grapevines (*Vitis vinifera* L.) are well-adapted to arid and semiarid climates, and they apparently depend on drought avoidance mechanisms under water stress conditions (Chaves *et al.*, 3). Iran is a vast phylloxera-free country with a variety of climate that mostly entails arid and semi-arid areas. In recent years, a breeding program is initiated which is conducted on native rootstocks being exposed to drought stress tolerance and screening germplasm of diverse Iranian grapevine genotypes (Hadadinejad *et al.*, 12). Drought oblige senility of older leaves, causes decrease in growth, a decrease in plant water potential, stomatal closure, lower transpiration and photosynthetic rate (Yordanov *et al.*, 27). Whereas, water shortage exacerbation resulted from climate change and irrigation limitations makes seeking more drought tolerant rootstock as an interesting goal (Serra *et al.*, 23). However, several other characteristics are also required, such as rooting and propagation, suitability for grafting, tolerance to lime, salinity and drought, resistance to nematodes and Pierce's disease and vigour (Granett *et al.*, 10). It is proposed that studies on responses of vines to drought in new scion/rootstock combinations will gain importance over time as producers try to increase yield and quality despite the ever increasing water shortage on the faces of climate change. The intricate interactions between scion and rootstock have been widely studied, especially the effects of rootstock on shoot development and grape quality. Rootstocks can profoundly influence the traits of the scion such as leaf area and canopy development (Koundouras *et al.*, 15), and have been reported to modify *Vitis*

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vinifera varieties' water status and gas exchange in pot conditions (Iacono *et al.,* 13). While there is plenty of information on drought-related changes in the development and operation of grapevine (Lovisolo *et al.,* 16,), especially in own-rooted vines, which serve as the propagating material for establishing vineyards in many parts of the world. Many researchers have shown that grapevine response to drought stress involves internode elongation and decrease in leaf expansion (Lovisolo *et al*., 16), a reduction in stomatal conductance and photosynthesis (Koundouras *et al*., 15); and drought can cause cellular water loss, affects cell division and elongation, and consequently affects the growth of different organs. Furthermore, it is well accepted that drought stress reduces parameters of gas exchange in plants such as net photosynthesis (PN) and transpiration (E), while other parameters such as water-use efficiency (WUE) tend to respond differently and typically increase as water stress invigorates (Gómez-del-Campo *et al*., 9). Stomatal closure is driven by several factors such as phytohormones accumulation (Serra *et al*., 23). Most studies of WUE are performed on the basis of immediate measurements of leaf photosynthesis and transpiration, on the obligation that they are representative of whole-plant WUE (Tomás *et al*., 25). WUE determinations rely on direct measurement of urgent gas exchange rates (photosynthesis and transpiration) at the leaf level with portable equipment. (Medrano *et al*., 19). The main objective of this research is to study the effects of drought stress treatment upon some morphological and physiological characteristics of Sultana own root in comparison to its scions grafted on two Iranian cultivars to select them as superior rootstocks.

MATERIALS AND METHODS

The experiment was carried out at the Urmia Dr. Beheshti high school's greenhouse in Iran in 2015. In the present research work, Sultana was used as a scion along with cultivars of 'Qare Gandomeh' and 'Kaj Angour Bojnoord' (both from *Vitis vinifera*) as rootstocks were prepared from Kahriz Agricultural Research Station (Urmia-Iran) and National Iranian Grapes Station located in Takestan (Qazvin) respectively. The scion of *Vitis vinifera* L. cv. Sultana was bench grafted to rootstock varieties of 'Qare Gandomeh' and 'Kaj Angour Bojnoord' via an Omega grafting tool (Rico Professional, Turkey) and cuttings were immediately transferred to a rooting environment containing a mixture of peat and perlite at 25° C for 20 days. The bare-rooted cuttings were planted in 3-liter plastic pots and after reaching a sufficient growth, vines were potted into 28 L black-plastic pots (30 cm high and 90.6 cm in diameter at the top) filled with sandy loam soil potting medium.

Some samples were taken by standard cylinders from the soil surrounding the roots and were transferred to Soil Science Laboratory of Urmia University for determination of F.C. and soil water potential. After the placement of samples on the pressure plate device and reaching the balance, RETC software was used to determine the moment of attaining stress levels in the soil (Hadadinejad *et al*., 12). Soil water potential was evaluated according to a reference curve with soil moisture (MPa of soil pressure to percent of its moisture volume) preliminary established. Then real time soil water potential was estimated from regular soil sampling during the stress treatments. Plant sampling and physiological measurements were conducted at the end of 3nd sequence repeat of reaching soil water potential to the targeted values. The water availability treatments were drought stressed on three surfaces: non-stressed (-0.1 MPa) (NS), moderate stressed (-1 MPa) (MS) and severe stressed (-2 MPa) (SS). The experiment was conducted with 2 years old Sultana scion grafted on the two above-mentioned rootstocks and own-rooted Sultana with four replications in a completely randomized factorial design under greenhouse condition.

In order to measure the relative water content (RWC), the method by Rabiei *et al*. (20) was used. For determination of leaf area (LA), five healthy leaves of each treatment and 4 replicates was measured using the AM 200 portable instrument (ADC Bio Scientific Ltd. UK). The fresh mass (FM) of the leaves was weighed and the dry mass (DM) was estimated after oven drying at 75 °C for 48 h. Specific leaf area (SLA, $cm^2 \cdot g^{-1}$) was determined as the ratio of LA to DM of the five leaves. To estimate of leaf structural traits such as SLA, leaf thickness (LT) was calculated as the ratio of FM to LA and leaf tissue density (D) as (DM/FM) × 1000 (Koundouras *et al*., 15). The root length (RL) was measured and root dry matter (RDM) was estimated after oven drying at 75 °C for 48 h. The chlorophyll content of leaves was measured with SPAD index by chlorophyll meter (502, Konica Minolta, Tokyo, Japan).Some gas exchange measurements such as photosynthesis rate (A) and transpiration (E) were recorded using the LCi portable gas exchange system (ADC Bio Scientific Ltd, UK). Measurements were taken on 3rd leaf from top of each plant from 10:00 to 13.00 hours under the sunlight leaves per plot (photosynthetic photon flux density > 1200 $mmol \cdot m^2 \cdot s^{-1}$) with the following specifications/ adjustments of the leaf chamber: leaf surface area 6.25 cm^2, CO_2 reference (Cref) 403vpm, temperature of leaf chamber (Tch) varied from 26.7 to 36.4°C, leaf chamber molar gas flow rate (U) 203µmol·s^{-1}, atmospheric pressure (P) 883mBar and P.A.R .incident on leaf surface at (Q leaf) maximum up to 1585 µmol·m^2·s^{-1}. Consequently, sampling for water use efficiency (A/E) analysis was performed at the end of the study. Gas exchange measurement was conducted at midday in order to obtain an accurate indication of grapevine response to environmental stress (Medrano *et al*., 19).

Statistical analysis was performed using SAS 9.2 (SAS Institute Inc., Cary, NC) and means for each treatment were compared by Tukey's range test (HSD). Differences were considered significant at $p < 0.05$. The correlation of means calculated via SPSS 23 (IBM SPSS Statistics version 23). The Excel 2013 software was also used for drawing graphs.

RESULTS AND DISCUSSION

Variance analysis showed the significant effects of drought stress on all evaluated traits (except for LA), (Table 1) and also for the effects of rootstock. Moreover, the interaction of stress levels and rootstocks was significant on leaf area, leaf density, leaf thickness, specific leaf area and WUE. Based on the results (Fig. 1A), relative water content (RWC) index for own-rooted Sultana had no significant difference up to MS (86.44%), which explains the relative drought tolerance characteristic of Sultana and also indicates that Sultana can be used for deficit irrigation. Under SS, a significant decline in RWC was observed in own-rooted Sultana (83. 62 %). Whereas, the decrease of RWC under SS in Sultana scion grafted on KA (87.12%)was not significant compared with MS (87.53 %) which indicates the positive effects of the used rootstocks under SS. Furthermore, one of the mechanisms underlying drought tolerance is maintaining the essential functions with less relative water content and high temperature. Interactions between the studied traits indicated that leaf area (LA) of Sultana scion grafted on both rootstocks (KA and QG) had no significant difference in MS(335.07, and 294.58 cm^2, respectively) compared to own rooted Sultana (373.83 cm^2).While, at SS, un-grafted Sultana (244.38 cm^2) had significantly lower LA than onto rootstocks (Fig. 1B). Grapevine rootstocks can affect leaf area and root extension depending on the vigour inducing capacity (Gambetta *et al*., 7) affecting the canopy water demand and supply. In order to rank the rootstocks for drought tolerance, the ratio between total active leaf area and stomatal conductance had been considered in active leaves under developing water restrictions during the day and the season (Carbonneau, 2). Moreover, in

Table 1. Analysis of variance of the effect of rootstock and different levels of water stress on physiological traits in Sultana.

Sources of changes		Mean of Squares												
		RWC	LA	FM	DM	D	LT	SLA	RDM	RL	Greeness index	A	E	WUE
		%	cm^2	g	g	mg·g^{-1}	mg·cm^{-2}	cm^2·g^{-1}	g	cm	Spad	µmol CO_2·m^{-2}·s^{-1}	mmol H_2O·m^{-2}·s^{-1}	µmol CO_2·m^{-2}·s^{-1}/ mmol H_2O·m^{-2}·s^{-1}
Stress	2	48.27**	23995.75**	9.58**	13.46**	426259.8**	17.04**	300168.42**	5.22**	24.57	77.64**	105.39**	31.45**	0.203^{ns}
Rootstock	2	22.18*	3225.64^{ns}	1.98**	0.67**	39621.78**	14.89**	40174.68**	22.40**	259.71**	14.89**	1.81*	0.0006^{ns}	0.38^{ns}
Stress × Rootstock	4	4.14^{ns}	4816.18*	0.63^{ns}	0.02^{ns}	4436.18**	7.32*	13429.57**	5.11**	4.87^{ns}	0.5^{ns}	0.66^{ns}	0.93^{ns}	0.75**
Error	27	5.42	1521.78	0.24	0.04	818.26	2.41	1120.51	0.75	35.43	1.06	0.46	0.68	0.16
CV	-	2.68	12.01	11.48	14.36	9.1	11.28	11.1	10.26	13.57	3.41	12.36	24.57	23.6

RWC = Relative water content, LA = individual leaf area, FM = leaf fresh mass, DM = leaf dry mass, D = leaf density, LT = leaf thickness, SLA = specific leaf area, RDM = root dry matter, RL = root length, greeness index = chlorophyll content, A = photosynthesis rate and E = transpiration of Sultana scion.
Comparison of means were performed using Tukey's Studentized Range (HSD) at P < 0.05. * and **: significant at the 5% and 1% levels of probability, respectively. ^{ns}is not significant.

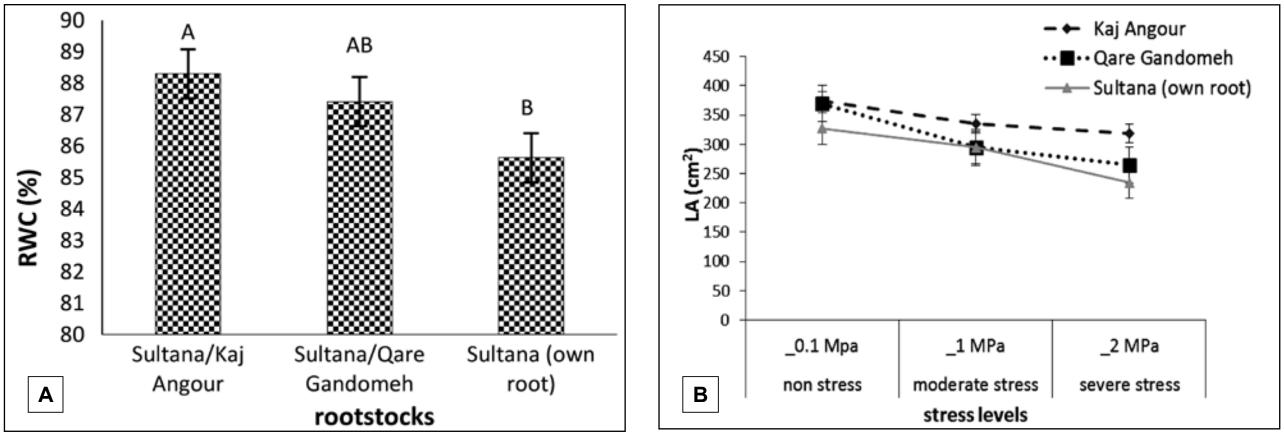

Fig. 1. Effects of stress and rootstock on: relation water content (RWC) (A). Interaction of stress and rootstock on: individual leaf area (LA) (B).Comparison of means were performed using Tukey's Studentized Range (HSD) at P<0.05.

tolerant grapevine varieties, regulation of hydraulic conductivity is accomplished by reduction of leaf area or stomatal regulation (Winkel and Rambal, 26). Based on the previous reports, drought stress led to reduction of leaf area in Shiraz grapevine variety (Winkel and Rambal, 26) which is consistent with results of the present experiment.

All three rootstocks did not show any significant differences in Leaf fresh mass (FM) under NS, while under MS,the FM of Sultana grafted on KA (5.6 g) was significantly higher than Sultana grafted on QG (4.3075 g) and un-grafted Sultana (4.205 g)(Fig. 2A).Under SS, FM index of Sultana scion did not show significant differences between the two grafted rootstocks; however the own-rooted Sultana (3.025 g)showed the least amount of FM compared to the other rootstocks.

Effect of different levels of drought stress and rootstocks on Leaf dry mass (DM) were significant at 1% level (Fig. 2B). Nonetheless, in NS, the DM level for grafted Sultana on QG (2.8933 g) which was significantly different with un-grafted Sultana (2.3 g); this trend was maintained for both MS and SS levels. In both MS and SS, the DM was greater for the scion grafted on KA (1.1768 g, and 0.8003 g, respectively). These results are in agreement with the earlier reports of De Herralde *et al*.(5). The marked reductions of the leaf DM in water deficit plants was mainly due to reduction in leaf thickness and size. Decreased DM accumulation of leaves as a result of stress may be assigned to the altered nitrogen and carbon metabolisms (Kluge, 14) and due to both senescence and death of leaves, which was considered an avoidance mechanism

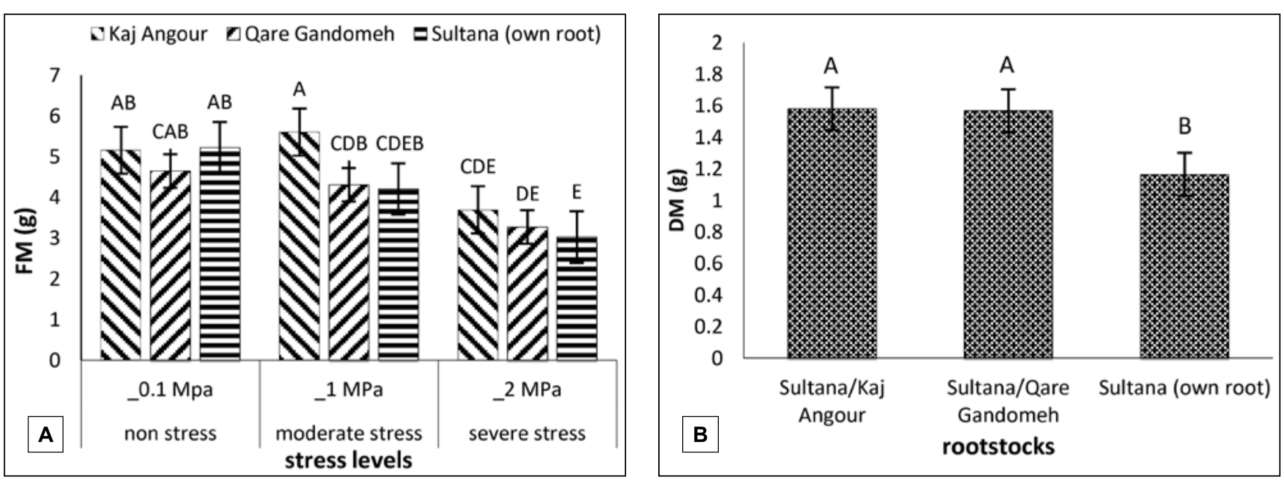

Fig. 2. Means comparison of: leaf fresh mass (FM) (A) and leaf dry mass (DM) (B). Means in columns with the same letters are not significantly different by Tukey's Studentized Range (HSD) at P <0.05.

that allows minimizing water losses (De Herralde *et al*., 5).

With the onset of drought stress, leaf tissue density (D) was reduced substantially on both grafted and un-grafted rootstocks. In MS conditions, the highest and lowest D were belonged to QG (260.82 mg·g^{-1})rootstock and un-grafted Sultana(212.21 mg·g^{-1}), respectively (Fig. 3A). Under SS, the D on QG (223.26 mg·g^{-1}) under gone reduction and on KA (216.02 mg·g^{-1}) it showed a slight and insignificant increase compared with MS, while the own-rooted Sultana (113.47 mg·g^{-1})significantly recordedthe lowest D among others. Leaf structural adjustments to water limitation are rather less explored compared to physiological ones (Manoj *et al*., 17). Increased leaf density (D) is a mechanism that enables plants to reduce transpiration rateby trapping the moisture in the mesophyll (Gullo and Salleo, 11). So, the vegetative growth is terminated by the stress and with respect to the activation of photosynthetic system, hydrocarbon substances store in the remaining cells and cause increased density (Koundouras *et al*., 15).

Based on the interactions between stress and rootstock, under NS the leaf thickness (LT**)** of un-grafted Sultana (15.973 mg·cm^{-2}) was higher than KA and QG grafted rootstocks (13.73 mg·cm^{-2}, and 12.626 mg·cm^{-2}, respectively). However, under MS, LT had a significantly decreasing trend (Fig. 3B). In contrast, under MS, LT of Sultana grafted on KA (16.97 mg·cm^{-2}),had a significant difference withQG(13.014 mg·cm^{-2}). In SS, none of the three rootstocks showed significant differences in terms of the LT index. A decrease in leaf expansion and thickness of the water deficit leaves indicates that both cell division and enlargement were significantly affected (Bertamini *et al*., 1).

The results indicated that the Specific leaf area (SLA) index was significantly different among various levels of NS (136.62 cm^2·g^{-1}), MS (316.27 cm^2·g^{-1})

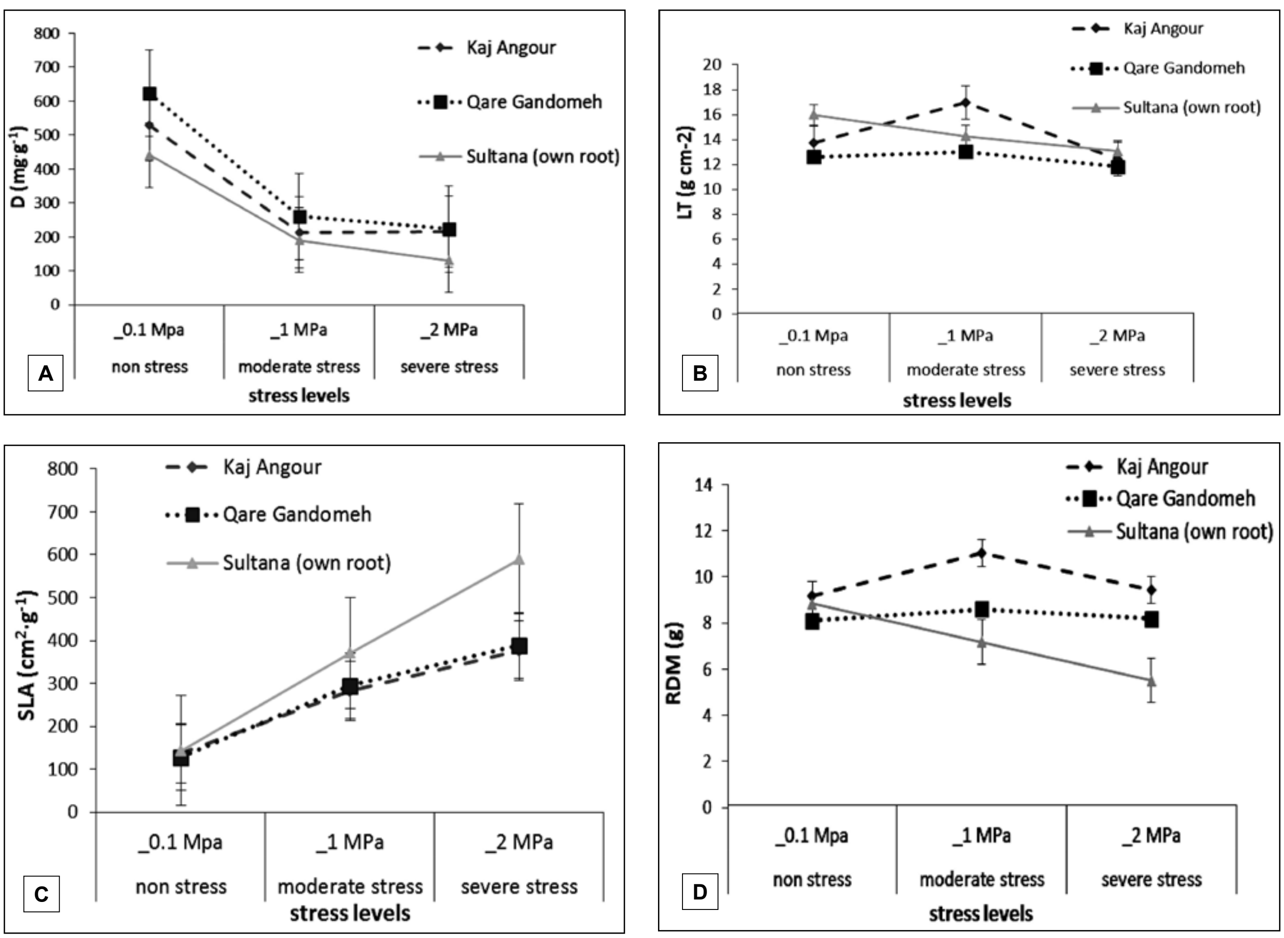

Fig. 3. Interaction of stress and rootstock on: leaf tissue density (D) (A); leaf thickness (LT) (B); specific leaf area (SLA) (C) and root dry matter (RDM) (D). Comparison of means were performed using Tukey's Studentized Range (HSD) at P < 0.05.

and SS (451.91 $cm^2 \cdot g^{-1}$).Sultana scion on different rootstocks did not show any differences under NS and MS conditions(Fig. 3C).However, under SS, un-grafted Sultana (590.35 $cm^2 \cdot g^{-1}$) showed significant differences with QG (388.91 $cm^2 \cdot g^{-1}$) and KA (376.48 $cm^2 \cdot g^{-1}$) rootstocks. Therefore, rootstocks significantly affected SLA under SS condition. The greatest impact of environmental conditions on growth rate in comparison to photosynthesis, occur when the SLA decrease (Tardieu *et al*., 24). Grapevine is drought tolerant and mild stress reduces the shoot growth and leaf expansion without any significant effect on photosynthesis. It will cause the increase in SLA, however it could be harmful if the defoliation occurs due to severe stress. Due to an increase in shoot dry matter during growth cease, it would be better to graft the varieties on 1103P rootstocks (Koundouras *et al*., 15). It should be noted that SLA and D indices have inverse relationships (Koundouras *et al.,* 15).

The root dry matter (RDM) content of grafted KA was 17% higher under MS (11.06 g) and 2% higher under SS (9.43) than under NS (9.2) conditions, and also RDM content of grafted QG was 6% higher in plants under MS (8.61) and 1% higher under SS (8.18) than under NS (8.11) conditions, whereas, RDM of un-grafted Sultana was 23% lower under MS (7.18) and 60% lower under SS (5.51) than under NS (8.84) conditions (Fig. 3D). Rabiei *et al*. (20) found that the Sultana grape cultivars had the most weight loss due to the root dry matter under drought stress, which caused the decrease in root growth rate due to drought stress. Also indicating the lack of information about root, the possibility of root growth during and after drought stress has also been mentioned.

The results indicated that the Root Length(RL) of un-grafted Sultana (38.57 cm) was significantly difference compared to grafted KA (47.36) and QG (45.62) (Fig. 4A). German *et al*. (8) demonstrated that inoculation with *A. brasilense* Cd increased root length and specific root area, as compared with non-inoculated controls of common bean (*Phaseolus vulgaris* L.) under drought stress. Satisha and Prakash (22) imparted that there was an increase in total root length and increased root-to-shoot-length ratio of the rootstocks Dog Ridge and Salt Creek at 50% stress compared with when under control conditions. This increased root length in these rootstocks at 50% stress might have efficiently absorbed water from the lower soil surface and thus maintained a high RWC, resulting in better leaf and osmotic potential of the scion varieties budded on them.

The highest chlorophyll content was observed in Sultana scion grafted on KA under NS and MS levels (32.675mg·kg^{-1}, and 32.525mg·kg^{-1}, respectively), but the rootstocks had no significant differences under these levels. Under SS, the chlorophyll amount of grafted Sultana on both KA and QG (28.08mg· kg^{-1}, and 28.075 mg·kg^{-1}, respectively) was higher than un-grafted (25.725 mg·kg^{-1}) ones with the least amount of chlorophyll (Fig. 4B). Santos (21) reported that during the early days after osmotic stress, there is an increase in chlorophyllase enzyme activity that leads to Chlorophyll degradation however over time and with prolonged stress, the reduced production of Chlorophyll is the major reason for its decrease; because, excessive dehydration prevents the formation of amino levulinic acid that is the precursor of proto-chlorophyll and it converts to chlorophyll by exposure to the sun light. Leaf

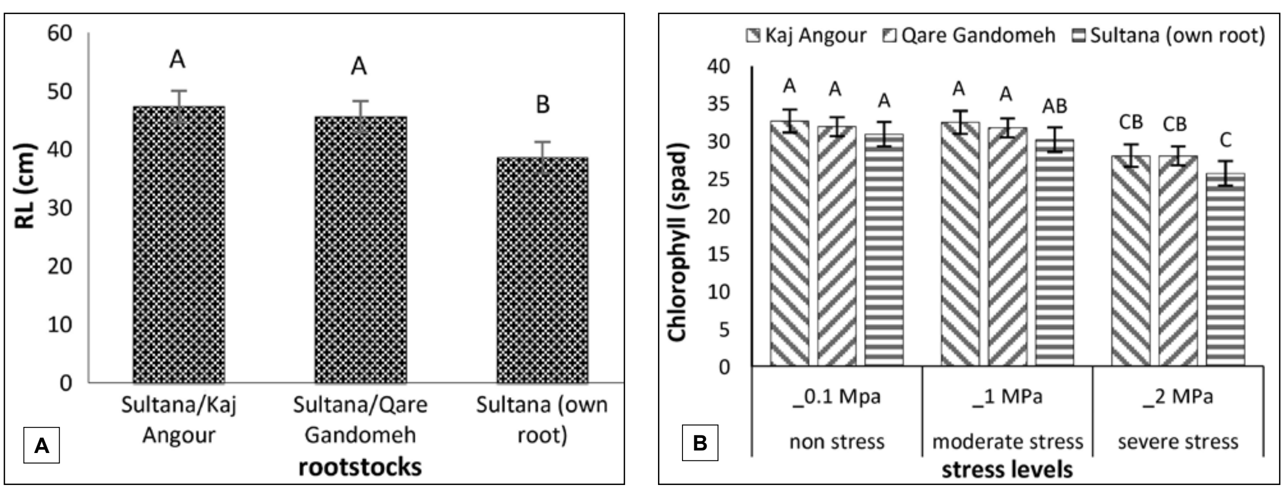

Fig. 4. Means comparison of root length (RL) (A) andchlorophyll in SPAD unit (greeness index) (B). Means in columns with the same letters are not significantly different by Tukey's Studentized Range (HSD) at $P < 0.05$.

Chlorophyll is one of the most important factors indicating the environmental pressures exerted on the plant and it is believed that the Chlorophyll index is reduced under severe stress which results in a reduced absorption of light by the plant.

The results indicated that grafting of Sultana on rootstocks in different treatments including NS and MS, can improve the photosynthesis rate (A) significantly compared to the un-grafted plants (Fig. 5A). Furthermore, Photosynthesis of Sultana on QG rootstocks (5.8517 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) and Sultana on KA (5.5692) had significant differences with own-rooted Sultana (5.0842). Photosynthesis reduction under mild and moderate drought stress is related to stomatal closure and diffusion of CO_2 inside of the simple photosynthesis system (Lovisolo *et al*., 16). Marguerit *et al*. (18) have identified the stable QTLs for this trait and explained the genetic basis of stomatal closure in scion by rootstocks. Factors limiting photosynthesis under water stress are either as stomatal limiting factors that reduce the diffusion of CO_2 to intracellular space due to the reduction of stomatal conductance or non-stomatal limiting factors that is because of direct effect of water shortage on biochemical processes (Flexas *et al*., 6).

The results demonstrated that under MS, Transpiration (E) of the Sultana scion on KA (3.37 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$) had a significant decrease compared to Sultana (2.86) (as control) (Fig. 5B). Under SS, Sultana scion grafted on KA (1.47) and QG (2.24) rootstocks had the least transpiration while the un-grafted Sultana (2.32) showed the most transpiration rate. Plant efficiency has a positive correlation with water loss in stomatal transpiration and stem development. Plant productivity is positively correlated with water losses in transpiration through stomata and shoots development. Plants water decreases through transpiration at the same time of the CO_2 absorption by stomata. To avoid the negative effects of stomata closure on absorption of atmospheric CO_2, researchers are trying to reduce transpiration rate at night as a strategy to limit water use (Coupel-Ledru *et al*.,4). The reduction of the leaf relative water content (RWC) can be detected as another reason of different stomatal conductance and perspiration among different moisture regimes. Furthermore, moderate drought stress leads to an improvement in water maintenance of Tempranillo and Montenegro grapes. Nonetheless, the severe stress triggered a downward trend in photosynthesis regulation and transpiration in the mentioned vines (Medrano *et al*., 19). Mild drought stress enhanced the water condition of two grape varieties "Tempranillo" and "Manto Negro"; however severe stress caused a downward adjustment of photosynthesis and transpiration in above-mentioned varieties (Medrano *et al*., 19).

From the results of the present study, there was no significant difference between rootstocks and stress levels in Water use efficiency (WUE), however interaction of stress and rootstock showed significant difference and the highest WUE on KA at SS (2.44μmol$CO_2 \cdot m^{-2} \cdot s^{-1}$/mmol $H_2O \cdot m^{-2} \cdot s^{-1}$) seen, however, MS decreased WUE non-significantly the KA (1.39) (Fig. 6). While, own-rooted Sultana at MS (1.44) and SS (1.19) had a low range of WUE. Thus, the higher WUE of KA-grafted vines under SS was probably the result of its better access to soil water compared to QG-grafted and own-rooted Sultana. Improving Water Use Efficiency (WUE) in viticulture will be an important issue under climate change. WUE determinations rely on direct measurement

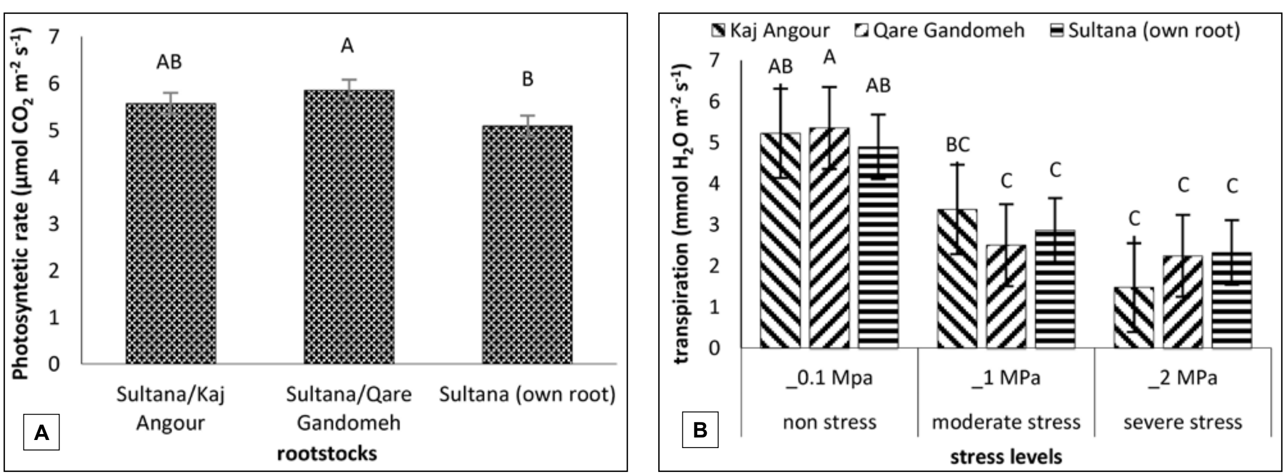

Fig. 5. Means comparison of: photosynthesis rate (A) (A) and transpiration (E) (B). Means in columns with the same letters are not significantly different by Tukey's Studentized Range (HSD) at P<0.05.

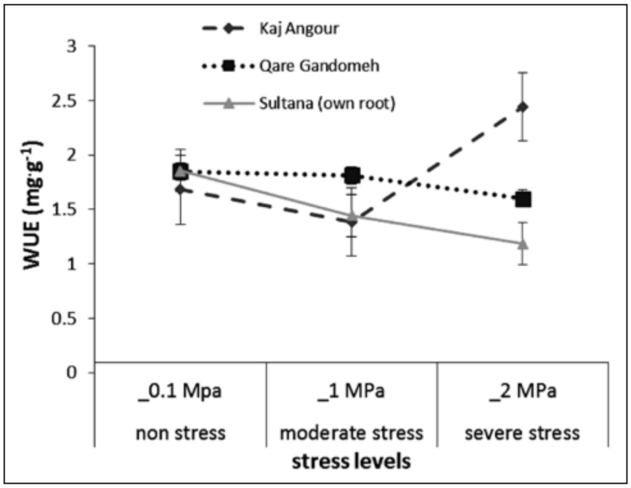

Fig. 6. Interactive effects of stress and rootstock on: water use efficiency (WUE). Comparison of means were performed using Tukey's Studentized Range (HSD) at P < 0.05.

of immediate gas exchange rates (photosynthesis and transpiration) at the leaf level with portable equipment. In grapevines, improving WUE with sectional root drying techniques changes the balance between vegetative and reproductive development and is associated with some betterment of fruit quality (Chaves *et al*., 3).It must be emphasized that there exist a few studies pertaining to recovery responses of water-stressed grapevines; however, these studies primarily dealt with rootstocks showing increases in its water use efficiency (WUE) after a period of water deficit (Tomás *et al*., 25), but upon grafting, the grafted vines failed to show similar response (Gomez-del-Campo *et al*., 13).This indicates that stomatal limitations still dominate, although in some cultivars WUE starts decreasing at this stage, indicating predominant non-stomatal limitations. The results of correlation analysis between the studied traits (Table 2) showed a positive and (mostly) significant correlation between the traits, except for SLA, Lt, Rl and WUE.

Morphological and structural differences at the leaf level might also participate in the physiological behavior of rootstocks. With considering all measured traits and analysis of data, Kaj Angour was selected as a promising rootstock for grape cv. Sultana under studied drought stress conditions. Deficit irrigation is an important strategy to balance of grapevine vigor and WUE with yield quality. These results indicate that a proper selection of rootstock can affect the performance of the scion even under drought conditions and more morphological and physiological traits of the scion can be modified by the rootstock.

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REFERENCES

1. Bertamini, M., Zulini, L., Muthuchelian, K. and Nedunchezhian, N. 2006. Effect of water deficit on photosynthetic and other physiological responses in grapevine (*Vitis vinifera* L.

Table 2. Linear correlation coefficient (r) between studied traits.

	RWC	LA	FM	DM	D	LT	SLA	RDM	RL	Chl	A	E	WUE
RWC	1												
LA	.624**	1											
FM	.454**	.652**	1										
DM	.606**	.613**	.651**	1									
D	.575**	.519**	.456**	.963**	1								
LT	.023	.318*	.726**	.161	-.045	1							
SLA	-.636**	-.644**	-.727**	-.893**	-.856**	-.302*	1						
RDM	.376*	.334*	.543**	.264	.197	.329*	-.514**	1					
RL	.352*	.122	.220	.209	.201	-.103	-.266	.458**	1				
Chl	.613**	.513**	.728**	.631**	.572**	.349*	-.805**	.513**	.312*	1			
A	.495**	.503**	.536**	.933**	.938**	.113	-.861**	.225	.135	.602**	1		
E	.374*	.481**	.550**	.824**	.794**	.196	-.718**	.084	.151	.564**	.875**	1	
WUE	.178	.094	-.044	.152	.208	-.209	-.244	.324*	.124	.020	.187	-.257	1

** and *: Correlation is significant at the 0.01 and 0.05 level, respectively.

cv. Riesling) plants. *Photosynthetica,* **44**: 151-54.

2. Carbonneau, A. 1985. The early selection of grapevine rootstocks for resistance to drought conditions. *American J. Enol. Vitic.* **36**: 195-98.

3. Chaves, M. M., Zarrouk, O., Francisco, R., Costa, J. M., Santos, T., Regalado, A. P., and Lopes, C. M. 2010. Grapevine under deficit irrigation: hints from physiological and molecular data. *Ann. Bot.* **105**: 661-76.

4. Coupel-Ledru, A., Lebon, E., Christophe, A., Gallo, A., Gago, P., Pantin, F. and Simonneau, T. 2016. Reduced nighttime transpiration is a relevant breeding target for high water-use efficiency in grapevine. *Proc. Natl. Acad. Sci.* **113**: 8963-68.

5. De Herralde, F., Biel, C., Savé, R., Morales, M. A., Torrecillas, A., Alarcón, J. J., and Sánchez-Blanco, M. J. 1998. Effect of water and salt stresses on the growth, gas exchange and water relations in *Argyranthemum coronopifolium* plants. *Plant Sci.* **139**: 9-17.

6. Flexas, J., Barón, M., Bota, J., Ducruet, J. M., Gallé, A., Galmés, J. and Tomàs, M. 2009. Photosynthesis limitations during water stress acclimation and recovery in the drought-adapted Vitis hybrid Richter-110 (*V. berlandieri* × *V. rupestris*). *J. Exp. Bot.* **60**: 2361-77.

7. Gambetta, G. A., Manuck, C. M., Drucker, S. T., Shaghasi, T., Fort, K., Matthews, M. A. McElrone, A. J. 2012. The relationship between root hydraulics and scion vigour across Vitis rootstocks: what role do root aquaporins play?. *J. Exp. Bot*. **63**: 6445-55.

8. German, M. A., Burdman, S., Okon, Y., and Kigel, J. 2000. Effects of *Azospirillum brasilense* on root morphology of common bean (*Phaseolus vulgaris* L.) under different water regimes. *Biol. Fert. Soils,* **32**: 259-64.

9. Gómez-del-Campo, M., Baeza, P., Ruiz, C., Sotés, V., and Lissarrague, J. R. 2015. Effect of previous water conditions on vine response to rewatering. *VITIS J. Grapevine Res.* **46**: 51.

10. Granett, J., Walker, M. A., Kocsis, L., and Omer, A. D. 2001. Biology and management of grape phylloxera. *Ann. Rev. Ent.* **46**: 387-412.

11. Gullo, M. A., and Salleo, S. 1988. Different strategies of drought resistance in three Mediterranean sclerophyllous trees growing in the same environmental conditions. *New Phytol*. **108**: 267-76.

12. Hadadinejad, M., A. Ebadi, R. Fattahi, M.A. Nejatian, A. Musavi., and G. Santesteban. 2013. The effect of drought stress on photosynthetic traits and certain gene expression of some Iranian grapevine candidate rootstocks. *Acta Hort.* **1045**: 133-38.

13. Iacono, F., Buccella, A. and Peterlunger, E. 1998. Water stress and rootstock influence on leaf gas exchange of grafted and un grafted grapevines1. *Scientia Hort.* **75**: 27-39.

14. Kluge, M. 1976. Carbon and nitrogen metabolism under water stress. In Water and Plant Life (pp. 243-252). Springer, Berlin, Heidelberg.

15. Koundouras, S., Tsialtas, I. T., Zioziou, E., and Nikolaou, N. 2008. Rootstock effects on the adaptive strategies of grapevine (*Vitis vinifera* L. cv. Cabernet–Sauvignon) under contrasting water status: leaf physiological and structural responses. *Agri. Eco. Env.* **128**: 86-96.

16. Lovisolo, C., Perrone, I., Carra, A., Ferrandino, A., Flexas, J., Medrano, H., and Schubert, A. 2010. Drought-induced changes in development and function of grapevine (*Vitis* spp.) organs and in their hydraulic and non-hydraulic interactions at the whole-plant level: a physiological and molecular update. *Funct. Pl. Biol.* **37**: 98-116.

17. Manoj, K., Tushar, B., and Sttshama, C. 2007. Anatomical variability in grape (*Vitis vinifera)* genotypes in relation to water use efficiency (WUE). *American J. Plant Physiol.* **2**: 36-43.

18. Marguerit, E., Brendel, O., Lebon, E., Van Leeuwen, C., and Ollat, N. 2012. Rootstock control of scion transpiration and its acclimation to water deficit are controlled by different genes. *New Phytol.* **194**: 416-29.

19. Medrano, H., Escalona, J. M., Cifre, J., Bota, J., and Flexas, J. 2003. A ten-year study on the physiology of two Spanish grapevine cultivars under field conditions: effects of water availability from leaf photosynthesis to grape yield and quality. *Funct. Pl. Biol.* **30**: 607-19.

20. Rabiei, V., A. Talaei, A. Ebadi, A. Ahmadi., and N.A. Khosh Kholgh Sima. 2004. Physiological and morphological response of some grapevine cultivars to water stress. Ph.D. Thesis. Faculty of Horticulture. University of Tehran., Iran. (In Persian).

21. Santos, C. V. 2004. Regulation of chlorophyll biosynthesis and degradation by salt stress in sunflower leaves. *Scientia Hort.* **103**: 93-99.

22. Satisha, J., and Prakash, G. S. 2017. The influence of water and gas exchange parameters on grafted grapevines under conditions of moisture stress. *South African J. Enol. Viti.* **27**: 40-45.

23. Serra, I., Strever, A., Myburgh, P. A., and Deloire, A. 2014. The interaction between rootstocks and cultivars (*Vitis vinifera* L.) to enhance drought tolerance in grapevine. *Australian J. Grapevine Res.* **20**: 1-14.

24. Tardieu, F., Granier, C., and Muller, B. 1999. Modelling leaf expansion in a fluctuating environment: are changes in specific leaf area a consequence of changes in expansion rate?. *New Phytol.* **143**: 33-43.

25. Tomás, M., Medrano, H., Pou, A., Escalona, J. M., Martorell, S., Ribas-Carbó, M., and Flexas, J. 2012. Water-use efficiency in grapevine cultivars grown under controlled conditions: effects of water stress at the leaf and whole-plant level. *Australian J. Grapevine Res.* **18**: 164-72.

26. Winkel, T., and Rambal, S. 1993. Influence of water stress on grapevines growing in the field: from leaf to whole-plant response. *Funct. Pl. Biol.* **20**: 143-57.

27. Yordanov, I., Velikova, V., and Tsonev, T. 2000. Plant responses to drought, acclimation, and stress tolerance. *Photosynthetica*, **38**: 171-86.

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