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# The Physiological Response of Three Iranian Grape Cultivars to Progressive Drought Stress

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## ABSTRACT

**Investigating the role of drought stress conditions on physiological characteristics of plant may provide means to understand basic drought resistance. Differences in leaf emergence rate, leaf relative water content (RWC), membrane stability index (MSI), leaf mass area (LMA), net photosynthesis ($A_{net}$), stomatal conductance ($g_s$), transpiration rate (E), intercellular $CO_2$ concentration ($C_i$), water use efficiency ($A_{net}/g_s$) and recovery of gas exchange were investigated in two-year-old grapes of three *Vitis vinifera* L. cultivars ("Khoshnave", "Bidane-Sefid" and "Askari"), subjected to progressive drought stress (soil water potential: -0.2, -0.6, -1, and -1.5 MPa). The results showed temporary reduction in RWC, MSI, leaf emergence rate, LMA, $A_{net}$, $g_s$ and *E*. $C_i$ decreased with increasing drought stress. "Khoshnave" grape showed a higher photosynthesis rate than "Bidane-Sefid" and "Askari". Higher LMA of "Khoshnave" may be attributed to the potential for carbon absorbance and higher $A_{net}$ as compared to the other two cultivars. Complete recovery of $A_{net}$ for all cultivars occurred one day after rewatering at -0.6 MPa and four days after rewatering at -1 MPa treatments. Complete recovery of $g_s$ was not observed in either one or four days after rewatering except for "Askari". The results showed that $A_{net}$ of "Khoshnave" recovered quickly as compared to those in the other two cultivars. Water use efficiency was maximum in all cultivars under -1 MPa treatment. Similar patterns of $A_{net}/g_s$ were observed for the three cultivars. "Khoshnave" had higher $A_{net}/g_s$ as compared to "Askari" and "Bidane-Sefid" under severe drought stress conditions. "Khoshnave" cultivar, with a higher $A_{net}$, higher leaf emergence rate, higher LMA, rapid recovery of $A_{net}$, higher $A_{net}/g_s$ was found to be promising for cultivation in rain-fed areas across the west of Iran in comparison with the other cultivars.**

**Keywords:** Drought stress, Gas exchange, Grapevine, LMA, Water use efficiency.

## INTRODUCTION

Water stress is considered to be a main environmental factor limiting crop growth and yield, including grape in Mediterranean areas (Gomez-del *et al.,* 2004). Stomatal closure in response to water stress can even occur before detectable change in leaf water potential. Water stress-induced change in photosynthetic rate can be more generally related to variation in $g_s$ under light saturating conditions than to RWC or leaf water potential (Flexas *et al.,* 2002; Medrano *et al.,* 2002). Therefore, $g_s$ may be a useful indicator of grapevine water stress. Predawn leaf water potential was only sensitive to severe drought stress, while stomatal conductance was responsive to mild stress (Pellegrino *et al.,* 2005), which caused decrease in $A_{net}$, *E* and $C_i$ (Sircelj *et al.,* 2007). Stomatal limitations were often thought to be the short term responses to drought stress, whereas non-stomatal effects are usually considered to be more important

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during longer and more severe drought stress events (Rouhi *et al.,* 2007). In *Vitis vinifera*, photosynthetic activity decreases during typical summer days due to stomatal (closure) as well as non-stomatal (biochemical reaction) limitations (Chaves *et al.,* 1987). Photosynthesis ($A_{net}$) is one of the key determinants for plant productivity and survival (Chaves *et al.,* 2003).

The study of water use efficiency ($A_{net}/g_s$) becomes particularly conspicuous in situations where growth is affected by limiting water availability (Anyia and Herzog, 2004). Maximum water use efficiency is achieved at the limit between diffusional and metabolic limitation to photosynthesis (Flexas *et al.,* 2004).

As the water content of the plant decreases, the cells shrink and cell wall relaxes, to result in turgor maintenance. On the other hand, water stress limits the size of individual leaves, leaf number (Tiaz and Ziger, 1998; Pellegrino *et al.,* 2005) and shoot growth (Pereira and Chaves, 1995). Greater leaf mass area across the woody species set as greater allocation of support and defense functions (Castro-diez *et al.,* 2000). In Mediterranean vegetation, this is often related to leaf resistance to dry conditions (Niinemets, 2001; Wright *et al.,* 2004).

Grapevine cultivars have been deemed to be adapted to arid conditions and produce high yield and product quality under non-optimal conditions (Gomez del *et al.,* 2004). Grapevine avoiding water stress deployed a range of physiological mechanisms in response to stress (Schultz, 1996). The selection of the best cultivar, based on ecophysiological drought stress characterization, is of ultimate importance for poetizing the production in dry environments. "Khoshnave" vineyards in west of Iran are typically non-irrigated but "Bidane-Sefid" and "Askari" vineyards are. To the best of authors' knowledge, net photosynthesis response, and thus indirect productivity, to drought stress in the three grape cultivars ("Khoshnave", "Bidane-Sefid" and "Askar") has not yet been studied. Therefore the aim of the present study was to compare photosynthetic gas exchange patterns of the three grape cultivars ("Khoshnave", "Bidane-Sefid" and "Askar")) to the progressive water deficit regimes and subsequent recovery period across the west parts of Iran.

## MATERIALS AND METHODS

Two-year-old, own-rooted plants of three grape (*Vitis vinifera* L.) cultivars ("Khoshnave", "Bidane-Sefid" and "Askar") were grown outdoor in the experimental site of the Department of Horticulture, University of Kurdistan, Sanandaj, Iran. The plants were grown in 18 L plastic pots (one plant per pot) filled with loamy soil. Pots were randomly and periodically rotated to minimize the effect of environmental heterogeneity. The trees were watered equally until June 2008 and then were subjected to a progressive drought stress. The experiment was comprised of factorial combinations of three cultivars by four watering regimes in a randomized complete block design. Water stress was imposed by withholding water from the plants until soil water potential reached -0.2 (CT), -0.6 (S1), -1 (S2) and -1.5 (S3) MPa during June-July 2008. Soil water content was determined through gypsum block and TDR (Time Domain Reflectometry). The physiological measurements were made in the four drought stress treatments, one as well as four days after rewatering. All measurements were made on sunny days using the fully irradiated youngest mature leaf ($5^{th}$ to $7^{th}$ leaf from apex).

Leaf relative water content (RWC) was estimated gravimetrically according to the method of Galmes *et al.* (2007). Leaf membrane stability index (MSI) was determined according to the method of Premchandra *et al.* (1990) modified by Sairam (1994). To measure leaf emergence rate, number of leaves produced during the experiment was counted (Pellegrino *et al.,* 2005).





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Leaf mass area (LMA) was calculated in four fully expanded young leaves from different plants of each species under different drought stress treatments. Leaf area was determined with an AM-100 leaf area meter (Light box model, Delta t) and then, the dry masses of these leaves were determined after oven drying for 24 hours at 70°C. LMA was calculated as the ratio of dry mass/leaf area (Muraoka *et al.,* 2002; Galmes *et al.,* 2007).

Leaf gas exchange measurements were made in the middle of the day at 11 am in the summer (with clear sky). For each treatment, six plants were transferred outdoors under natural irradiance. Net photosynthesis ($A_{net}$), stomatal conductance ($g_s$), transpiration rate (E) and intercellular $CO_2$ concentration ($C_i$) were also measured. Water use efficiency was calculated as the ratio of $A_{net}/g_s$. Measurements were performed on two well exposed and fully expanded mature but topmost leaves of each plant using a portable IRGA (LCA-4, Analytical Development Co., Hoddesdon, England). From the data collected, charts and curve fittings were performed using Microsoft Excel software and comparisons among the means were statistically analyzed using a factorial based on complete block design through SAS. Treatment means were compared using least significant difference test at 5% significance level.

## REAULTS AND DISCUSSION

The three investigated grape cultivars here showed a clear difference in their response to different applied drought stress levels. RWC did not show significant differences among the cultivars and different drought stress treatments, however, "Askari" had a lower RWC than those in "Khoshnave" and "Bidane-Sefid" (Table 1). The results demonstrated 4.3%, 5.7% and 4.0% reductions in RWC levels for "Khoshnave", "Askari" and "Bidane-Sefid", respectively, at S3 treatment as compared to control. On

**Table 1**. Means of relative water content (RWC), membrane cell stability index (MSI), leaf emergence rate and leaf mass area (LMA) for each of the three grape cultivars under different drought stress treatments.

| | RWC (%) | MSI (%) | Leaf number | Leaf mass area ( mg cm$^{-2}$ ) |
|---|---|---|---|---|
| 'Khoshnave' | | | | |
| CT | 89.95±0.67a | 77.38±0.69bc | 10.17±0.726a | 7.491±0.35a |
| S1 | 89.32±0.07ab | 78.99±0.51ab | 8.00±0.00b | 7.17±0.34ab |
| S2 | 88.16±0.17abc | 78.35±0.64ab | 8.33±0.17b | 6.62±0.07bc |
| S3 | 86.20±0.67cd | 74.04±0.64e | 5.83±0.17c | 6.09±0.04cd |
| 'Askari' | | | | |
| CT | 87.86±1.79abc | 78.06±0.37ab | 7.83±0.17b | 5.79±0.24de |
| S1 | 88.58±0.09abc | 80.00±0.513a | 8.00±0.50b | 5.26±0.41ef |
| S2 | 87.45±0.36abcd | 77.31±1.25bcd | 5.33±0.44c | 4.71±0.34fgh |
| S3 | 82.87±0.53e | 75.65±1.15cde | 4.00±0.29d | 4.88f±0.24fgh |
| 'Bidane-Sefid' | | | | |
| CT | 88.59±2.16abc | 77.85±0.12abc | 7.67±0.17b | 5.16±0.07efg |
| S1 | 88.97±0.22ab | 79.80±0.71a | 6.00±0.29c | 4.93±0.52fgh |
| S2 | 86.82±0.86bcd | 75.16±0.16de | 5.67±0.17c | 4.38±0.12gh |
| S3 | 85.14±0.55de | 71.74±0.90f | 3.00±0.00e | 4.32±0.24h |

Each value is a mean of 9 measurements. CT, S1, S2 and S3 indicate the different application of drought stress levels, with a water potential of soil of -0.2, -0.6, -1 and -1.5 MPa, respectively; values are measured only during stress treatment (CT, S1, S2 and S3) and before the subsequent recovery period. Within a column, values followed by different letters are significantly different (P≤ 0.05).

the other hand, the reductions in $A_{net}$ at S3 treatment and as compared with control were 97.6%, 97.2% and 99.3% for "Khoshnave", "Askari" and "Bidane-sefid", respectively. The smallest change in leaf RWC in reaction to drought stress was observed for these three grape cultivars, indicating a hydro stable nature, typical for drought avoiding species. In some species like grapevine, $A_{net}$ progressively declines during water stress, which is also accompanied by very low reduction in RWC (Flexas *et al.,* 2004). Among such C3 plants as grapevine, water-stress-induced changes in photosynthetic rate can be more generally related to variation in $g_s$ under light saturation conditions than to RWC or leaf water potential (Flexas *et al.,* 2004). Ghaderi *et al*. (2005) observed no significant differences in RWC under different drought stress regimes in grapevine when the amount of $A_{net}$ was reduced sharply. On the other hand, the isohydric behavior would be expected to limit the range of leaf water potential response to the differences in soil water content induced by irrigation treatment in grape (Sousa *et al.,* 2006). Significant differences in MSI (Table 1) was not observed among the three cultivars except in S2 and S3 treatments in which "Khoshnave" had a higher MSI than "Bidane-sefid". In the current study, a reduction in MSI at S3 treatment coincided with RWC decline. The reduction in cell membrane stability, with increasing drought stress, was also reported by Hura *et al.* (2007), and Pereira and Chaves (1995).

A progressive reduction in the rate of $A_{net}$ and $g_s$ was observed in the studied cultivars. Mean values of $A_{net}$ for plants not exposed to drought stress were 14.2, 12.5 and 11.6 μmol $CO_2$ $m^{-2}$ $s^{-1}$, respectively, for "Khoshnave", "Askari" and "Bidane-Sefid" (Table 2). The values of $A_{net}$ in the three cultivars were similar at the highest drought stress applied in this experiment. From Table 2, it can be seen that "Askari" and "Bidane-Sefid" had the largest reductions in $A_{net}$ as a consequence of drought stress imposed under S2 conditions. Maximal reductions in $A_{net}$ for all cultivars were observed at S3. A comparison of S2 values

**Table 2**. Mean values of net photosynthetic rate ($A_{net}$), stomatal conductance ($g_s$) and water use efficiency ($A_{net}/g_s$) for each of the three grape cultivars under different drought stress treatments.

| | $A_{net}$ (μmol $CO_2$ $m^{-2}$ $S^{-1}$) | $g_s$ (mmol $H_2O$ $m^{-2}$ $S^{-1}$) | ($A_{net}/g_s$) [ μmol ($CO_2$) $mol^{-1}$ ($H_2O$)] |
|---|---|---|---|
| "Khoshnave" | | | |
| CT | 14.17±0.35a | 537.30±14.90b | 26.38±1.04de |
| S1 | 10.46±0.71c | 201.70±21.07d | 52.32±2.67c |
| S2 | 4.053±0.28e | 42.33±6.36f | 98.55±10.95a |
| S3 | 0.34±0.02g | 10.00±0.00fg | 34.33±1.67d |
| "Askari" | | | |
| CT | 12.46±0.71b | 346.00±24.00c | 36.07±0.50d |
| S1 | 8.64±0.08d | 157.30±11.57e | 55.41±3.40c |
| S2 | 2.94±0.09f | 31.67±4.18fg | 95.10±8.58a |
| S3 | 0.36±0.02g | 16.67±2.03fg | 21.99±1.71de |
| "Bidane-Sefid" | | | |
| CT | 11.60±0.08b | 593.30±31.79a | 19.69±1.26e |
| S1 | 10.44±0.44c | 205.70±6.33d | 50.80±1.75c |
| S2 | 2.19±0.14f | 28.33±1.67fg | 77.87±6.84b |
| S3 | 0.02±0.00g | 4.00±0.00g | 5.00±0.00f |

Each value is the mean obtained from 18 measurements. CT, S1, S2 and S3 indicate the different application of drought stress levels, with a water potential of soil at -0.2, -0.6, -1 and -1.5 MPa, respectively; they were measured at PAR intensities above 1000 μmol $m^{-2}s^{-1}$. Within a column, values followed by different letters are significantly different (P≤ 0.05).

with *CT* ones obtained indicated that 71.4%, 76.4% and 81.1% reductions in $A_{net}$ were obtained for "Khoshnave", "Askari" and "Bidane-sefid", respectively. During the experimental period, $g_s$ values were the highest for *CT* when compared to the other treatments. In S2-plants, $g_s$ decreased dramatically to below the threshold of 0.05 mol of $H_2O$ $m^{-2}$ $s^{-1}$ that generally identifies the stage at which metabolic limitation of photosynthesis occurs (Flexas *et al.,* 2004). The gradual decrease in $A_{net}$ and $g_s$ values with increasing drought stress, even at low drought stress levels, is a characteristic response of drought-adapted plants, as it has often been documented in almond (Rouhi *et al.,* 2007; Romero *et al.,* 2004). A close relationship between $A_{net}$ and $g_s$, as observed in this study (Figure 1) was also documented for grapevine (Escalona *et al.,* 1999). Therefore, based on these results it seems that "Khoshnave" had a higher stability in $A_{net}$ reduction and a more stable assimilation behavior as compared to other cultivars. Higher relationship between $A_{net}$ and $g_s$ for "Khoshnave" (Figure 1) may be related to higher resistance of this cultivar to drought stress. According to Chaves (1991), this close relationship between $A_{net}$ and $g_s$ is also a common feature of drought-adapted species. Use of $g_s$ as an indicator of the intensity of water stress has revealed a more general pattern of photosynthetic response to progressive water stress that is somewhat independent of the water stress imposition, the environmental conditions and the genotype. In fact, *it is* $g_s$ response to many internal and external factors involved in hormonal signaling, which makes $g_s$ an integrative parameter of all the signals associated with the plant responding to water stress (Flexas *et al.,* 2004). Bacelar *et al.* (2007) documented that water stress caused a marked decline on the photosynthetic and stomatal conductance in olive.

Reduction of $A_{net}$ and $g_s$ was accompanied by an initial reduction of $C_i$ and then an increase in $C_i$ in the three cultivars (Table 3). This indicated that for these cultivars stomatal conductance is the dominant factor that limits assimilation, irrespective of any

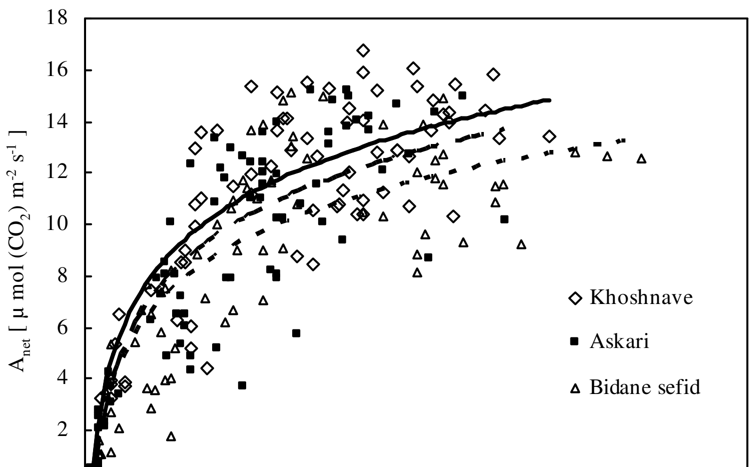


**Figure 1.** Relationship between net photosynthesis ($A_{net}$) and stomatal conductance ($g_s$) in three grape cultivars; "Khoshnave" (upper line), "Askari" (middle line) and "Bidane-Sefid" (lower line). Each symbol is a tow measurement for par intensities above 1000 µmolm$^{-2}$s$^{-1}$. Regression equations were: *y= 3.5231Ln(x)+16.088,* $R^2$*= 0.8339* ("Khoshnave"); *y= 3.5443Ln(x)+15.305,*$R^2$*= 0.7622* ("Askari"); *y= 3.1666Ln(x)+13.906,* $R^2$*= 0.7919* ("Bidane-Sefid")

**Table 3.** Mean values of transpiration (E) and intercellular $CO_2$ concentration ($C_i$) for each of the three grape cultivars under the different drought stress treatments.

| | E (mmol $H_2O$ $m^{-2}S^{-1}$ ) | $C_i$ (µmol $mol^{-1}$) |
|---|---|---|
| "Khoshnave" | | |
| CT | 10.77±0.61a | 263.30±8.34cd |
| S1 | 6.53±0.47c | 214.90±8.03efg |
| S2 | 3.20±0.49d | 202.50±15.40fg |
| S3 | 0.58±0.06e | 340.00±7.11b |
| "Askari" | | |
| CT | 8.21±0.95b | 231.30±7.38ef |
| S1 | 5.73±0.34c | 219.20±4.80efg |
| S2 | 2.05±0.10d | 196.10±3.23g |
| S3 | 0.68±0.05e | 357.00±12.92b |
| "Bidane-Sefid" | | |
| CT | 10.90±0.66a | 281.60±19.96c |
| S1 | 6.78±0.09c | 237.50±1.97de |
| S2 | 2.23±0.04d | 240.10±4.06de |
| S3 | 0.46±0.02e | 454.00±12.84a |

Each value is a mean determined from 18 measurements. CT, S1, S2 and S3 indicate the different application of drought stress levels, with a water potential of soil at -0.2, -0.6, -1 and -1.5 MPa, respectively; they were measured at PAR intensities above 1000 µmol $m^{-2}s^{-1}$. In each column, values followed by different letters are significantly different (P≤ 0.05).

metabolic impairment until S3 conditions. The consequence of increase $C_i$ in the three cultivars specially in "Bidane-Sefid" suggests an initial decrease of $CO_2$ availability at mesophyll level caused by stomatal closure, followed by a non-stomatal limitation for $CO_2$ assimilation which may be the principle cause for increase $C_i$. According to Ramanjulu *et al.* (1998) this increase $C_i$ indicates a decrease of carboxylation efficiency. This would mean that at these drought stress levels non-stomatal limitation is dominant in these cultivars. $A_{net}$ further decreases when $g_s$ drops to between 0.15 and 0.05 mol $H_2O$ $m^{-2}$ $s^{-1}$. A continuous decline in sub-stomatal $CO_2$ concentration suggests that stomatal closure is still the dominant limitation for photosynthesis. In this stage, water use efficiency still increased in all cultivars studied in this experiment and reached its maximum values at $g_s$ 0.05 mol of $H_2O$ $m^{-2}$ $s^{-1}$ (Table 2). The above results are consistent with the results obtained by Flexas *et al.* (2004). Increasing $C_i$ in S3 treatment obtained at $g_s$ below 0.05 mol $H_2O$ $m^{-2}s^{-1}$ showed that may be due to photosynthesis impairment.

Higher LMA in "Khoshnave" (Table 1) might contribute to the higher potential for carbon absorption and higher tolerance to drought as compared with the other two cultivars. High leaf mass area values in Mediterranean vegetation are often related to leaf resistance to dry conditions (Niinemets, 2001). According to the results of this study, low water availability affected leaf emergence rate (Table 1). "Khoshnave" had the highest leaf emergence rate during the stress period, this response may be related to the higher $A_{net}$ in this cultivar. "Askari" also produced a higher leaf emergence rate than "Bidane-sefid". Drought stress reduced both leaf area and number (Tiaz and Ziger, 1998). Pellegrino *et al.* (2005) reported that leaf emergence rate of grape was the most sensitive to drought stress. Differences among MSI, $A_{net}$ and $C_i$ in the three cultivars under similar drought stress plans showed that "Khoshnave" has an array of tolerance mechanisms during drought stress period. Transpiration (E) clearly decreased as a





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response to increasing drought stress (Table 3). *E* values for S1, S2 and S3 were not significantly different among the cultivars. E reduction under drought stress is one of the plant responses for water maintenance (Bacelar et al., 2007). Similar results have been reported for apple (Sircelj *et al.,* 2007).

"Bidane-Sefid" had a lower power for recovery of $A_{net}$ after rewatering under severe drought stress (Table 4). A higher percent of $A_{net}$ recovery after drought for "Khoshnave" can be related to the greater tolerance of this cultivar to drought. According to Torrecillas *et al.* (1996), rapid recovery of $A_{net}$ after stress conditions can be related to a greater physiological tolerance to drought. In the present study, when $g_s$ was lower than 0.05 mol of $H_2O$ $m^{-2}s^{-1}$ $A_{net}$ didn't reover one day after rewatering. However, four days after rewatering of the plants, $A_{net}$ recovered completely for S2 but not for S3. Therefore, it is expected that under severe drought stress, at least four days after rewatering was needed for complete recovery of $A_{net}$ in grape. Flexas *et al.* (2004) reported complete recovery of $A_{net}$ four days after rewatering under severe drought stress, not similar to the present results. This difference shows that $A_{net}$ recovery is dependent on the drought severity and the type of cultivars. Similar results have been reported for almond (Romero *et al.,* 2004). Rouhi *et al.* (2007) mentions that recovery of $A_{net}$ rate after severe drought stress did not happen three weeks after rewatering for almond. Stomatal conductance ($g_s$) of the plants studied in the present study showed a slow rate of recovery as compared with $A_{net}$ recovery. "Bidane-Sefid" had significantly a lower percent of $g_s$ recovery compared with the other two cultivars (Table 4). These results show that $A_{net}$ recovery was quicker than $g_s$ recovery in "Khoshnave" but $A_{net}$ and $g_s$ recovery were similar in "Askar" and "Bidane-Sefid". Flexas *et al.* (2004) reported that $g_s$ recovery was similar to $A_{net}$ recovery. Such differences in the results may be related to the experimental conditions and also to the type of cultivars. The drought induced alteration in bulk of abscisic acid may explain the slow stomatal recovery, that could be a result of the persistent effects of that hormone produced during the water stress period (Miller *et al.,* 1998). Montanaro *et al.* (2007) reported that $A_{net}$ recovered to values up to 80% of irrigated plants by day 2 after rewatering in Kiwifruit, but $g_s$ of these plants showed a slow rate of recovery even 13 days after irrigation was reinitiated.

**Table 4**. Net photosynthesis rate ($A_{net}$) and stomatal conductance ($g_s$) of water-stressed plants as % of irrigated plants during one and four days after rewatering.

| | One day after rewatering | | Four days after rewatering | |
|---|---|---|---|---|
| | $A_{net}$ recovery (%) | $g_s$ recovery (%) | $A_{net}$ recovery (%) | $g_s$ recovery (%) |
| "Khoshnave" | | | | |
| S1recovery | 94.95±2.56a | 66.59±0.99b | - | - |
| S2recovery | 82.42±2.27b | 65.92±3.49b | 100.00±0.00a | 84.75± 4.38b |
| S3recovery | 58.63±6.59cd | 41.93±2.65c | 87.63±2.49bc | 71.87b±4.89bc |
| "Askari" | | | | |
| S1recovery | 97.54±1.24a | 83.6±7.75a | - | - |
| S2recovery | 68.41±1.44c | 60.46±3.85b | 97.43±2.57ab | 98.83±1.17a |
| S3recovery | 53.33±4.94d | 58.93±2.13b | 88.09±6.55abc | 98.47±1.53a |
| "Bidane-Sefid" | | | | |
| S1recovery | 99.72±0.28a | 60.20±2.53b | - | - |
| S2recovery | 47.99±4.55de | 25.78±1.22d | 100.00±0.00a | 82.99±6.48b |
| S3recovery | 41.01±4.09e | 16.55±0.91e | 83.18±3.74c | 61.23±4.64c |

Measurements were taken at PAR intensities above 1000 μmol $m^{-2}$ $s^{-1}$. Each value is a mean determined from 18 measurements. In each column, values followed by different letters are significantly different, ($P \leq 0.05$).

"Khoshnave" had higher $A_{net}/g_s$ than "Bidane-Sefid" at S2 conditions (Table 2). The valus of $A_{net}/g_s$ were significantly higher for "Khoshnave" than for "Askari" and "Bidane-Sefid" at S3. The increase of $A_{net}/g_s$ under water stress is attributed to biomass production being less reduced by drought than water use (Anyia and Herzog, 2004). This cultivar ("Khoshnave") characterized by a high value of $A_{net}/g_s$ appears to be the most promising for production on relatively dry sites. Increasing of $A_{net}/g_s$ under mild drought stress is a response more typical of an isohydric strategy (Poni *et al.,* 2007).

From the behavior of cultivars in the present study, it is considered that "Khoshnave" is promising for cultivation in rain-fed areas in west Iran as compared to "Askari" and "Bidane-Sefid". "Bidane-Sefid" indicated the lowest suitibility for cultivation in these conditions. Further research especially under field conditions is needed to support this statement.

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# واکنش فیزیولوژیکی سه رقم انگور ایرانی به تنش خشکی فزاینده

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## چکیده

ارزیابی نقش تنش آبی بر خصوصیات فیزیولوژیکی گیاه ممکن است اساس ارزیابی مقاومت به خشکی را فراهم کند. تفاوت در میزان برگ تولید شده، محتوای نسبی آب برگ (RWC)، شاخص پایداری غشاء سلولی (MSI)، نسبت وزن به سطح برگ [Leaf mass area (LMA)]، میزان فتوسنتز ($A_{net}$)، هدایت روزنه ای ($g_s$)، تعرق (E)، $CO_2$ زیر روزنه ای ($C_i$)، کارایی مصرف آب ($A_{net/}$ $g_s$) و بازیابی فتوسنتز و هدایت روزنه‌ای در سه رقم انگور دوساله ( خوشناو، بیدانه سفید و عسکری) تحت تنش خشکی فزاینده ( ۰/۲-، ۰/۶-، ۱- و ۱/۵- مگاپاسکال) مورد ارزیابی قرار گرفتند. نتایج، کاهش MSI ،RWC، میزان تولید برگ، LMA، $A_{net}$، $g_s$ و E را تحت تنش خشکی را نشان داد. این در حالی بود که میزان $C_i$ ابتدا کاهش و تحت شرایط تنش شدید خشکی (۱/۵- مگاپاسکال) افزایش یافت. رقم خوشناو میزان $A_{net}$ بیشتری در مقایسه با رقم بیدانه سفید و عسکری داشت. LMA بیشتر رقم خوشناو ممکن است به این رقم در افزایش قابلیت فراوری کربن و داشتن $A_{net}$ بیشتر در مقایسه با دو رقم دیگر کمک کرده باشد. بازیابی کامل فتوسنتز برای هر سه رقم یک روز بعد از آبیاری مجدد در تیمار ۰/۶- مگاپاسکال و چهار روز بعد از آبیاری مجدد در تیمار۱- مگاپاسکال روی داد. بازیابی کامل $g_s$یک و چهار روز بعد از آبیاری مجدد در هیچکدام از ارقام مورد مطالعه روی نداد. نتایج نشان داد که در رقم خوشناو بازیابی$A_{net}$ در مقایسه با دو رقم دیگر سریعتر صورت گرفت. $A_{net}/g_s$ تحت تیمار ۱- مگاپاسکال در هر سه رقم بالاترین میزان بود. الگوی مشابه تغییرات $A_{net}/g_s$ در هر سه رقم وجود داشت. تحت شرایط تنش شدید رقم خوشناو دارای کارایی مصرف آب بیشتری در مقایسه با دو رقم دیگر بود. بر اساس واکنشهای رقم خوشناو به مقادیر مختلف تنش خشکی ($A_{net}$ بالاتر، میزان تولید برگ بیشتر، LMA بیشتر، بازیابی سریعتر $A_{net}$ و کارایی مصرف آب بیشتر به نظر می رسد که این رقم برای کشت در شرایط دیم در غرب ایران در مقایسه با دو رقم دیگر مناسب تر باشد.





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