

## Effect of water-deficit stress on fruit yield, antioxidant activity, and some physiological traits of four Iranian melon genotypes

Taher Barzegar<sup>1\*</sup>, Hadi Lotfi<sup>2</sup>, Vali Rabiei<sup>3</sup>, Zahra Ghahremani<sup>1</sup> and Jafar Nikbakht<sup>4</sup>

1, 2, 3. Assistant Professor, M. Sc. Student and Associate Professor, Department of Horticultural Sciences, Faculty of Agriculture, University of Zanjan, Zanjan, Iran

4. Associate Professor, Department of Water Engineering Sciences, Faculty of Agriculture, University of Zanjan, Zanjan, Iran

(Received: May 1, 2016 - Accepted: Jul. 10, 2016)

### ABSTRACT

To evaluate the effect of water-deficit stress on the yield, antioxidant activity, and physiological traits of four Iranian melon genotypes ("Khatooni," "Suski-Sabz," "Zarde-Tabriz," and "Shiari"), an experiment was conducted. The irrigation levels were: (1) control (100%ETc); (2) deficit irrigation 66% (66%ETc); and (3) deficit irrigation 33% (33%ETc). The results showed that the yield and relative water content (RWC) significantly decreased in response to an increase in water-deficit stress. The highest yield reduction (60.7%) was measured in Khatooni under 33% ETc deficit irrigation. Water deficit had no significant effect on the Vitamin C content. Among genotypes, the highest value of Vitamin C was seen in Suski-Sabz. Water-use efficiency (WUE) increased under water-deficit stress conditions with higher WUE values recorded in the Suski-Sabz and Shiari genotypes. Significant proline accumulation was detected with increasing water-deficit stress and the highest value of proline was obtained in Shiari under 33%ETc deficit irrigation. The increase in water-deficit stress resulted in higher catalase and peroxidase activities in all genotypes. According to the results, the Suski-Sabz and Shiari genotypes showed the lowest yield reduction respectively, related to high antioxidant enzyme activity and proline accumulation under water-deficit conditions.

**Keywords:** Deficit irrigation, proline accumulation, water-use efficiency, yield.

### اثر تنش کم آبی بر عملکرد، فعالیت آنتی اکسیدانی و برخی شاخص‌های فیزیولوژیکی چهار ژنوتیپ خربزه ایرانی

طاهر برزگر<sup>۱\*</sup>، هادی لطفی<sup>۲</sup>، ولی ربیعی<sup>۳</sup>، زهرا قهرمانی<sup>۱</sup> و جعفر نیکبخت<sup>۴</sup>

۱، ۲ و ۳. استادیار، دانشجوی کارشناسی ارشد و دانشیار، گروه علوم باغبانی، دانشکده کشاورزی، دانشگاه زنجان، زنجان، ایران

۴. دانشیار، گروه علوم مهندسی آب، دانشکده کشاورزی، دانشگاه زنجان، زنجان، ایران

(تاریخ دریافت: ۱۳۹۵/۲/۱۲ - تاریخ پذیرش: ۱۳۹۵/۴/۲۰)

### چکیده

به منظور مطالعه اثر تنش کم آبی بر عملکرد، فعالیت آنتی اکسیدانی، کارایی مصرف آب و برخی شاخص‌های فیزیولوژیکی چهار ژنوتیپ خربزه ایرانی (خاتونی، سوسکی سبز، زرد تبریز و شیاری) آزمایشی بصورت کرت‌های خرد شده در قالب طرح بلوک‌های کامل تصادفی در ۳ تکرار در ایستگاه تحقیقاتی دانشکده کشاورزی دانشگاه زنجان در سال ۱۳۹۳ انجام شد. تیمارهای آبیاری شامل سه سطح ۳۳، ۶۶ و ۱۰۰ درصد نیاز آبی گیاه بود. نتایج نشان داد که افزایش تنش کم آبی، عملکرد و محتوای نسبی آب برگ را کاهش داد. بیشترین کاهش عملکرد (۶۰/۷ درصد) در ژنوتیپ خاتونی در شرایط تنش آبی ۳۳٪ نیاز آبی گیاه حاصل شد. تنش آبی تاثیر معنی‌داری بر محتوای ویتامین ث نداشت و در بین ژنوتیپ‌ها، بیشترین مقدار ویتامین ث در ژنوتیپ سوسکی سبز مشاهده گردید. کارایی مصرف آب در شرایط تنش کم آبی افزایش یافت و حداکثر کارایی مصرف آب در ژنوتیپ‌های سوسکی سبز و شیاری ثبت گردید. با افزایش تنش کم آبی، محتوای پرولین افزایش یافت و بالاترین مقدار آن در ژنوتیپ شیاری در آبیاری ۳۳٪ نیاز آبی گیاه به دست آمد. با افزایش در تنش کم آبی، میزان فعالین آنزیمهای کاتالاز و پراکسیداز در همه ژنوتیپ‌ها افزایش یافت. با توجه به نتایج این پژوهش، ژنوتیپ‌های سوسکی سبز و شیاری با داشتن بیشترین فعالیت آنزیمی و تجمع پرولین در شرایط کم آبی، کمترین کاهش عملکرد را نشان دادند.

**واژه‌های کلیدی:** تجمع پرولین، کارایی مصرف آب، کم آبیاری، عملکرد.

## Introduction

Melons (*Cucumis melo* L.) are an important horticultural crop with a worldwide production of 31.92 million tons. Iran, with a total production of 1,450,000 tons, was the third-largest producer after China and Turkey in 2013 (FAO, 2013). Melon is an important fruit crop often cultivated in the arid and semiarid regions of Iran, where drought is one of the biggest environmental stresses, limiting the growth and fruit yield of melon.

Deficit irrigation, defined as a practice that applies water below full crop-water requirements, deliberately exposes plants to a certain level of moisture stress. Although deficit irrigation can reduce water consumption for the irrigation of annual and perennial crops and save a significant amount of irrigation water, there is also a risk of yield reduction in some crops and cultivars (Ferreles & Soriano, 2007). It is well known that drought stress results in dehydration of the cell and osmotic imbalance that impairs numerous metabolic and physiological processes in plants (Mahajan & Tuteja, 2005).

As drought stresses occur frequently, one of the mechanisms that have been developed in plants is the antioxidant defense system, which includes antioxidant enzymes and enzymatic activity of superoxide dismutases (SOD), peroxidases (POD), catalase (CAT), and ascorbate peroxidase (APX) in the shoot and root of plants, which increased during drought stress (Wang *et al.*, 2009).

Oxidative stress is one of the major causes of cellular damage in plants during stress (Miller *et al.*, 2010). However, to remove reactive oxygen species (ROS) and maintain redox homeostasis, plants have evolved a complex array of antioxidant defense

systems to prevent oxidative injury resulting from high levels of ROS, which includes antioxidative enzymes (Asada, 2006) and some compatible solutes such as betaines and proline. The defense systems may play a role in the protection of the cellular machinery against photo-oxidation by ROS and help the cells to maintain their hydrated state and, therefore, function to provide resistance against drought and cellular dehydration (Foyer & Noctor, 2005; Veljovic-Jovanovic *et al.*, 2006).

The feasibility of applying deficit irrigation to vegetable crops has been previously reported in the literature. In watermelons (*Citrullus lanatus* [Thunb]; Matsum & Nakai), deficit irrigation (75%ETc) saved 25% of irrigation water with a 34% reduction in yield (Leskovar *et al.*, 2004). Reduced irrigation volumes also caused a reduction in fruit size and yield in muskmelon cvs. Piel de sapo and Sancho (Fabeiro *et al.*, 2002; Cabello *et al.*, 2009). The highest squash yield was recorded under well-irrigated treatment (100%ETc) but non-significant differences were recorded between 100%ETc and 85%ETc irrigation. Therefore, under limited irrigation water, it is recommended to irrigate squash plants at 85%ETc irrigation to produce not only the same yields but also to save more water as compared to 100%ETc treatment (El-Mageed & Semida, 2015).

The application of proline on cucumber plant under salinity significantly increased PRO and CAT activities, and alleviated the growth inhibition of plants induced by NaCl (Huang *et al.*, 2009).

Sharma *et al.* (2014) evaluated yield and fruit quality responses of cvs. Mission (muskmelon; *reticulatus*), Da Vinci (tuscan; *reticulatus*), and Super Nectar (honeydew; *inodorus*) of melon

(*Cucumis melo* L.) to two irrigation rates (100%ETc and 50%ETc), and reported that deficit irrigation caused a 30% decrease in marketable yield, mainly due to a reduction in fruit size. Yield responses to deficit irrigation also varied with the cultivar.

Drought stress significantly decreased fruit yield, chlorophyll a, chlorophyll b, and total chlorophyll content, but increased proline accumulation in drought-stress conditions in all chickpea varieties investigated (Mafakheri *et al.*, 2010). Free proline contents increases under water and other environmental stress, and the accumulation of proline depends on the intensity of stress (Tamayo & Bonjoch, 2001).

Rouphael *et al.* (2008) reported that in grafted watermelon plants, yield water-use efficiency (WUE<sub>y</sub>) increased under water-stress conditions. Patil *et al.* (2014) studied the effect of seven and 14 days of water stress on the muskmelon variety Kundan and indicated that the water-use efficiency (WUE) of control was 0.23tha<sup>-1</sup>cm<sup>-1</sup>, and it decreased by 8.69% in seven days and 69.56% in 14 days of water stress during flowering. The WUE reduced markedly from 78.26% to 82.60% in seven to 14 days water stress in the fruiting phase, respectively.

To our knowledge, very little work has been carried out on the effect of water-deficit stress and its management on this Iranian melon. We expect this information will be useful for developing water-saving methods and producing high-quality melon fruit in Iran.

## Materials and methods

### Experimental site

A field experiment was conducted from June to September 2014 at the Research Farm of the Agriculture Faculty, University of Zanjan to study the effect of water-deficit stress on fruit yield,

antioxidant enzymes activities, WUE, proline, and Vitamin C content. The soil texture was sandy loam with 7.8 pH. The daily climate data during the growing season is shown in Figure 1.

### Plant materials and irrigation treatments

The experiment was done on a split plot model based on a completely randomized block design (three irrigation levels, four genotypes, and three replications). The three irrigation levels were calculated based on actual evapotranspiration (ETc): (1) control, irrigated 100% crop water requirement (I<sub>100</sub>), (2) deficit irrigation 66% ETc (I<sub>66</sub>), and (3) deficit irrigation 33% ETc (I<sub>33</sub>). The genotypes included four commercial Iranian melons, Khatooni, Suski-Sabz, Zarde-Tabriz, and Shiari (*Cucumis melo* L. Inodorous group), in the sub-plots.

Khatooni has a yellow-green netted skin and chimeric stripes; Zarde-Tabriz has a yellow netted skin; Suski-Sabz, with a green netted skin, is oblong in shape and large, weighing approximately 3–4kg per fruit at harvest time; and Shiari has a yellow semi-netted skin with deep stripes (Figure 2). The seeds for the experiment were collected from Iranian farmers in Azerbaijan and Mashhad. Fertilizers were delivered as a pre-plant base comprising 80kg N/ha, 50kg P/ha, and 80kg K/ha. The seeds were sown at 3–4cm depth, 50cm spacing in rows, with 200cm between rows on the farm. After the plants grew, at a very early stage they were pruned (removing the apex of the main stem), and trained to have two lateral branches.

All other necessary operations such as pests and weeds control were performed according to recommended package of practices during crop growth. The fruits were harvested when the color changed from green to yellow and the netted pattern appeared.

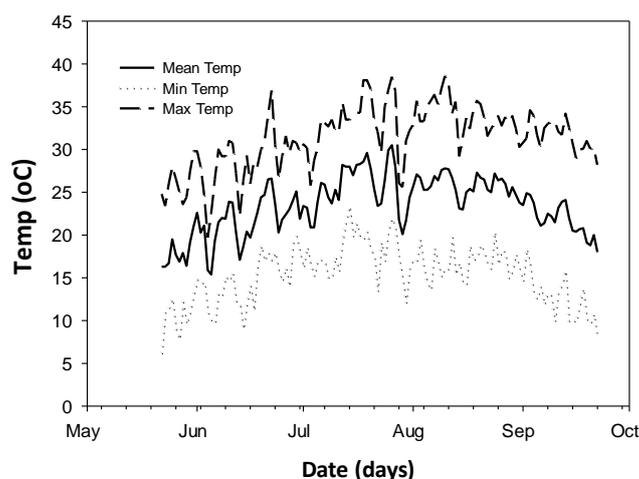


Figure 1. Mean, minimum and maximum temperatures ( $^{\circ}\text{C}$ ) during 2014 seasons, Zanjan, Iran.

### Fruit yield

The number of fruits per plant and fruit weight was measured to determine total yield. The total yield was expressed in  $\text{tonha}^{-1}$ .

### Proline content

The proline content was determined by the ninhydrin method (Bates *et al.*, 1973). Mature leaves of the plants were sampled 70 days after the onset of the experiment. Proline was extracted from a sample of 0.5g fresh leaf material samples in 3% (w/v) aqueous sulfosalicylic acid and

estimated using the ninhydrin reagent. The absorbance of fraction with toluene aspirated from the liquid phase was read at a wave length of 520nm. Proline concentration was determined using a calibration curve and expressed as  $\text{mmol proline g}^{-1}\text{FW}$ .

### Catalase and peroxidase enzymes activity

Samples were taken from the fully expanded leaf and transferred to the laboratory and put on ice. A leaf sample (0.5g) was frozen in liquid nitrogen and ground using a porcelain mortar and pestle.

CAT activity was measured by following the decomposition of  $\text{H}_2\text{O}_2$  at 240nm with a UV spectrophotometer

(Havir & McHale, 1987). Samples without  $\text{H}_2\text{O}_2$  were used as blank. The activity of CAT was calculated by the differences obtained at OD240 values at 30-second intervals for 2min after the initial biochemical reaction. POX activity was measured using the modified method of Tuna *et al.* (2008) with guaiacol at 470nm. A change of 0.01 units per minute in absorbance was considered to be equal to one unit of POD activity, which was expressed as U (unit)  $\text{mg}^{-1}$  protein.

### Leaf relative water content

Leaf relative water content (RWC) was determined by sampling the upper fully expanded young leaves at noon, according to Yamasaki and Dillenburg (1999). Leaf RWC was calculated according to the equation:

$$\text{RWC (\%)} = \frac{\text{fresh weight} - \text{dry weight}}{\text{saturated weight} - \text{dry weight}} \times 100$$

### Water-use efficiency

Based on total crop yield and water applied during the growth period, WUE was determined for all treatments. WUE was calculated as the fruit yield divided by the seasonal water applied (crop evapotranspiration).

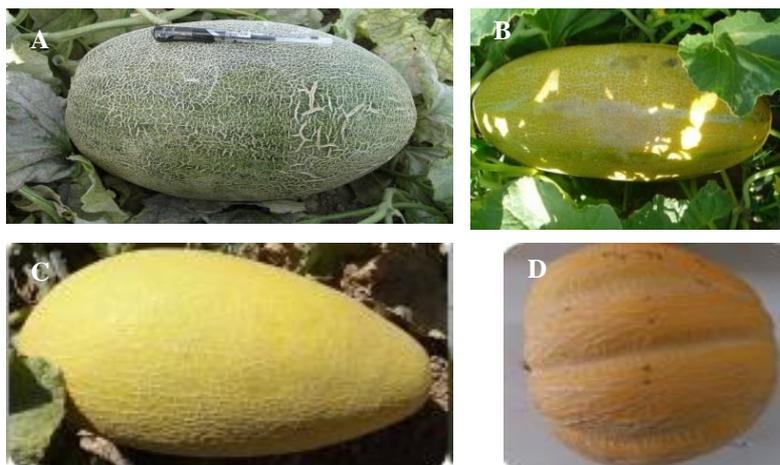


Figure 2. Iranian melon genotypes studied, A. "Suski-Sabz", B. "Khatooni", C. "Zarde-Tabriz" and D. "Shiari"

### Statistical analysis

For data analysis, a split plot model based on a completely randomized block design was used (three irrigation levels  $\times$  four genotypes  $\times$  three replications  $\times$  five observations per experimental unit). The data were analyzed using the SAS statistical program (SAS Institute Inc, Cary, NC, USA), and the means were compared by Duncan's multiple-range tests at 5% probability level. The values were expressed as mean $\pm$ SE (standard error).

## Results

### Yield

The total yields were significantly influenced by the irrigation rate. As an exception, the highest yield was obtained in control irrigation (100%ETc) (37,426.1kg.ha<sup>-1</sup>). Deficit irrigation significantly reduced the yield by 38.1% in 66%ETc and 56.5% in 33%ETc (Table 1). Among the genotypes, Khatooni produced the highest yield (28,514kg.ha<sup>-1</sup>) that had no significant difference with Suski-Sabz and Shiari (Table 1). Significant differences were observed on the irrigation rate  $\times$  genotype interaction for yield. Deficit irrigation (33% ETc) caused the highest reduction in yield in the Zarde-Tabriz genotype, 43% (p= 0.001) (Figure 3).

### Vitamin C

Deficit irrigation had no significant effect on Vitamin C content (Table 1). Genotype Suski-Sabz had the highest Vitamin C compared to other genotypes (Table 1). Irrigation  $\times$  genotype interactions had significant effect on the Vitamin C content (Figure 4). As the result indicated, the highest Vitamin C content was observed in Suski-Sabz at control irrigation that had no significant difference with 66%ETc and 33%ETc irrigation.

### Proline

Water-deficit stress significantly increased proline accumulation. In 33%ETc irrigation, the proline content was significantly higher (Table 1). Proline accumulation increased with increasing levels of water-deficit stress. There was a significant difference in the proline content among genotypes and the highest value was observed in Shiari (Table 1). The proline content of the leaf increased at all genotypes of melon in response to water-deficit stress (Figure 5). In control irrigation, the differences in proline content among all genotypes were significant. The highest level of proline was obtained from the Shiari genotype under 33% ETc irrigation (Figure 5).

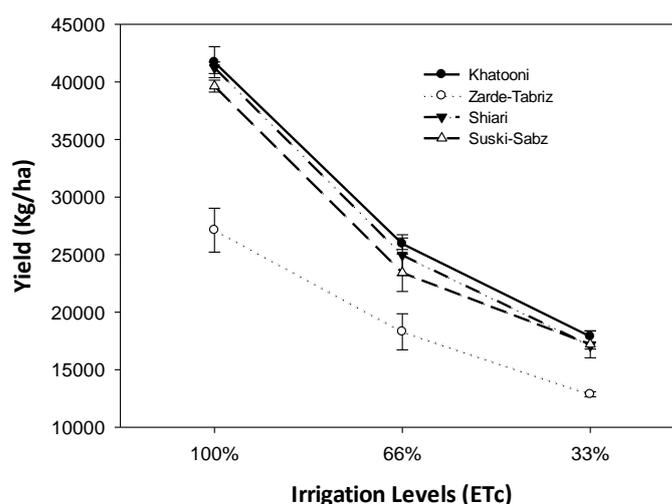


Figure 3. Effects of deficit irrigation based on evapotranspiration (ETc) rates on fruit yield of four melon genotypes. Values were the means of three replicates and bars represent the standard errors (n = 3).

Table 1. Main effects of deficit irrigation based on evapotranspiration (ETc) rates and genotypes on proline content, relative water content (RWC), vitamin C content, catalase (CAT) and peroxidase (POX) enzymes activities, yield and water use efficiency (WUE)

Treatments	Proline (mg g <sup>-1</sup> FW)	RWC (%)	Vitamin C (mg 100ml <sup>-1</sup> )	CAT (μmol H <sub>2</sub> O <sub>2</sub> .g <sup>-1</sup> FW.min <sup>-1</sup> )	POX (units.g <sup>-1</sup> FW.min <sup>-1</sup> )	WUE (kg m <sup>-3</sup> )	Yield (kg. ha <sup>-1</sup> )
<b>Irrigation rate</b>							
100% ETc	1.12±0.1 c	78.89±0.75 a	0.96±0.06 a	4.62±0.33 c	0.44±0.022 c	13.51±1.06 b	37426.1±188 a
66% ETc	1.81±0.12 b	73.53±0.56 b	0.93±0.05 a	6.99±0.41 b	0.53±0.015 b	13.27±1.37 b	23155.6±108 b
33% ETc	3.02±0.22 a	72.45±0.61c	0.86±0.05 a	8.66±0.22 a	0.73±0.046 a	17.51±0.91 a	16269.2±660 c
<b>Genotypes</b>							
Khatooni	1.41±0.18 d	76.42±0.58 a	0.86±0.03 b	6.21±0.62 b	0.57±0.06 a	15.63±0.83 a	26959±352 b
Zard-Tabriz	2.18±0.25 b	74.41±0.54 b	0.95±0.05 b	6.80±0.84 ab	0.56±0.034 a	11.62±1.12 b	19432±219 d
Shiari	2.54±0.38 a	74.64±2.06 b	0.73±0.03 c	6.47±0.70 b	0.53±0.051 a	16.94±1.77 a	28762±359 a
Suski-Sabz	1.79±0.33 c	74.35±1 b	1.13±0.03 a	7.56±0.51 a	0.61±0.07 a	14.86±1.37 ab	24759±339 c

Means in a column followed by the same letter are not significantly different at P<0.001 according the Duncan's multiple range tests.

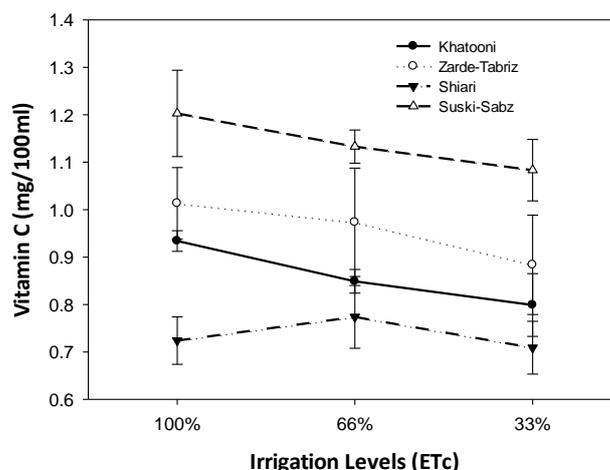


Figure 4. Proline (mg g<sup>-1</sup>FW) contents of four melon genotypes in control (100% Etc) and deficit irrigation (66% and 33% ETc). Values were the means of three replicates and bars represent the standard errors (n = 3).

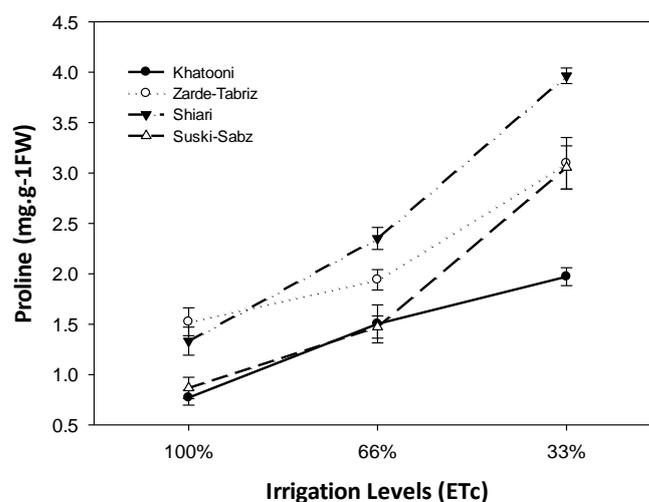


Figure 5. Vitamin C ( $\text{mg}\cdot 100\text{ml}^{-1}$ ) contents of four melon genotypes in control (100% Etc) and deficit irrigation (66% and 33% ETc). Values were the means of three replicates and bars represent the standard errors ( $n = 3$ ).

#### Catalase and peroxidase activity

The water-deficit stress increased the CAT activity compared to the control condition of irrigation. Significant differences were found among the genotypes. At the control condition of irrigation, the highest and lowest CAT activity was observed in genotype of Suski-Sabz and Khatooni, respectively (Table 1). CAT activity increased under deficit irrigation in all the genotypes compared to the activities occurring in the control plants. The highest value of CAT activity ( $8.98$  and  $8.93\mu\text{mol H}_2\text{O}_2\cdot\text{g}^{-1}\text{FW}\cdot\text{min}^{-1}$ ) was found in Suski-Sabz and Zarde-Tabriz under 33%ETc irrigation, respectively, that had no significant differences with the two other genotypes (Figure 6). Similar to CAT, POX activity increased in response to an increase in water-deficit stress (Table 1). While no significant differences were observed among genotypes for POX, the highest POX activity ( $0.811\text{units}\cdot\text{g}^{-1}\text{FW}\cdot\text{min}^{-1}$ ) was obtained in Suski-Sabz under 33%ETc irrigation (Figure 6).

#### Relative water content (RWC)

RWC was significantly affected by water-

deficit stress. The highest values were recorded in the control irrigation treatment in comparison to plants treated with deficit irrigation (Table 1). Among the genotypes at the optimum conditions of irrigation, the highest RWC (82.79%) was observed in Shiari, although the difference between the Khatooni and Suski-Sabz genotypes was not significant (Table 1). At both moderate and extreme water-deficit stress (66%ETc and 33%ETc irrigation), Khatooni had lower reduction in RWC compared with the control condition of irrigation (Figure 7).

#### Water-use efficiency (WUE)

The results showed in Table 1 that WUE was highly influenced by deficit irrigation. The highest WUE ( $17.51\text{kg}\cdot\text{m}^{-3}$ ) was found in irrigation level 33%ETc. The differences between genotypes were significant. The highest WUE ( $16.94\text{kg}\cdot\text{m}^{-3}$  and  $15.63\text{kg}\cdot\text{m}^{-3}$ ) were noted in the genotypes Shiari and Khatooni (Table 1). The interaction difference of irrigation and genotype was statistically significant. The genotypes Shiari and Suski-Sabz exhibited higher WUE in response to 33% ETc irrigation (Figure 8).

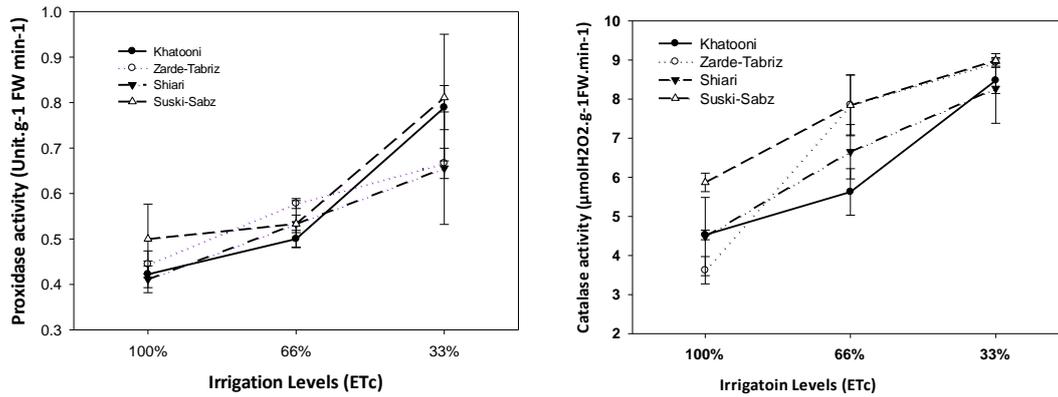


Figure 6. Changes in CAT ( $\mu\text{molH}_2\text{O}_2.\text{g}^{-1}\text{FW}.\text{min}^{-1}$ ) and POX ( $\text{unit}.\text{g}^{-1}\text{FW}.\text{min}^{-1}$ ) activity of four melon genotypes in control (100% Etc) and deficit irrigation (66% and 33% ETC). Values were the means of three replicates and bars represent the standard errors ( $n=3$ ).

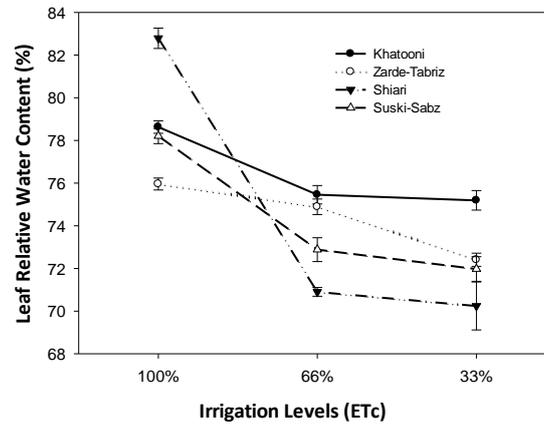


Figure 7. Relative water content (%) of leaves of four melon genotypes in control (100% Etc) and deficit irrigation (66% and 33% ETC). Values were the means of three replicates and bars represent the standard errors ( $n=3$ ).

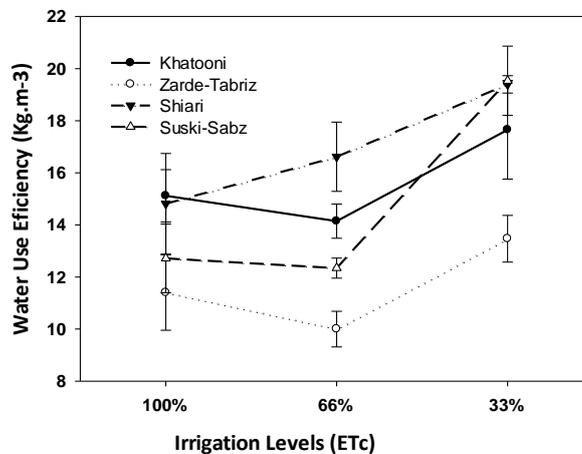


Figure 8. Water use efficiency ( $\text{kg m}^{-3}$ ) of four melon genotypes in control (100% Etc) and deficit irrigation (66% and 33% ETC). Values were the means of three replicates and bars represent the standard errors ( $n=3$ ).

### Discussion

The main aim of the present work was a better understanding of the physiological response of Iranian melon to water-deficit stress. In this study, the effect of water-deficit stress on the growth, proline content, WUE, RWC, Vitamin C content, and antioxidant enzyme activity of four Iranian melons were conducted.

Water-deficit stress caused significant reductions in yield (Table 1). Our results are in agreement with many open-field studies on watermelon (Leskovar *et al.*, 2004), cucumber (*Cucumis sativus* L.; Ertek *et al.*, 2006), melon (Yildirim *et al.*, 2009), and muskmelon (*Cucumis melo* L.; Fabeiro *et al.*, 2002). The fruit yield was highly influenced by the irrigation regime and deficit irrigation significantly reduced yield due to a reduction in the number of fruits per plant, fruit weight, and fruit size. The results of Sensoy *et al.* (2007) showed that the irrigation treatments had a significant effect on melon fruit yield, and a positive correlation was obtained between the melon fruit yield and irrigation treatment levels. Simsek and Comlekcioglu (2011) reported that the favorable yield obtained from using both the 80%ETc and 100%ETc irrigation levels might be due to adequate available soil moisture within the root zone that increases the various physiological processes such as better uptake of nutrients, plant growth, and photosynthesis rates, which lead to the best yields. The response of fruit yield to deficit irrigation differed among genotypes. Shiari showed high sensitivity to water deficit.

The effects of water-deficit stress on the proline content in plants of four genotypes were determined after 30 days' exposure to treatment. The increase in proline content was more in 33%ETc irrigation. So the proline content increased under water-deficit

stress that this amino acid plays a role as an osmotic compatible and adjust the osmotic potential in melon. Proline accumulation is believed to play adaptive roles in plant stress tolerance (Verbruggen & Hermans, 2008).

Accumulation of proline has been advocated as a parameter of selection for stress tolerance (Jaleel *et al.*, 2007). The proline that accumulated in the leaves under a water-limited environment is a cellular regulator helping to sustain the activity of the cell and tissue in water-deficit conditions by preventing injuries to the internal apparatus of cells (Ahmed *et al.*, 2009). In our study, the genotypes showed significant differences in the proline content (Figure 2). The Shiari genotype had the highest proline content and the lowest RWC. Our results agree with those of Reddy *et al.* (2004), who indicated that proline accumulation increased with a significant decrease in RWC and that this accumulation can maintain membrane integrity.

Water deficit can cause oxidative damage. CAT is the principal enzyme that scavenges harmful oxygen species in plants (Pereira *et al.*, 2002). The CAT activity generally increased in the melon genotypes under water-deficit stress conditions compared to the control irrigation. However, this increase was significantly lower in the sensitive melon genotypes than the tolerant ones. Antioxidative enzymes like POX and CAT play a major role in conferring drought tolerance, and the CAT and POX activity of drought-tolerance genotypes were higher than of sensitive genotypes under drought stress (Hameed *et al.*, 2013). In this study, no significant difference was found in POX activity among genotypes when exposed to water stress. However, POX activity was lower in the control irrigation and a significant difference was observed in water-deficit treatment

(Figure 6). The promotion of antioxidant activity is probably a defense response. It has been found that changes in antioxidant enzyme activities under drought stress are dependent on the severity and duration of the treatment, as well as on the species and the age of the plant (Pan *et al.*, 2006). Kavas *et al.* (2013) suggested that higher concentrations of CAT were induced by drought stress. The antioxidant activity of CAT plays a protective role for drought tolerance in melon that seems to keep the H<sub>2</sub>O<sub>2</sub> content at a certain level, inhibiting production of the free radicals that may lead to peroxidation of membrane lipids. It is evident that the increase in the level of antioxidative enzymes is at least one component of the mechanism of drought tolerance in most plants, and the mechanism of antioxidant production differs among species and even among cultivars of a single species (Huseynova, 2012).

RWC is considered an important criterion of plant water status. Under drought stress, leaf RWC plays an important role in the tolerance of plants to stress by inducing osmotic adjustments due to the accumulation of osmoprotectants (Barnabás *et al.*, 2008; Zhang *et al.*, 2012). The maintenance of a high plant water status during stress is an important defensive mechanism to retain enough water by minimizing water loss (e.g. caused by stomatal closure, trichomes, reduced leaf area, senescence of older leaves, etc.) and maximizing water uptake (e.g. by increased root growth) (Barnabás *et al.*, 2008). In our study, RWC in the leaves of water deficit-treated plants declined significantly ( $p \leq 0.001$ ). This decline was sharp under the applied 33%ETc irrigation (Table 1). Similarly, it is reported that drought stress and its interaction with species significantly affected the RWC, leading to a

significant decrease (Rahimi *et al.*, 2010). According to Khanna-Chopra and Selote (2007), under stress, drought-resistant wheat plants maintained higher turgor potential and RWC compared to sensitive genotypes. The differences in RWC in all genotypes could be associated with their ability to absorb water from soil. The genotype Khatooni had the highest RWC under severe water-stress conditions (33%ETc).

The physiological parameter of crop WUE is important to describe the relationship between plant water use and dry matter production (Cai & Starman, 2012). The highest WUE value was determined in 33%ETc irrigation. It was calculated that WUE values increased with the decrease in the amount of water. This result is similar to the previous finding of Zeng *et al.* (2009), who reported that the maximum WUE for potato was obtained with low irrigation. Yildirim *et al.* (2009) indicated that WUE decreased with an increase in the irrigation water applied. Increased WUE values under water-stress conditions were also found in mini-watermelon (Rouphael *et al.*, 2008), garden roses (Cai & Starman, 2012), and watermelon (Simsek *et al.*, 2004). With increased WUE, there is a greater biomass production per amount of water transpired, and less water is needed for growth and development (Nemali & van Iersel, 2008).

### Conclusions

In total, the results indicated that water-deficit stress significantly reduced yield and RWC, and increased the WUE, CAT, and POX activity, as well as the proline content of melon. In all of the investigated melon genotypes, fruit yield was reduced in deficit irrigation-treated plants and the highest reduction (60.7%) among genotypes was obtained in Khatooni.

Finally, because of the lower reduction of yield in Suski-Sabz and Shiari, these results suggest that (i) Suski-Sabz and Shiari are more tolerant genotypes respectively, (ii) drought tolerance in both genotypes might be closely related to an increase in capacity

for antioxidant (CAT, POX) enzyme activity and accumulation of proline, and (iii) also, tolerant genotypes had a high WUE. Comparing these responses will help to identify drought-tolerance mechanisms in Iranian melon genotypes.

## REFERENCES

1. Ahmed, C. B., Rouina, B. B., Sensoy, S., Boukhris, M. & Abdallah, F. B. (2009). Changes in gas exchange, proline accumulation and antioxidative enzyme activities in three olive cultivars under contrasting water availability regimes. *Environmental and Experimental Botany*, 67, 345-352.
2. Asada, K. (2006). Production and scavenging of reactive oxygen species in chloroplasts and their functions. *Plant Physiology*, 141, 391-396.
3. Barnabás, B., Jäger, K. & Fehér, A. (2008). The effect of drought and heat stress on reproductive processes in cereals. *Plant, Cell & Environment*, 31, 11-38.
4. Barzegar, T., Badeck, F.W., Delshad, M., Kashi, A. K., Berveiller, D. & Ghashghaie, J. (2013). <sup>13</sup>C-labelling of leaf photoassimilates to study the source-sink relationship in two Iranian melon cultivars. *Scientia Horticulturae*, 151, 157-164.
5. Bates, L., Waldren, R. P. & Teare, I. D. (1973). Rapid determination of free proline for water stress studies. *Plant and Soil*, 39, 205-207.
6. Cabello, M. J., Castellanos, M. T., Romojaro, F., MartínezMadrid, C. & Ribas, F. (2009). Yield and quality of melon grown under different irrigation and nitrogen rates. *Agricultural Water Management*, 96, 866-874.
7. Cai, X. & Starman, T. (2012). Response of selected garden roses to drought stress. *HortScience*, 47(8), 1050-1055.
8. El-Mageed, T. A. & Semida, W. M. (2015). Effect of deficit irrigation and growing seasons on plant water status, fruit yield and water use efficiency of squash under saline soil. *Scientia Horticulturae*, 186, 89-100.
9. Ertek, A., Sxensoy, S., Gedik, I. & Kyumuk, C. (2006). Irrigation scheduling based on pan evaporation values for cucumber (*Cucumis sativus* L.) grown under field conditions. *Agricultural Water Management*, 81, 159-172.
10. FAO. (2013). FAOSTAT. Available at <http://faostat3.fao.org/home/index.html> (accessed on 08.14.13).
11. Fabeiro, C., Martin, F. & De Juan, J. A. (2002). Production of muskmelon (*Cucumis melo* L.) under controlled deficit irrigation in a semiarid climate. *Agricultural Water Management*, 54, 93-105.
12. Fereres, E. & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany*, 58, 147-159.
13. Foyer, C. H. & Noctor, G. (2005). Oxidant and antioxidant signaling in plants: a reevaluation of the concept of oxidative stress in a physiological context. *Plant, Cell & Environment*, 28, 1056-1071.
14. Hameed, A., Goher, M. & Iqbal, N. (2013). Drought induced programmed cell death and associated changes in antioxidants, protease and lipid peroxidation in wheat leaves. *Plant Biology*, 57, 370-374.
15. Havir, E. A. & McHale, N. A. (1987). Biochemical and developmental characterization of multiple forms of catalase in tobacco leaves. *Plant Physiology*, 84 (2), 450-455.

16. Huang, C. J., Zhao, S. Y., Wang, L. C., Anjum, S. A., Chen, M., Zhou, H. F. & Zou, C. M. (2013). Alteration in chlorophyll fluorescence, lipid peroxidation and antioxidant enzymes activities in hybrid ramie (*Boehmeria nivea* L.) under drought stress. *Australian Journal of Crop Science*, 7, 594-599.
17. Hunag, Y., Zhilong, B., Zhixiong, L., Ai, Z. & Weijuan, W. (2009). Protective role of proline against salt stress is partially related to the improvement of water status and peroxidase enzyme activity in cucumber. *Soil Science & Plant Nutrition*, 55, 698-704.
18. Huseynova, I. M. (2012). Photosynthetic characteristics and enzymatic antioxidant capacity of leaves from wheat cultivars exposed to drought. *Bachelor of Business Administration*, 1817, 1516-1523.
19. Jaleel, C. A., Gopi, R., Sankar, B., Manivannan, P., Kishorekumar, A., Sridharan, R. & Panneerselvam, R. (2007). Studies on germination, seedling vigor, lipid peroxidation and proline metabolism in *Catharanthus roseus* seedlings under salt stress. *South African Journal of Botany*, 73, 190-195.
20. Kavas, M., Balogu, M. C., Akca, O., Kose, F. S. & Gokcay, D. (2013). Effect of drought stress on oxidative damage and antioxidant enzyme activity in melon seedlings. *Turkish Journal of Biology*, 37, 491-498.
21. Khanna-Chopra, R. & Selote, D. S. (2007). Acclimation to drought stress generates oxidative stress tolerance in drought resistant than susceptible wheat cultivar under field conditions. *Environmental and Experimental Botany*, 60, 276-283.
22. Leskovar, D., Bang, H., Crosby, K., Maness, N., Franco, J. & PerkinsVeazie, P. (2004). Lycopene, carbohydrates, ascorbic acid and yield components of diploid and triploid watermelon cultivars are affected by deficit irrigation. *Journal of Horticultural Science and Biotechnology*, 79, 75-81.
23. Mafakheri, A., Siosemardeh, A., Bahramnejad, B., Struik, P. C. & Sohrabi, Y. (2010). Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Australian Journal of Crop Science*, 4(8), 580-585.
24. Mahajan, S. & Tuteja, N. (2005). Cold, salinity and drought stresses: An overview. *Archives of Biochemistry and Biophysics*, 444, 139-158.
25. Miller, G., Suzuki, N., Ciftci-Yilmaz, S. & Mittler, R. (2010). Reactive oxygen species homeostasis and signaling during drought and salinity stresses. *Plant Cell and Environment*, 33, 453-467.
26. Nemali, K. S. & Van Iersel, M. W. (2008). Physiological responses to different substrate water contents: Screening for high water-use efficiency in bedding plants. *Journal of the American Society for Horticultural Science*, 133, 333-340.
27. Pan, Y., Wu, L. J. & Yu, Z. L. (2006). Effect of salt and drought stress on antioxidant enzymes activities and SOD isoenzymes of liquorice (*Glycyrrhiza uralensis* Fisch). *Plant Growth Regulators*, 49, 157-165.
28. Patil, D. V., Bhagat, K. P., Saha, S., 2014. Effect of water stress at critical growth stages in irrigated muskmelon (*Cucumis melo* L.) of semi-arid region of western Maharashtra, India. *Plant Archives*, 14(1), 161-169.
29. Pereira, G. J. G., Molina, S. M. G., Lea, P. J. & Azevedo, R. A. (2002). Activity of antioxidant enzymes in response to cadmium in *Crotalaria juncea*. *Plant Soil*, 239, 123-132.
30. Rahimi, A., Madah Hosseini, S., Pooryoosof, M. & Fateh, I. (2010). Variation of leaf water potential, relative water content and SPAD under gradual drought stress and stress recovery in two medicinal species of *Plantago ovata* and *P. psyllium*. *Plant Ecophysiology*, 2, 53-60.

31. Reddy, A. R., Chaitanya, K. V. & Vivekanandan, M. (2004). Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Plant Physiology*, 161, 1189-1202.
32. Roupheal, Y., Cardarelli, M. & Colla, G. (2008). Yield, mineral composition, water relations and water use efficiency of grafted mini-watermelon plants under deficit irrigation. *HortScience*, 43(3), 730-736.
33. Sensoy, S., Ertek, A., Gedik, I. & Kucukyumuk, C. (2007). Irrigation frequency and amount affect yield and quality of field-grown melon (*Cucumis melo* L.). *Agricultural Water Management*, 88, 269-279.
34. Sharma, S. P., Leskovar D. I., Crosby K. M., Volder, A. & Ibrahim, A. M. H. (2014). Root growth, yield, and fruit quality responses of reticulatus and inodorus melons (*Cucumis melo* L.) to deficit subsurface drip irrigation. *Agricultural Water Management*, 136, 75-85.
35. Simsek, M. & Comlekcioglu, N. (2011). Effects of different irrigation regimes and nitrogen levels on yield and quality of melon (*Cucumis melo* L.). *African Journal of Biology*, 10(49), 10009-10018.
36. Simsek, M., Kacira, M. & Tonkaz, T. (2004). The effect of different drip irrigation regimes on watermelon [*Citrullus lanatus* (Thunb)] yield and yield components under semi-arid climatic conditions. *Australian Journal of Agricultural Research*, 55, 1149-1157.
37. Tamayo, P. R. & Bonjoch, N. P. (2001). Free proline quantification: M. J. Reigosa Roger. *Handbook of plant ecophysiology techniques*, Springer, pp. 365-382.
38. Tuna, L., Kaya, C., Dikilitas, M. & Higgs, D. (2008). The combined effects of gibberellic acid and salinity on some antioxidant enzyme activities, plant growth parameters and nutritional status in maize plants. *Environmental Experimental Botany*, 62, 1-9.
39. Veljovic-Jovanovic, S., Kukavica, B., Stevanovic, B. & Navari-Izzo, F. (2006). Senescence- and drought-related changes in peroxidase and superoxide dismutase isoforms in leaves of *Ramonda serbica*. *Journal of Experimental Botany*, 57, 1759-1768.
40. Verbruggen, N. & Hermans, C. (2008). Proline accumulation in plants: a review. *Amino Acids*, 35, 753- 759.
41. Wang, W.B., Kim, Y.H., Lee, H.S., Kim, K.Y., Deng, X.P. & Kwak, S.S. (2009). Analysis of antioxidant enzyme activity during germination of alfalfa under salt and drought stresses. *Plant Physiology and Biochemistry*, 47 (7), 570-577.
42. Yamasaki, S. & Dillenburg, L. C. (1999). Measurements of leaf relative water content in *Araucaria angustifolia*. *Revista Brasileira de Fisiologia Vegetal*, 11(5), 69-75.
43. Yildirim, O., Halloran, N., Cavusoglu, S. & Sengul, N. (2009). Effects of different irrigation programs on the growth, yield, and fruit quality of drip irrigated melon. *Turkish Journal of Agriculture*, 33, 243-255.
44. Zhang, L., Gao, M., Hu, J., Zhang, X., Wang, K. & Ashraf, M. (2012). Modulation role of abscisic acid (ABA) on growth, water relations and glycinebetaine metabolism in two maize (*Zea mays* L.) cultivars under drought stress. *International Journal of Molecular Sciences*, 13, 3189-3202.
45. Zeng, C. Z., Bie, Z. L. & Yuan, B. Z. (2009). Determination of optimum irrigation water amount for drip-irrigated muskmelon (*Cucumis melo* L.) in plastic greenhouse. *Agricultural Water Management*, 96, 595-602.