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Gas exchange activities and relative water content at different fruit growth and developmental stages of ON and OFF cultivated pistachio trees

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Abstract

The present research was carried out to study gas exchange activities at different stages of fruit growth and development in OFF and ON pistachio cultivars including Ohadi, Kalleh-Ghochi, Akbari, Ahmad-Aghaii, Rezaii Zoudras and Haratii. Thus, different OFF and ON shoots were chose at different stages of fruit growth and development and also postharvest stage as followed: 1- beginning of endocarp growth; 2- pith hardening; 3- beginning of endosperm rapid growth; 4- end of embryo development; 5- ripening and harvesting times and 6- post harvest. Data indicated that gas exchange activities and relative water content significantly affected by cultivar, fruit growth and development stages and ON and OFF bearing statuses. The highest amount of photosynthetic activity was shown by Rezaii Zoudras followed by Akbari, Ohadi, Ahmad-Aghaii, Kalleh-Ghochi and Haratii, respectively. The highest and lowest photosynthetic (Pn) and transpiration (E) rates were resulted from 'Rezaii Zoudras' and 'Haratii', respectively. The highest rates of stomatal conductance (gs) and relative water content (RWC) were obtained by 'Ohadi', and 'Ohadi' and 'Kalleh-Ghochi', respectively. Data showed the highest and lowest Pn at first (T1) and fifth (T5) stages of fruit growth and development. The highest and lowest rates of E were obtained at second and third stages and fifth stage, respectively. Our results illuminated that gas exchange activity studies are the main way choosing the best cultivar for a special condition.

Keywords: Gas exchange activities, fruit growth and development, pistachio (*Pistacia vera* L.), relative water content

Introduction

Pistachio tree is one of the most important tree fruit crops in the arid region, especially in the central desert of Islamic Republic of Iran. Leaf gas exchange activities have an important role in plants productivity, and its study allow a direct evaluation of physiological responses of plants to environmental conditions. Photosynthesis is the basic case for gas exchange activity, growth, and biomass production by plants. Photosynthetic responses to rising global mean temperature of terrestrial plants can potentially change carbon balance and cycling of ecosystem (Rustad et al., 2001). De Herralde et al. (2003) reported that leaf photosynthetic activity can be used as a helpful means to classify tolerable plants under drought stress. Gomes- Laranjo et al. (2006) showed that there is an important correlation between irrigation and gas exchange activities, which can be suitable to find the drought resistance crop species. Wang et al. (2007) illuminated that gas exchange activities strongly change under different environmental temperatures . Flexas et al. (2001) reported the positive correlation between photosynthesis and stomatal conductance in pistachio trees. David (2002) found a positive correlation between photosynthesis and evaporation in olive trees. Moreover, it was shown that low relative water content strongly reduced photosynthesis, stomatal conductance and evaporation activities in olive trees (David, 2002). Unlike other woody species, very few studies have been done on photosynthetic activities in nut crops, especially with pistachio. There were many trials that assessed the rates of net CO_2 uptake and stomatal conductance in some pistachio cultivars (Vemmos, 1994; Novello and de palma, 1995), however, there

Table 1. Soil characteristics and weather conditions of Iranian Pistachio Research Institute

Variable	Amount
Clay (%)	6.4
Silt (%)	11.4
Sand (%)	82.2
EC (ds.m1-)	3.5
pH	8.2
P (mg.Kg-1)	14
K (mg.Kg-1)	251
Na (ppm)	14
Mg (ppm)	6.5
Ca (ppm)	12
Annual precipitation	98 mm
Mean high temperature	43 ºC
Mean low temperature	-16.6 ºC

were no reports regarding to gas exchange activities at different fruit growth and development stages under ON and OFF bearing statuses of different pistachio genotypes. There are many benefits studying the plant eco-physiological characteristics that warrant plant and cultivar cultivation under special environment and reduce damages made by chilling injuries, chilling requirements, salinity and drought stress, and so no. In crops, yield is dependent on photosynthetic rate and on the allocation of assimilates to different sinks such as flowers, fruits or leaves. In fruit trees, canopy architecture makes the relationship even more complex (Pearcy and Sims, 1994). However, the leaf photosynthetic characteristics are a very good initial approach to the response of plants to environmental conditions (Dejong, 1986). Choosing the proper commercial cultivars as rootstock, scion and/or their combinations regarding to the highest yield, fruit quality, pest and disease resistance, and adaptability is the most important case of horticultural research. Considering climatic diversity in pistachio plantation; it is not easy to advise all commercial cultivars for many conditions. Thus, this investigation was conducted to evaluate the eco-physiological responses of six Iranian pistachio cultivars at different stages of fruit growth and development under ON and OFF statuses and to find the best for stress conditions.

Materials and methods

This research was carried out in Iranian Pistachio Research Institute (IPRI) in Rafsanjan (Table 1) from 2005 to 2006 growing seasons, using 20 years old pistachio trees including 'Ohadi', 'Kalleh-Ghochi', 'Akbari', 'Ahmad-Aghaii', 'Rezaii Zoudras' and 'Haratii', as scions on 'Badami-Zarand' as a common rootstock in Iran. Pistachio trees, similar in height and vigor, were equally supplied and irrigated. Gas exchange activities including photosynthetic rate (μmolm^{-2}s^{-1}), transpiration rate (μmol m^{-2}s^{-1}), stomatal conductance (μmol m^{-2}s^{-1}) and relative water content (%) were measured using both ON and OFF shoots at different stages of fruit growth and development and postharvest as followed: 1- beginning of endocarp growth (T1); 2- pith hardening (T2); 3- beginning of endosperm rapid growth (T3); 4- end of embryo development (T4); 5- ripening and harvesting times (T5) and 6- postharvest (T6). Gas exchange activities were assessed using an infrared gas analyzer (ADC, LAC4 Analytical Development, ADC- Bioscientific LTD, UK) between 9 and 11 AM. Relative water content (RWC) was evaluated in each replication preparing ten leaf disks in 1.5 cm^2 and means of all replicates were shown. The fresh weight of each disk was measured immediately (W), and then samples was hydrated with deionized water to full turgidity under normal room temperature and light for 4h. Consequently, samples take out of water and were well dried of any surface moisture quick and lightly using filter paper. The weight of each sample was measured to obtain fully turgid weight (TW). Samples were oven-dried at 80 ºC for 24h separately and weighted to obtaine dry weight (DW). These data were used in following formula and data were shown as percent (Barr and Weatherly, 1962):

$$RWC (\%) = [(W-DW)/ (TW-DW)] \times 100$$

W= sample fresh weight (g); TW= sample turgid weight (g); DW= sample dry weight (g).

Although the best irrigation period is 30 days for experimental condition in Rafsanjan, however, 45 days period was used because of low accessibility to water. Thus, these plants were generally under drought stress. The experiment was done in a randomized complete block design (RCBD) in split-plot with 72 treatments and three replications. Each replication consisted of three trees. Means were compared using least significant difference (LSD) at 5% level of confidence.

Results and discussion

Our data showed the variability of gas exchange activities and relative water content by different pistachio cultivars, indicating the highest and lowest photosynthetic (Pn) and transpiration (E) rates by 'Rezaii Zoudras' and 'Haratii', respectively (Table 2). The highest rates of stomatal conductance (gs) and relative water content (RWC) were shown by 'Ohadi', and 'O hadi' and 'Kalleh-Ghochi', respectively (Table 2). Results illuminated that fruit growing stages had strong effect on gas exchange activities (Table 3). As data shown, the highest and lowest Pn were obtained at first (T1) and fifth (T5) stages of fruit growth and development (Table 3).

Table 2. The mean gas exchange activities and relative water contents of different pistachio cultivars in OFF and ON trees

*Cultivar	RZ	A	O	AA	KG	H
Photosynthesis (µmol m^{-2} s^{-1})	4.15 a	4.08 ab	3.79 a-c	3.70 a-c	3.58 bc	3.42 c
transpiration (µmol m^{-2} s^{-1})	4.20 a	3.74 ab	4.00 a	4.17 a	4.82 a	3.42 b
stomata conductive (µmol m^{-2} s^{-1})	0.96 ab	0.90 b	1.00 a	0.94 b	0.95 ab	0.92 b
RWC (%)	86 b	87 b	90 a	86 b	89 a	87 b

*RZ: Rezaii Zoudras; A: Akbari; O: Ohadi; AA: Ahmad-Aghaii; KG: Kalleh-Ghochi; and H: Haratii,
**Within each row, same letter indicates no significant difference between treatments at 5% levels of LSD.

Table 3. The mean gas exchange activities rates in different stages of fruit growth and development and postharvest

Stages	T1	T2	T3	T4	T5	T6
Photosynthesis (µmol m^{-2} s^{-1})	5.65 a	5.08 b	4.37 c	2.48 de	2.27 e	2.88 d
transpiration (µmol m^{-2} s^{-1})	3.85 b	5.11 a	5.04 a	3.06 c	2.54 d	-
stomata conductive (µmol m^{-2} s^{-1})	1.06 b	1.13 a	1.04 b	0.89 c	0.80 d	0.75 d
RWC (%)	85 e	89 b	90 a	88 bc	87 cd	86 de

Within each row, same letter indicates no significant difference between treatments at 5% levels of LSD.

Table 4. The photosynthetic rates of different cultivars on different stages of fruit growth and development

*Cultivar	O	KG	A	AA	H	RZ
**Stage						
T1	6.48 a	3.91 b	6.36 a	5.54 a	4.22 a	7.35 a
T2	4.19 c	5.86 a	5.54 a	4.82 ab	4.07 ab	5.98 b
T3	5.19 b	3.79 b	4.47 b	3.93 bc	3.76 a-c	5.08 c
T4	2.43 d	2.16 d	3.37 c	2.22 d	2.32 d	2.40 d
T5	1.42 e	2.51 cd	1.83 d	2.87 cd	2.95 cd	2.01 d
T6	3.01 d	3.24 bc	2.88 c	2.84 cd	3.19 b-d	2.10 d

*RZ: Rezaii Zoudras; A: Akbari; O: Ohadi; AA: Ahmad-Aghaii; KG: Kalleh-Ghochi; and H: Haratii,
**Within each column, same letter indicates no significant difference between treatments at 5% levels of LSD.

The highest and lowest rates of E were obtained at second and third stages, and fifth stage, respectively (Table 3). Data showed the highest rates of gs and RWC at second and third stages of fruit growth and development, respectively (Table 3). Regarding to different cultivars, it is clear that gas exchange activities strongly influenced by different cultivars at different stages of fruit growth and development. However, genotype had no effect on RWC at different stages of fruit growth and development. Data showed the highest rate of Pn by 'Ahmad-Aghaii', 'Akbari', 'Haratii', 'Ohadi', and 'Rezaii Zoudras' at first stage of fruit growth and development (Table 4). The lowest rates of Pn were obtained by 'Ahmad-Aghaii', 'Haratii' and 'Kalleh-Ghochi' at T4 (Table 4). The highest rate of E in 'Akbari', 'Ahmad-Aghaii', 'Rezaii Zoudras' and 'Kalleh-Ghochi' was shown at T2 (Table 5). The highest E by 'Ohadi' was resulted at T3 and there were no significant differences between second and third stages by 'Rezaii Zoudras' and 'Haratii' (Table-5). Data showed the reduction of stomatal conductance from the T1 to T6 in different cultivars (Table 6). The lowest rate of stomatal conductance was obtained at T6 in cultivars with the exception of Haratii cultivar that showed at T5 (Table 6). Results showed a significant influence of fruit growth and development on RWC (Table 7). Data indicated no significant differences of photo-synthetic rates between ON and OFF trees, with the exception of 'Akbari' and 'Haratii' (Table 8). It was showed that photosynthesis increased by ON trees of 'Akbari' and 'Haratii' compared with OFF trees (Table 8). Data showed no significant differences between transpiration rates of ON and OFF trees (Table 8). As data shown, stomatal conductance was unaffected with ON and OFF statuses of different cultivars with the exception of 'Ahmad-Aghaii' (Table 8). RWC also did not influence with different cultivars at different stages of fruit growth with the exception of 'Ohadi'. Regarding to different stages of fruit growth and development in

Table 5. The transpiration rates of different cultivars on different stages of fruit growth and development

*Cultivar / **Stage	O	KG	A	AA	H	RZ
T1	4.00 bc	3.51 bc	3.84 bc	4.25 bc	3.42 bc	4.10 b
T2	4.75 ab	5.63 a	5.04 a	5.64 a	4.16 ab	5.40 a
T3	5.93 a	5.07 ab	4.39 ab	4.61 b	4.54 a	5.71 a
T4	2.89 cd	3.32 c	3.19 c	3.49 cd	2.71 cd	2.79 c
T5	2.47 d	2.51 c	2.26 d	2.86 d	2.29 d	2.85 c
T6	-	-	-	-	-	-

*RZ: Rezaii Zoudras; A: Akbari; O: Ohadi; AA: Ahmad-Aghaii; KG: Kalleh-Ghochi; and H: Haratii,
**Within each column, same letter indicates no significant difference between treatments at 5% levels of LSD.

Table 6. The stomata conductive of different cultivars on different stages of fruit growth and development

*Cultivar / **Stage	O	KG	A	AA	H	RZ
T1	1.10 ab	1.04 ab	1.05 b	0.99 b	1.05 b	1.11 b
T2	1.17 ab	1.12 a	1.11 a	1.09 a	1.13 a	1.18 a
T3	1.20 a	1.01 ab	0.96 c	0.97 b	1.02 b	1.09 b
T4	0.91 b	0.95 bc	0.85 d	0.90 c	0.83 c	0.93 c
T5	0.87 b	0.87 bc	0.77 e	0.89 c	0.68 d	0.74 d
T6	0.77 b	0.73 c	0.68 e	0.77 d	0.80 c	0.72 d

*RZ: Rezaii Zoudras; A: Akbari; O: Ohadi; AA: Ahmad-Aghaii; KG: Kalleh-Ghochi; and H: Haratii,
**Within each column, same letter indicates no significant difference between treatments at 5% levels of LSD.

Table 7. The RWC of different cultivars on different stages of fruit growth and development

*Cultivar / **Stage	O	KG	A	AA	H	RZ
T1	90 a	86 b	84 a	81 c	84 c	83 b
T2	91 a	90 ab	88 a	85 b	89 a	89 a
T3	90 a	91 a	90 a	91 a	90 a	90 a
T4	91 a	89 ab	87 a	87 b	88 ab	85 b
T5	89 a	91 a	86 a	86 b	86 bc	83 b
T6	87 b	86 b	87 a	86 b	85 c	88 b

*RZ: Rezaii Zoudras; A: Akbari; O: Ohadi; AA: Ahmad-Aghaii; KG: Kalleh-Ghochi; and H: Haratii,
**Within each row, same letter indicates no significant difference between treatments at 5% levels of LSD.

ON and OFF trees, there were no significant differences between Pn of ON and OFF trees in different stages of fruit growth and postharvest, with the exception of T2 and T3 (Table 9). Data showed the increment of this variable with ON trees at second and third stages of fruit growth and development compared with OFF trees (Table 9). Results illustrated an increment of stomatal conductance at T4 in OFF trees compared with ON trees (Table 9). Transpiration rate and RWC were unaffected by different cultivars at different stages of fruit growth and development (Table 9). Larcher (1969) found that although pistachio trees accounted as C_3 plant, however they have high photosynthetic efficiency as almond as and higher than apple, peach, plum, sweet cherry, apricot, and walnut trees. David (2002) showed a positive correlation between relative water content and gas exchange activities, and reported that reduction of relative water content strongly reduces photosynthesis, transpiration and stomatal conductance. Data indicated the different photosynthetic rates by different cultivars under similar environmental conditions that were in agreement with findings of De Herralde et al. (2003) and Gomes-Laranjo et al. (2006) on almond and with Wang et al. (2007) on apricot trees. Results showed the different photosynthetic rates by trees at different stages of fruit growth and postharvest. The photosynthetic rate was higher at first and reduced toward the sixth stage. It is suggested that because of high rate of cell division by endosperm and embryo in two first stages, photosynthetic rates was higher than other stages. However, it is obvious that this variable significantly reduced from first toward sixth stage, which may be due to leaf senescence or high temperatures that were in agreement with findings of Proietti (2000) in olive and Wang et al. (2007) in apricot. Regarding to sixth stage, photosynthesis significantly increased compared with former stage, which may be due to a reduction in temperature. Membrane activities and enzymatic reaction influence by high temperatures that lead to photosynthetic variation. High summer temperatures potentially damage photosynthetic tissues, which induces photorespiration (Angelopoulos et al. 1996). The related process is that high temperatures destroy membranes, therefore, reduces their activities and create conditions making oxidative radicals compared with carboxylation reactions, resulted in the high photorespiration reaction. There were no significant differences between photosynthetic rates at fourth and fifth stages of fruit growth and development among

Table 8. The mean gas exchange activities rates of ON and OFF trees in different cultivars

*Cultivar		O	KG	A	AA	H	RZ
**Tree							
Photosynthesis	OFF	3.56 a	3.67 a	3.73 b	3.70 a	3.01 b	4.12 a
(µmol m^{-2} s^{-1})	ON	4.01 a	3.50 a	4.42 a	3.70 a	3.83 a	4.19 a
transpiration	OFF	3.91 a	4.05 a	3.58 a	4.33 a	3.48 a	4.24 a
(µmol m^{-2} s^{-1})	ON	4.10 a	3.99 a	3.90 a	4.01 a	3.37 a	4.09 a
stomata conductive	OFF	1.04 a	0.98 a	0.90 a	0.98 a	0.92 a	0.99 a
(µmol m^{-2} s^{-1})	ON	0.97 a	0.93 a	0.91 a	0.89 b	0.92 a	0.93 a
RWC	OFF	89 b	89 a	88 a	87 a	87 a	87 a
(%)	ON	91 a	89 a	86 a	85 a	87 a	85 a

*RZ: Rezaii Zoudras; A: Akbari; O: Ohadi; AA: Ahmad-Aghaii; KG: Kalleh-Ghochi; and H: Haratii,
**Within each row, same letter indicates no significant difference between treatments at 5% levels of LSD.

Table 9. The mean gas exchange activities rates of ON and OFF trees in different stages of fruit growth and development

Stage		T1	T2	T3	T4	T5	T6
Tree							
Photosynthesis	OFF	5.48 a	4.38 b	3.84 b	2.48 a	2.43 a	2.93 a
(µmol m^{-2} s^{-1})	ON	5.81 a	5.77 a	4.90 a	2.49 a	2.10 a	2.83 a
transpiration	OFF	3.92 a	4.97 a	5.47 a	3.15 a	2.45 a	-
(µmol m^{-2} s^{-1})	ON	3.86 a	5.26 a	5.31 a	2.97 a	2.52 a	-
stomata conductive	OFF	1.07 a	1.14 a	1.10 a	0.95 a	0.80 a	0.75 a
(µmol m^{-2} s^{-1})	ON	1.05 a	1.13 a	0.98 a	0.84 b	0.80 a	0.74 a
RWC	OFF	84 a	89 a	91 a	87 a	88 a	87 a
(%)	ON	85 a	89 a	90 a	88 a	86 a	85 a

Within each row, same letter indicates no significant difference between treatments at 5% levels of LSD.

different cultivars, however, there was a significant differences among different cultivars regarding to Pn of third, fourth and fifth stages with the exception of 'Akbari', 'Kalleh-Ghochi' and 'Ohadi' that showed a reduction in this variable at these stages. These data illuminated that 'Ahmad-Aghaii', 'Rezaii Zoudras' and 'Haratii' unaffected by high temperatures and drought stress that shows their adaptability to high summer temperatures and drought. Data indicated no significant differences in photosynthetic rates between ON and OFF statuses of different cultivars, with the exception of 'Akbari' and 'Haratii'. It is clear that this variable increased in ON trees of 'Akbari' and 'Haratii' compared with OFF trees. It is suggested that because of higher crop loading by these cultivars than others (Data not shown), fruits acted as a powerful sink in ON trees, led to the higher photosynthetic rate than non-bearing status that was in agreement with Fuji and Kennedy (1985) in apple trees. Data showed a reduction in photosynthetic rates by OFF trees at second and third stages of fruit growth and development, although, there were no significant differences regarding to this variable between ON and OFF trees at first and fourth to sixth stages. It may be due to higher cell division and elongation by fruit cells at second and third stages. Vemmos (1994) reported that yield and gas exchange activities increased by pistachio trees from beginning of spring to fill the fruit cavity. Moreover he showed that gas exchange activities of bearing trees are same or lower than non-bearing trees. In addition, Vemmos (1994) found that fruit bearing increased the stomatal opening that led to higher photosynthetic activity.

Conclusion

In the light of this experiment it is concluded that: Eco-physiological studies are of the best tools to choose the efficient cultivars for different environmental conditions, which reduce the orchard cost, and remove the possibility of damages by stress conditions. As data shown, 'Kalleh-Ghochi', 'Ahmad-Aghaii', 'Rezaii Zoudras' and 'Haratii' are the best to plant uner high-temperature conditions.

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