Fruits 73(2), 97–104 | ISSN 0248-1294 print, 1625-967X online | https://doi.org/10.17660/th2018/73.2.3 | © ISHS 2018

Original article

Effects of early harvest times on nut quality and physiological characteristics of pistachio (*Pistacia vera*) trees

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Summary

Introduction – **Pistachio harvesting at the appropriate time is one of the key factors affecting the product quality. The effects of early harvest time on quantitative and qualitative properties of pistachio nuts were investigated.** *Materials and methods* – **The 'Ohadi' pistachio cultivar was used as the market reference in Iran. Five harvest times (July 27, August 6, August 16, August 27 and September 6) were studied over four consecutive years (2008–2011) as treatments in the field experiment. Nut weight parameters, hull discoloration, hulling, cracked nuts, early-split nuts, kernel protein, mineral and chlorophyll contents were evaluated at each harvest time.** *Results and discussion* – **The fresh and dry nut weights showed the maximum and the minimum nut production rates for the last (September 6) and the first (July 27) harvest times, respectively. Percentages of hull discoloration, cracked nuts and immature nuts were significantly influenced by harvest time. The early-split nut percentage was not significantly different at the various harvest times. The maximum potassium, calcium, magnesium and nitrogen, protein and chlorophyll contents were obtained at the first harvest time. The growth of current year shoots, leaf area, percentages of vegetative and reproductive buds were not influenced by the harvest time, whereas the abscission of reproductive buds was minimum at the first harvest time and significantly different from all other times.** *Conclusion* - **Early harvesting of pistachio is preferable in terms of crop health indicators, nutritional value and color of the kernels. However, it is not preferable in terms of yield (nut and kernel production per hectare) for the producers, although potentially more sustainable.**

Keywords
Iran, pistachio, *Pistacia vera*, fruit quality, orchard management, yield components

Significance of this study

What is already known on this subject?

- Pistachio harvesting at the appropriate time is one of the key factors affecting the product quality.

What are the new findings?

- Early harvest time of pistachio is preferable in terms of crop health indicators, nutritional value, and color of the kernels.
- Orchard management sustainability can balance lower yielding performance of early harvesting.

What is the expected impact on horticulture?

- If promoted by policy makers, early harvest time can increase the commercial value of pistachios with bright green color and reduced risk of aflatoxin contamination.

Résumé

Effets de la précocité de récolte sur la qualité des pistaches et les caractéristiques physiologiques des pistachiers (*Pistacia vera*).

Introduction – **Le choix de la date de récolte des pistaches est l'un des facteurs clés affectant la qualité du produit. Les effets de la précocité de la récolte sur les caractéristiques quantitatives et qualitatives des pistaches ont été étudiés.** *Matériel et méthodes* – **Le cultivar de pistachier 'Ohadi' a été utilisé comme étant la référence sur le marché en Iran. Cinq dates de récolte (27 juillet, 6 août, 16 août, 27 août et 6 septembre) ont été étudiées pendant quatre années consécutives (2008-2011) et correspondent aux traitements d'un essai sur le terrain. Les paramètres de poids des noix, de décoloration de la coque, de décorticage, les taux de noix concassées, de noix séchées précocement, les teneurs en protéines, en minéraux et en chlorophylle des noix ont été évalués pour chaque date de récolte.** *Résultats et discussion* – **Les poids de pistaches fraîches et sèches ont présenté des valeurs de production maximales et minimales pour les dernières (le 6 septembre) et les premières dates de récolte (27 juillet), respectivement. Les pourcentages de décoloration de la coque, de noix concassées et de noix immatures ont été significativement influencés par la date de récolte. Le pourcentage de noix hâtives divisées n'était pas significativement différent aux diverses dates de récolte. Les teneurs maximales en potassium, calcium, magnésium et azote, protéines et chlorophylle ont été obtenues à la première date de récolte. La croissance des pousses de l'année en cours, la surface foliaire, les pourcentages de bourgeons végétatifs et reproducteurs n'ont pas été influencés par la date de récolte, alors que**

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l'abscission des bourgeons reproducteurs était minimale à la première récolte et significativement différente de toutes les autres. *Conclusion* **– Un timing de récolte précoce des pistaches s'est révélé préférable en termes d'indicateurs sanitaires des cultures, de valeur nutritionnelle et de couleur des graines. Il porte cependant préjudice aux producteurs en termes de rendement (production de noix et de grains par hectare), tout en étant potentiellement plus durable.**

Mots-clés
Iran, pistachier, *Pistacia vera*, qualité du fruit, gestion des vergers, composante de rendement

Introduction

Pistachio is one of the most important horticultural crops in Iran with high economic and nutritional values. Harvesting at appropriate time is a key factor affecting the yield and the qualitative characteristics of the fruit crop. Pistachio harvesting starts when the hull is easily separated from the hard shell. Considering pistachio production diversity in Iran and in the world, harvest period starts in early August (early time) and continues until October (delayed harvest).

The most appropriate harvesting time can be estimated from the qualitative indicators like hulling percentage, splitting percentage, shell color, kernel dry weight, total fat and sugar contents. Crane (1987) reported that harvesting time was effective on quantitative and qualitative characteristics of the crop. Moreover, the pistachio nut maturity is associated with physiological and compositional changes including nut dry weight, fat, shell splitting and shell discoloration, which are completed within a week after the easy separation of the hull from the shell (Crane, 1987; Labavitch *et al.*, 1982; Panahi and Khezri, 2011).

Previous studies on the most appropriate harvest time of Iranian pistachio cultivars showed that each pistachio cultivar was harvested until the beginning of September in order to avoid contamination with aflatoxin-producing fungi and to produce intact crop (Panahi and Khezri, 2011; Panahi *et al.*, 2005). Since the cvs. Ahmadaghaei and Kalleghuchi expressed the highest contamination rate with aflatoxin, these cultivars should be harvested from 13 to 20 September (Panahi and Khezri, 2011). Contamination of pistachios with aflatoxin is one of the most serious challenges for producers, processors and exporters. In recent years, extensive efforts have been made to reduce it in pistachio crops, with a lot of success in this regard (Bui-Klimke *et al.*, 2014). Since the orchard can be the starting point for *Aspergillus flavus* contamination, controlling the effective factors during the production chain can greatly reduce the risk of contamination by aflatoxin (Doster *et al.*, 2014).

Karaca and Nizamoglu (1995) reported that the maximum amount of fat and sugar is obtained at ripening time. They also believed that it would be difficult to separate the hull from the shell during the early harvest time. Kunter *et al.* (1994) investigated the effects of five harvest times with one week interval (starting from August 26) on the Turkish pistachio cultivars. They reported that the delayed harvesting time significantly reduced the total chlorophyll amount, and the kernel green color changed into yellowish green. The highest protein content was also observed 3 weeks before full maturity of nuts. Total A and B chlorophylls have been reported to be 150 mg kg^{-1} in pistachios with green kernels and the ratio of chlorophyll A to B was about 3. The chlorophyll amount of the ripe Turkish pistachio was 25 mg kg^{-1} (Bellomo and Fallico, 2007).

Considering the appropriate market-friendly of the harvested kernels in the beginning of the season and even before nut ripening (kernel with green color and high quality) for use in the confectionery, ice cream, sliced and powder pistachio producing industries as well as reduction of damaged nuts in early harvest time; and early harvest effects on vegetative and reproductive traits of the plant, the present study was conducted in order to achieve these goals. The aim of this study was to investigate the effects of early harvest time on the quality and quantity of pistachio kernels to potentially stimulate the consumption and increase the export market. Meanwhile, the effects of treatments on some pistachio vegetative and reproductive traits have been studied that could influence pistachio farmers in the management of their orchard.

Materials and methods

Plant material and experiment

The study was performed on 30-year old pistachio trees of the cv. Ohadi grafted on *Pistacia vera* cv. Badami-Riz as rootstock, in the Kerman Pistachio Research Station (Kerman, Iran), located 30°19'42/01N, 57°03'20/22E, and 1,753 m above sea level. 'Ohadi' was studied as the major pistachio nut cultivar grown in Iran. The experiment was arranged in a randomized complete block design with five treatments and three replicates over four consecutive years from 2008 to 2011. The climatic conditions during the study period are indicated in Figure 1.

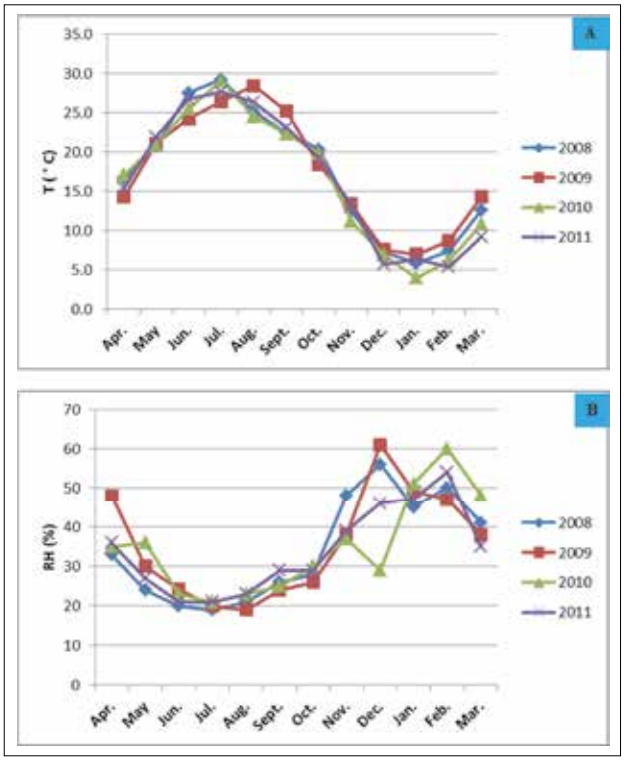

Figure 1. Climatic parameters during the four-year period (2008–2011) of the study on pistachio in the Kerman province, Iran. A: Average monthly temperatures; B: Average monthly relative humidity. Source: The IR of Iran Meteorological Organization (IRImo, http://irimo.ir.).

In Iran generally, pistachio harvesting occurs between the 6th of September and the 6th of October. As we wanted to evaluate the early harvest time, it was decided to sample at four different times before the traditional harvest time (September 6) as early treatments. These treatments started from July 27 with an interval of 10 days (July 27, August 6, August 16, August 27 and September 6). For each sampling time, 30 fruit clusters were picked at random in each geographical direction of each tree, combined and hand sorted into mature, immature, early-split, blank and hull cracked nuts.

Fruit parameters measurements

After removing and discarding all blank nuts, the samples were dehulled (to separate the soft hull from nuts) and the percentage of hulling was determined. Almost 100 hulled nuts of each geographical direction of each tree was weighted before drying (hull fresh weight), then dried to constant weight in an oven at 100 °C for 5 h and weighted for calculating the weight of 100 shell nuts (shell dry weight). After that, the dehulled dried split pistachios were used to determine the weight of 100 dried kernel by deshelling.

An amount of 500 g whole pistachio nuts was taken and the number of nuts with hull discoloration, cracked nuts and early-split nuts was counted. The percentages of each of these three mentioned parameters were calculated from the following equations (Eq. 1–3):

$$\%\ \text{hull discoloration/cracking} = \frac{\text{Number of nuts with hull discoloration/cracking}}{\text{Total number of nuts}} \times 100 \quad \text{Eq. (1/2)}$$

$$\%\ \text{early-split nuts} = \frac{\text{Number of nuts with early split}}{\text{Total number of nuts}} \times 100 \quad \text{Eq. (3)}$$

Hulling percentage was counted based on the percentage of nuts easily hulled with fingers in a set of 100 nuts. Unhulled pistachios were considered as immature nuts.

Kernel composition analysis

Chlorophyll content

Pistachio kernel (150 mg fresh weight – FW) was ground with liquid nitrogen. After extraction in 80% acetone, samples were shaken and then stored at -20 °C for 24 h. Pigments were measured spectrophotometrically ($UVIKON_{XL}$, BIO-TEK Instrument, USA) in three replicates (plants). Chlorophyll A (Chl *a*), chlorophyll B (Chl *b*), and carotenoids (Car) (µg g^{-1} FW) were calculated according to Lichtenthaler (1987):

Chl a = 12.25 $A_{663.2}$ - 2.79 $A_{646.8}$,
Chl b = 21.5 $A_{646.8}$ - 5.1$A_{663.2}$, and
Car = (1000 A_{470} - 1.82 Chl a - 85.02 Chl b) /198.

Kernel mineral element content

At each treatment, thirty fruit clusters were sampled from every plant, and these were combined to form a single sample for later analyses. Kernel tissues were oven dried at 100 °C for 5 hours (Memmert oven, UK) and then ground to a 40 mesh in a Wiley mill. Dried kernel samples were used to determine the mineral element concentration. Each sample was replicated three times for every treatment. Phosphorus (P), calcium (Ca), magnesium (Mg) were estimated in an atomic absorption spectrophotometer using respective hollow cathode tubes (Ehleringer *et al.*, 1986) whereas potassium (K) was estimated in a known volume of acid extract using a flame photometer (Hald, 1947). To estimate the nitrogen values we used the Kjeldahl method in the kernel samples (Joshi *et al.*, 2015).

Protein content

Protein content was calculated based on a nitrogen conversion factor of 5.3 (Eq. 4) (Joshi *et al.*, 2015):

$$\%\ Protein = \%\ Nitrogen \times 5.3 \quad \text{Eq. (4)}$$

Measurement of growth parameters

At the end of the harvest season and in the beginning of November, four branches were randomly selected in different geographical directions. The whole number of lateral buds on the current year shoot was recorded as total of reproductive and vegetative buds. Then, reproductive and vegetative buds counted separately and the following equation (Eq. 5) was used to determine the respective percentage of buds:

$$\%\ \text{reproductive/vegetative buds} = \frac{\text{Number of reproductive/vegetative buds}}{\text{Total number of buds}} \times 100 \quad \text{Eq. (5)}$$

Then according to the total number of reproductive buds, abscission and remaining reproductive buds were calculated based on the following equation (Eq. 6):

$$\%\ \text{abscission/remaining buds} = \frac{\text{Number of abscission/remaining buds}}{\text{Total number of reproductive buds}} \times 100 \quad \text{Eq. (6)}$$

The leaf area per plant was determined using a leaf area meter (Model CI-201, CID. Inc., ADC, England) (Ahmed *et al.*, 2011). The length growth of selected branches was measured with a ruler (± 0.1 cm) from their base (the point where shoot began to grow) at the beginning of spring and at the end of the experiment (in autumn).

Statistical analysis

A two-way analysis of variance was used to test for the effects of harvest times as the treatments. Means (per year) were separated by Turkey's HSD test ($P \leq 0.05$). Prior to statistical analysis, data were subjected to transformation, where necessary, for normalizing the frequency distribution. All analyses were performed by SPSS version 20 (IBM Corporation, USA).

Results and discussion

Yield components analysis

Considering the purpose of this study, which was to evaluate the early harvest efficacy as a strategy to use the green kernel, early harvest yield was evaluated and the crop production rates were compared at other harvest times. The kernel yield reduced by half (25.1 g per 100 kernels) at the earliest harvest time (July 27) compared with the yield (48.9 g per 100 kernels) at the latest harvest time (September 6) (Table 1). These results are consistent with the results of other studies conducted on Iranian pistachios (Bolling *et al.*, 2011; dos Santos Navarro *et al.*, 2012; Giacalone *et al.*, 2012; Kay *et al.*, 2010).

The results of the measurement of fresh and dry weights of 100 nuts showed that there are significant differences be-

Table 1. Amounts of fresh and dry weights of nuts and kernels and crop maturity changes at different harvest times (July 27, August 6, August 16, August 27, and September 6) of 'Ohadi' pistachio fruit. Values are means of four years (2008–2011).

Measured parameters	Harvest times				
	Jul. 27	Aug. 6	Aug. 16	Aug. 27	Sep. 6
Fresh weight of 100 nuts (g)	193.9 d	206.1 c	216.3 bc	220.5 b	234.1 a
Dry weight of 100 nuts (g)	80.1 d	94.3 c	95.2 c	102.8 b	110.2 a
Dry weight of 100 kernels (g)	25.1 e	33.1 d	40.3 c	44.5 b	48.9 a
(%)Hull discoloration[x]	0.33 d	4.9 d	28.8 c	52.8 b	62.0 a
(%)Cracked nuts[y]	0.0 c	1.0 c	6.0 bc	12.0 ab	13.9 a
(%)Early-split nuts[z]	1.2 a	1.3 a	1.9 a	2.2 a	2.2 a
(%)Immature nuts[w]	98.3 a	90.9 a	58.3 b	30.9 c	30.9 c

Different letters within a row indicate significant differences by Tukey's HSD test at $P \leq 0.05$; no letter within a row indicates no significant difference.

[x] Hull discoloration: the process that fruit hull color changes from green to red or yellow and indicates pistachio is ripened.

[y] Cracked nuts: nuts with ruptured hulls not necessarily along the shell suture and with non-dehisced shell.

[z] Early-split nuts: nuts with split hull and dehisced shell along the shell suture.

[w] Immature nuts; nuts with non-dehisced shell and undeveloped kernel.

tween different treatments ($P \leq 0.05$). The lowest and highest crop weights (fresh and dry) related to July 27 (first) and September 6 (fifth) harvest times, respectively (Table 1). The lowest amount of dry kernel (25.1 g) was also obtained in July 27 (first harvest time) and the production rate increased over time, as maximum production rate of kernel (48.9 g) was in September 6 (last harvest time).

Fruit quality – physical properties and food safety

The hull discoloration percentages were less than 5% in July 27 (first) and August 6 (second) harvest times, which were not statistically significant. However, this percentage increased more than 60% in September 6 (fifth harvest), which was significantly higher compared with the previous harvests (Table 1).

The nut cracking percentage increased in delayed harvest times and maximum percentage obtained in September 6 was significantly higher than other treatments. The maximum percentage of this trait was 13.9% at the last harvest date (September 6) (Table 1). The percentages of pistachio cracked nuts (regular and non-regular) in the earlier harvest times were less than at the traditional harvest time ($P \leq 0.05$). These results are consistent with those of Panahi and Khezri (2011) and Crane (1987), also on pistachio nuts.

The percentage of early-split nuts increased during the various harvest times, while the differences were not statistically significant (Table 1). It was less than 2.0% in the first (July 27), second (August 6) and third (August 16) harvest times and around 2.2% in the fourth (August 27) and last (September 6) harvest times. These results are consistent with those (~2%) reported by Sommer *et al.* (1986). The occurrence of early split nuts in the orchard can be considered as a crop health indicator, and delaying harvest time provides more opportunity for *Aspergillus flavus* fungi to grow and aflatoxin to contaminate pistachios (Hepsag *et al.*, 2014). Therefore, harvesting the product as soon as possible (when 60–80% of the hull is easily removed from the shell) should contribute to reduce aflatoxin contamination of the product (Al-Moghazy *et al.*, 2014).

The percentage of immature nuts gradually decreased over the harvest times. The highest amounts of immature nuts were observed in July 27 (first) and August 6 (second) harvest times (above 90%), while the lowest percentage was observed in August 27 (fourth) and September 6 (fifth) harvest times (less than 31%). The percentage of immature nuts was about 58% in the August 16 (third) harvest time (Table 1). Increased percentage of immature nuts in the early harvest time (July 27) and their significant difference with harvest at traditional time (September 6) was a disadvantage. These results are consistent with other studies conducted in this regard (Esmaeilpour *et al.*, 2010; Panahi and Khezri, 2011; Panahi *et al.*, 2005). Immature nuts, *i.e.*, lack of color change in hulls and lack of preparedness to be separated from the shell, make the peeling process slow and even

Table 2. Changes of nitrogen, protein, phosphorus, potassium, calcium and magnesium contents at different harvest times (July 27, August 6, August 16, August 27 and September 6) of 'Ohadi' pistachio nut kernels. Values are means of four years (2008–2011).

Measured parameters	Harvest times				
	Jul. 27	Aug. 6	Aug. 16	Aug. 27	Sep. 6
Nitrogen content (%)	4.1 a	3.9 a	3.9 a	3.5 b	3.3 b
Protein content (%)	25.7 a	24.3 a	24.0 a	21.4 b	20.6 b
Phosphorus content (%)	0.23 a	0.26 a	0.24 a	0.23 a	0.25 a
Potassium content (%)	0.9 a	0.8 a	0.73 a	0.7 a	0.7 a
Calcium content (%)	0.9 a	0.5 b	0.77 ab	0.43 b	0.43 b
Magnesium content (%)	0.4 a	0.2 a	0.36 a	0.17 a	0.13 a

Different letters within a row indicate significant differences by Tukey's HSD test at $P \leq 0.05$.

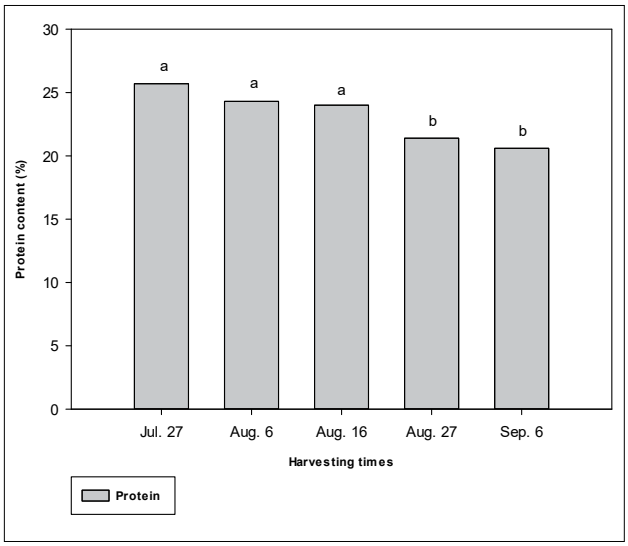

Figure 2. Changes of protein contents at different harvest times (July 27, August 6, August 16, August 27 and September 6) in pistachio fruit kernels. Each value is the mean of six replicates. [a] and [b] indicate means significantly different (Turkey's HSD test, $P \leq 0.05$).

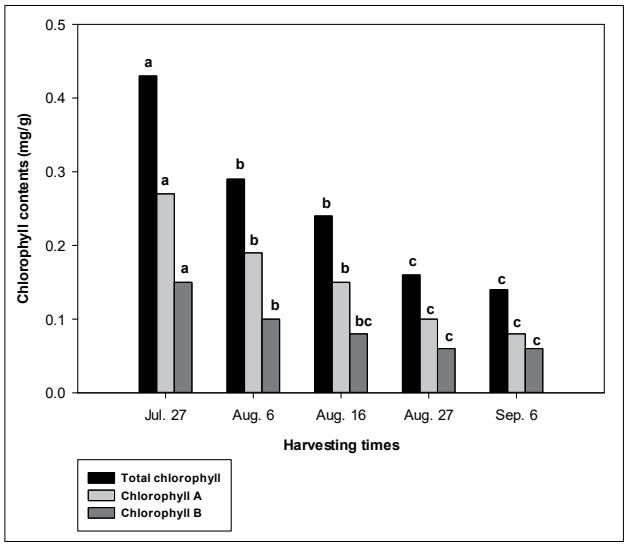

Figure 3. Changes of chlorophyll contents at different harvest times (July 27, August 6, August 16, August 27, and September 6) in pistachio fruit kernels. Each value is the mean of six replicates. [a, b] and [c] indicate means significantly different (Tukey's HSD test, $P \leq 0.05$).

impossible in some cases. Considering the kernel production rate per hectare, the earliest harvest time (July 27) yielded half (278.4 kg ha^{-1}) compared with other harvest times, especially the last harvest time (September 6) (542.9 kg ha^{-1}) (Table 1).

Fruit quality – nutritional and visual properties

There were no statistically significant differences among the different harvest times in terms of the amount of phosphorus, potassium, and magnesium (Table 2). Nitrogen amount significantly decreased in August 27 and September 6, although there were no significant differences between the three earlier harvest times for this parameter. Calcium amount decreased over the time, as the first harvest time (July 27) had the significantly higher calcium rates among the other harvest dates treatments (Table 2). Among the mineral elements measured in pistachio kernels (nitrogen, phosphorus, potassium, calcium and magnesium), only nitrogen and calcium concentrations were significantly higher in the early harvest time (July 27) than the traditional harvest time (September 6). These results are consistent with those of Giacalone *et al.* (2012), who reported that mineral concentrations of the nut decreases with the passage of time. In contrast, the results of the present study are inconsistent with those of Murray *et al.* (2001), who stated that calcium, magnesium and phosphorus concentrations increase as nut ripening time of buckthorn (*Rhamnus* spp.) approaches.

The amount of protein was different at various harvest times. At the earliest harvest time (July 27), the amounts of protein (Figure 2) were maximum and were reducing over time. The protein concentration, one of the main ingredients of pistachio kernels, showed statistically significant differences between early and traditional harvest times. The protein content was maximum (27%) at the earliest harvest, and decreased over time to reach ~22% (Figure 2). In previous reports, the highest protein concentration was observed 3 weeks before pistachio full maturity (Kunter *et al.*, 1994). According to Labavitch *et al.* (1982) the pistachio protein content was ~30% in the second week of August, but this amount would decrease with time (Ardakani *et al.*, 2006). Protein and fat were reported to decrease over time in the pistachio fruit (Labavitch *et al.*, 1982; Youmbi *et al.*, 2010).

Chlorophyll contents were different at various harvest times. At the earliest harvest time (July 27), the amounts of total chlorophyll, chlorophyll A and chlorophyll B (Figure 3) were maximum, and were reducing over time. Available information indicated that the sooner pistachio harvest, the higher the quality of harvested crop (especially greener color of the kernels). These observations were consistent with those on the pistachio nuts. In comparison to the aforementioned reports, increased amount of chlorophyll, reduced ratio of chlorophyll A to B or increased amount of chlorophyll B in the present study could be due to the difference of the cultivar and different harvest times of cultivars. More importantly, based on the results of the present study, the chlorophyll amount in the first harvest time (July 27) was much more than the previous reports on Turkish, Italian and Greek pistachio (Bellomo and Fallico, 2007), which increase Iranian pistachio use in the confectionery, and sliced and powder pistachio producing industries.

Tree and orchard management

Early harvest times had no significant effect on the length growth of the current year shoot of the new shoots and the number of vegetative and reproductive (flowers) buds and the differences were not statistically significant (Table 3). The flower bud abscission rate was significantly lower in early harvest time (July 27) when compared with those at other harvest times in this study. Amount of this parameter is against to the remaining reproductive buds percentage. Therefore, the percentage of remaining reproductive buds was significantly higher in first harvesting time compared to other treatments. There were no significant differences between the rates of these parameters in other four harvesting times. In addition, there was no significant difference in leaf area between the different harvest times (Table 3).

Reduced reproductive (flower) bud abscission was only significantly different at the first harvest time (July 27) compared with other times. This reduction is not unexpected considering a period of 40 days earlier than the traditional

Table 3. Changes of length growth, percentage of vegetative and reproductive buds, percentage of loss and remaining reproductive buds and leaf area values at different harvest times (July 27, August 6, August 16, August 27, and September 6) of 'Ohadi' pistachio trees. Values are means of four years (2008–2011).

Measured parameters	Harvest times				
	Jul. 27	Aug. 6	Aug. 16	Aug. 27	Sep. 6
Length growth (cm)	10.8 a	11.7 a	11.4 a	10.7 a	11.1 a
Vegetative buds (%)	30.4 a	31.6 a	29.2 a	29.7 a	27.4 a
Reproductive buds (%)	69.6 a	68.4 a	70.8 a	70.3 a	72.6 a
Flower bud abscission (%)	29.6 b	48.3 a	49.7 a	58.4 a	57.5 a
Flower buds retention (%)	70.4 a	51.7 b	50.3 b	41.6 b	42.5 b
Leaf area (cm^2)	96.9 a	103.0 a	94.2 a	92.5 a	90.2 a

Different letters within a row indicate significant differences by Tukey's HSD test at $P \leq 0.05$.

harvest time (September 6). In other words, the plant can use carbohydrate, water and energy to continue growth and development of flower buds and prevent their abscission due to a lack of carbohydrates. Reducing the abscission of the flower buds will increase crop production in the following year and on the contrary, increasing the abscission of the flower buds due to late harvesting will reduce the nut production in the following year, and subsequently increase the amount of alternate bearing phenomenon in pistachio (Esmaeilpour and Khezri, 2006; Panahi and Khezri, 2011). Therefore, one of the advantages of early harvesting of pistachio nuts is the positive effect on the tree crop potential and the decrease in alternate bearing (Esmaeilpour *et al.*, 2010). This phenomenon should be more effective and useful in pistachio cultivars with high alternate bearing intensity.

Environmental effects

The effects of treatments (harvest times) were significant ($P \leq 0.01$) on fresh and dry nut weights, kernel dry weight, bud abscission percentage and remaining reproductive bud percentage, while they were non-significant for length growth, vegetative and reproductive bud percentage (Table 4). The year effects were significant on all above-mentioned parameters except the length growth. The interaction effects of harvest time and year were not significant for fresh and dry weights of nuts and kernels (Table 4). This indicates that the effects due to different harvest treatments are stable over different years and not affected by environmental conditions.

Table 4. Analysis of variance for different parameters on 'Ohadi' pistachio at different harvest times over four years (2008–2011).

Measured parameters	Treatment	Year	Treatment × Year
Nut fresh weight	**	**	ns
Nut dry weight	**	**	ns
Kernel dry weight	**	**	ns
Length growth	ns	ns	ns
Vegetative buds	ns	**	ns
Reproductive buds	ns	**	ns
Flower bud abscission	**	**	ns
Flower bud retention	**	**	ns
Chlorophyll A	**	ns	ns
Chlorophyll B	**	ns	ns
Chlorophyll AB	**	ns	ns

**: Significant at $P \leq 0.01$.

As harvest is traditionally carried out from July to September, temperatures are regularly maximum and relative humidity minimum at this period (Figure 1). Similarly, the observed variations of temperature and relative humidity in different years (2008–2011) were low (3–4 °C and 4–5 %, respectively). Therefore, little variations of these parameters did not affect much pistachio maturity times, whereas considerable changes in temperature during the growing season can be effective on the ripening time (Esmaeilpour *et al.*, 2010): as temperatures increase, the rate of kernel growth increases and subsequently accelerates the maturity of pistachio fruit.

Sustainability promoted by early harvesting

Our findings suggest that pistachio growers should harvest a part of the nuts at earlier times than traditionally, especially when pistachio nut yield is high ("on-years"). It is also advisable to harvest the product earlier in areas lacking adequate heat requirement for pistachio full ripening. Earlier pistachio harvest holds higher nutritional values in protein, chlorophyll and calcium contents, while it is more expensive in terms of price kg^{-1}. Therefore, the main advantage of earlier harvesting is to obtain a healthy product with higher qualitative and nutritional properties. Earlier harvesting also offers the growers the possibility to adjust the alternate bearing intensity of their pistachio trees, by reducing the competition of carbohydrate intake between growing fruits and developing flower buds, as well as by providing the required carbohydrate content from the leaf, what both ultimately reduce the alternate bearing intensity on a long-term period (Esmaeilpour *et al.*, 2010; Panahi *et al.*, 2005). Alternate bearing causes unbalanced production from year to year, reducing its intensity would significantly contribute to balance the market supply in nuts and prevent the price fluctuations (Ferguson, 2005).

There is a wide genetic variation among pistachio cultivars in Iran (more than 150 varieties) and currently more than 10 commercial pistachio cultivars are planted and produced in different areas of the country. Most regions except arid tropical areas and moderate humid regions are suitable to plant and produce pistachio. Therefore, it would be relevant to evaluate the maturity time of each pistachio cultivar in the different regions of the country. Based on consumer's taste and market demand, pistachio should be harvested at the most suitable time, combining agronomic, nutritional and economic traits.

Conclusion

With a quick look at advantages and disadvantages of the different harvest times, it becomes clear that early har-

vesting is preferable in terms of crop health and quality indicators (lower cracked nuts and early-split nuts), nutritional value (higher protein, calcium and nitrogen contents), consumers' quality trait (kernel chlorophyll content), and agronomic trait (lower flower bud abscission). However, the performance of early harvesting is less than the traditional harvest time (September 6) in terms of crop yield (weight of 100 kernels and production per hectare) and maturity (percentage of immature nuts).

Choosing early harvest time would be fully justified if all the studied parameters would have the same ranking value. However today, the most important and perhaps the only parameter valid for producers is the immediate income per hectare. Unfortunately, the other parameters related to safety, nutritional value and sustainability (including market-friendly crop production) are ignored. It is hoped that by valuing each of the above attributes, sufficient attention will be given to crop safety, nutritional value, market and consumers' demands and that finally, production cost per unit area and harvest time will be integrated based on these parameters. Further studies should investigate genetic and agronomic innovations in order to best adapt the Iran's pistachio production to climate changes and market demands.

Acknowledgments

The authors would like to thank the Pistachio Research Center for financial support of this work. They also greatly appreciate the help and co-operation of all their colleagues: Dr. M. Abdolahi, Ir. M. Heidari and Ir. A. Esmaili-Ranjbar during the implementation of this study.

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Received: Jun. 21, 2017
Accepted: Feb. 12, 2018