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Effects of Soil Texture, Irrigation Intervals, and Cultivar on some Nut Qualities and Different Types of Fruit Blankness in Pistachio (Pistacia vera L.)

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ABSTRACT

Fruit blankness is an important problem of pistachio cultivation, which results from many reasons. The aim of this study was to determine the effects of soil texture, irrigation interval, and cultivar on nut quality and blankness of pistachio. The treatments included soil texture (light and heavy), irrigation intervals (24 and 48 days), cultivar (Kaleghoochi and Ahmadaghaei), and their interactions were studied. Measured traits were flower and small fruit abscission rate, nut weight, blank and semi-blank fruit percentage, splitting percentage, and ounce. Symptoms of fruit blankness were determined by anatomical study of blank fruits. Results showed that a 48-day irrigation interval produced nuts with higher quality, lower blankness percentage, higher weight and size, and higher number of split ones than the other treatments. It is assumed that plants produce more fruits by sufficient water supply, thus the competition for photosynthetic products results in smaller, lower-weight seeds. Light soil was more suitable regarding nut qualities, but flower and small fruit abscission rates were higher in light soil probably because of temperature fluctuations in this soil. Anatomical studies showed that blankness could result from a lack of fertilization (parthenocarpy) or embryo abortion (stenospermocarpy). Parthenocarpy mostly occurred in the more sensitive cultivar, Kaleghoochi, while the more tolerant cultivar, Ahmadaghaei, mostly had stenospermocarpic blank fruits. It was also determined that embryo abortion could occur at different stages of development.

Introduction*

Pistachio (*Pistacia vera* L.) is a dioecious tree species that produces commercially valuable edible seeds (Pourmohammadali et al., 2019). Female inflorescences usually have 150-250 flowers with unilocular ovary each containing a single anatropous ovule with basal placentation. Pistachio fruit is of drupe type and the pericarp is composed of flexible exomesocarp (hull) and stiff endocarp (shell). Almost six weeks after pollination and fertilization of egg cell, the pericarp grows to its final size; however, zygote division starts 2 weeks after the complete growth of pericarp. The cotyledonary embryo is first seen almost 12 weeks after pollination and the cotyledons reach their final size in 3 weeks, filling the fruit space completely (Hormaza and Polito, 1996; Ferguson et al., 2005). If the ovule does not develop into a seed or produces an imperfect seed, it will lead to blank or semi-blank fruits. Fruit blankness is one of the most important problems of pistachio cultivation, which causes a severe decrease in trees yield annually. Lack of seed growth can be a result of two situations. In the first situation, pollination occurs but fertilization does not. However, pollination or pollen tube growth in the style are sufficient to stimulate the ovary to develop into a fruit. Lack of fertilization results in the lack of seed development and fruit blankness in the form of parthenocarpy (Crane, 1973; Ferguson et al., 2005). In the second situation, fertilization occurs, but the ovule does not completely develop into a seed due to embryo abortion at early stages. Fruit blankness due to embryo abortion is named stenospermocarpy (Mesejo et al., 2014). Crane (1973) showed that parthenocarpy occurred in pistachio cv. Kerman, but it was not the main reason of fruit blankness. He suggested embryo abortion to be the main

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reason of pistachio fruit blankness. Polito (1999) reported that using radiated pollen that is not able to fertilize the egg cell, parthenocrpy induce pistachio fruit blankness up to three times. Stenospermocarpy was also observed in some other single-seed plants such as mango (Sukhvibul et al., 2005) or avocado (Hershkovitz et al., 2009). Many factors, including temperature (Thompson and Liu, 1973), genotype (Mehlenbacher and Smith, 1991), growth regulators, and nutrients (Stephenson, 1981; Guitian, 1993) have been suggested as the reasons of plant embryo abortion and fruit abnormality. In pistachio, nutrient shortage, rain during bloom time, and water shortage during seed development are among the suggested reasons for embryo abortion (Maggs 1973; Crane et al., 1976; Grundwag, 1976; Jordano, 1989). Embryo abortion in plants can be induced by synthetic growth regulators (e.g., maleic hydrazide) (Mesejo et al., 2014), low temperature treatments (Sukhvibul et al., 2005) or ethylene inhibitors (Hershkovitz et al., 2009).

Soil quality and available water are key factors affecting crop yield. The soil of pistachio cultivation areas is often poor and fertilizer application is necessary for obtaining better fruit yield and quality (Norozi et al., 2019). Pourmohammadali et al. (2019) revealed that pistachio yield is highly sensitive to irrigation features. Moazenpoor et al. (1993) showed that long irrigation intervals increase the pistachio fruit blankness through salt and drought stresses. Soil texture is an important and variable soil feature that is very effective on soil ability to retain water, soil fertility and crop production. Light soils have better ventilation and permeability, but nutrient waste is also high. Heavy soils, have high microbial biomass, water and nutrient maintenance ability and lower need of irrigation, but poor ventilation and permeability (Sujihara et al., 2010; Mohamadi, 2006). Because different cultivars may respond to external conditions in a different way, our experiments were done on two different cultivars including Kaleghoochi and Ahmadaghaei. Kaleghoochi is a sensitive cultivar to abiotic stresses and usually has higher percentage of fruit blankness in comparision with Ahmadaghaei, which is a more tolerant cultivar with lower production of blank fruits (Esmaeelpour, 2005).

Since dry pistachio nuts are normally presented to market and used by people, high quality indices and being completely filled by seeds are of great importance for pistachio nuts. In addition, fruit blankness imposes high economic losses to pistachio cultivation annually. This study, therefore, aimed to investigate the effects of two soil textures and two irrigation intervals on nut qualities, flower abscission, and occurrence of parthenocarpy and embryo abortion at three early stages of its development, in two commercial pistachio cultivars, Kaleghoochi and Ahmadaghaei.

Materials and methods

Plant material collection

Flower and fruit samples of two pistachio cultivars, Ahmadaghaei and Kaleghoochi, were harvested from four orchards located in Noogh region of Rafsanjan, Iran in 2011. Because inflorescence buds were formed in the previous year, the meteorological information was collected from 2010 and 2011 (Table 1) (www.irimo.ir).

Table 1. Meteorological information of the year of pistachio sampling and the year before that.

Year	Annual rainfall (mm)	Relative humidity (%)	Annual temperature (°C)
2010	65.5	28	19
2011	96.6	31	19.5

Soil texture of orchards was previously determined using hydrometer method in which, the percentage of three grains of sand, silt and clay was obtained and the texture was defined by soil textural triangle (Mohamadi, 2006). The four orchards had different soil texture and irrigation intervals as: orchard A (light soil, 24-day intervals), orchard B (light soil, 48-day intervals), orchard C (heavy soil, 24-day intervals) and orchard D (heavy soil, 48-day intervals). Soil analyses of the orchards are presented in Table 2.

Table 2. Soil analysis of the pistachio orchards

Orchard	Clay (%)	Silt (%)	Sand (%)	Texture	Depth (cm)	pH	EC s (dS/m)	K (mg/kg)	P (mg/kg)
A	19.8	25.6	54.6	Sandy loam (light)	30-60	8.23	3.90	310	6.4
B	19.8	17.6	62.6	Sandy loam (light)	30-60	7.83	7.71	360	3.2
C	39.8	31.6	28.6	Clay loam (heavy)	30-60	7.68	13.21	794	6.8
D	39.8	31.6	28.6	Clay loam (heavy)	30-60	7.68	13.21	794	6.8

Table 2. Continued

OC (%)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	B (ppm)	SAR	Mg s (meq/l)	Ca s (meq/l)	Na s (meq/l)
0.219	0.54	0.51	2.12	1.40	5.76	9.70	4.60	6.66	23.01
0.013	4.03	0.24	1.28	0.97	3.70	10.99	10.74	20.94	43.75
0.138	0.53	0.26	1.78	1.82	9.54	16.31	13.43	34.33	79.71
0.138	0.53	0.26	1.78	1.82	9.54	16.31	13.43	34.33	79.71

Orchards C and D were connected and their soil was analyzed for once.

The samples were collected from 25-year old female trees that were pollinated with the male trees of *P. vera* grown in the orchards. Eighteen trees (6 neighboring trees as one repeat) of each cultivar were selected at each orchard. Samples were collected from four sides of each tree. Sampling time for experiments was as fallowed: flower and small fruits abscission rate (8 weeks after full bloom), anatomical study of blank fruits (15 weeks after full bloom and 20 weeks after full bloom), total blank and semi-blank fruit rate and nut qualities (20 weeks after full bloom). All the samples were transferred to laboratory. The flower and small fruit abscission rate were counted from the inflorescences immediately after transfer. For anatomical studies, the blank and semi-blank fruits were fixed in FAA immediately after transfer. For nut quality experiments the hull was removed after harvest and the nuts (seed+shell) were air dried for 48 h and investigated thereafter.

Flowers and small fruits abscission rate

In each repeat (6 trees, as mentioned above), one inflorescence was selected from each of the four sides of the tree (24 inflorescences). The loss remainders of flowers and fruits on the inflorescence axis were counted. The maintained flowers and fruits were also counted. Then, the ratio of the loss remainders was expressed as a percentage of the total (loss remainders + maintained flowers and fruits).

Anatomical study for determination of the types of blankness

From each repeat, at least 10 blank fruits were fixed in FAA (formaldehyde: acetic acid: 70% ethanol, 5:5:90, v/v/v) for 24 h, washed with water several times, dehydrated in 30%, 50%, 70%, 80 %, 100% ethanol series and embedded in paraffin. 5 µm sections were cut by a rotary microtome (micro *Tec*, Germany), put on glass slides, stained by fast green and safranin (Johansen, 1940), observed by a light microscope (Olympus model CX21, Japan) and photographed. The ratio of each type of blankness was expressed as percentage.

Nut weight, total blank and semi-blank fruits, split nuts, ounce

From each repeat, 100 randomly selected dry nuts were weighted and the weight of one fruit was expressed as 0.01 of the total weight. The ratio of blank and semi-blank fruits and the ratio of split nuts were expressed as a percentage. The number of groups of five dry nuts in 142 g was measured and expressed as ounce.

Statistical analysis

Split split plot experiment was conducted in the form of blocks with three repeats. Analysis of variance of data was done using SAS 9.1 and MSTATC 5.4 statistical softwares. Data are presented as mean of three repeats $\pm$ standard error of means and compared using Duncan multiple range test at 0.01 and 0.05 significance levels.

Results

Anatomy of blank fruits

Ovule anatomy of blank fruits, after fruit set (15 days after full bloom) and at harvest time (20 weeks after full bloom) showed two status. 1: There was no trace of embryo sac in the nucleus tissue along with some degree of cell degradation and color dispersion. These cells were different from other parts of nucleus regarding tonality (Fig. 1A). These ovules showed the degradation of the major part of nucleus along with hypostase darkness (Fig. 1B). This status showed that the unfertilized ovules led to parthenocarp fruits. 2: an embryo sac was seen in the nucleus tissue with or without an embryo. Therefore, the embryo sacs without an embryo had endosperm only (Fig. 1C). In embryo sacs with an embryo, different developmental stages could be found including globular (Fig. 1E), heart-shaped (Fig. 1G) and cotyledonary (Fig. 1I) embryos. These four states were associated with a high degree of tissue degradation at harvest time (Figs. 1D, F, H, J). This status shows the fertilized ovules in which the embryos are aborted at different stages of development.

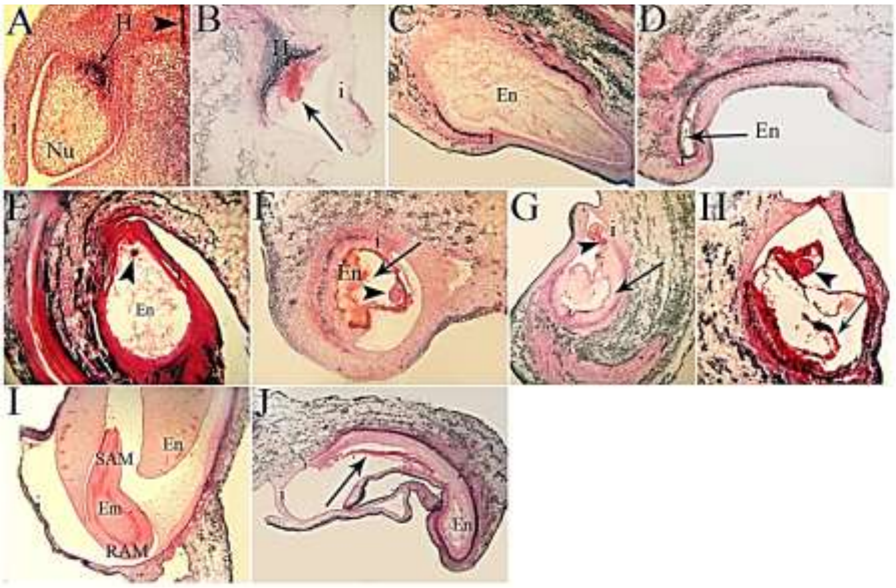

Fig. 1. A-J. Anatomical structure of ovule in blank fruits of *P. vera* cv. Kaleghoochi in longitudinal section. A. Ovules without embryo sac having a dark hypostase after fruit set, the arrowhead points to the funicule, where the vessels were cut, 15X. B. Ovules without embryo sac having a dark hypostase at harvest, the arrow points to burnout of nucellus, 7X. C. Embryo sac with endosperm and no embryo after fruit set, 3X. D. Embryo sac with endosperm and no embryo at harvest, 3X. E. Embryo sac with endosperm and globular embryo (arrowhead) after fruit set, 5X. F. Embryo sac with endosperm and globular embryo (arrowhead) at harvest with degradation signs of embryo sac cells (arrow), 7X. G. Embryo sac with endosperm (arrow) and heart-shaped embryo (arrowhead) after fruit set, 10X. H. Embryo sac with endosperm (arrow) and heart-shaped embryo (arrowhead) at harvest, 7X. I. Embryo sac with cotyledonary embryo and endosperm remaining after fruit set, 4X. J. Embryo sac with cotyledonary embryo that is degrading (arrow) and endosperm that is remaining at harvest, 3X. Nu: nucellus, i: integument (ovule coat) H: hypostase, En: endosperm, Em: embryo, SAM: shoot apical meristem, RAM: root apical meristem.

Table 3. Analysis of variance of some nut qualities and different causes of fruit blankness in pistachio under the effects of soil texture, irrigation interval, and cultivar

Sources of variation	df	Flower and fruit abscission	Blank and semi-blank fruits	Nut weight	Ounce	Split nuts	Parthenocarpy	Endosperm only	Globular embryo abortion	Heart-shaped embryo abortion	Cotyledonary embryo abortion
Repeat	2	3.04	5.54	0.011	4.23	2.34	0.0001	0.0072	0.000078	0.00015	0.0015
Soil	1	160.16*	748.16**	0.028**	282.89**	3012.80**	0.148**	0.0183ns	0.026**	0.031**	0.029ns
Error1	2	2.04	14.5	0.01	3.42	67.22	0.00062	0.007	0.00011	0.0001	0.0167
Irrigation	1	4.16ns	170.66**	0.11**	72.66**	1745.92**	0.226**	0.391**	0.000042ns	0.002**	0.354**
Soil×irrigation	1	13.5ns	112.66**	0.022ns	0.016ns	192.1ns	0.308**	0.357**	0.000032ns	0.002**	0.137**
Error2	4	1.46	31.04	0.0098	2.03	34.13	0.0003	0.0002	0.00023	0.00015	0.0018
Cultivar	1	13.5ns	2.66 ns	1.53**	1081.2**	8.52ns	0.148**	0.59**	0.026**	0.03182**	0.9349**
Soil×cultivar	1	13.5ns	560.66**	0.024ns	137.8**	320.74ns	0.417**	0.207**	0.027**	0.03182**	0.0631*
Irrigation×cultivar	1	4.1ns	504.16**	0.0077ns	6.09ns	0.093ns	0.308**	0.001ns	0.000032ns	0.002**	0.5881**
Soil×irrigation×cultivar	1	13.5ns	60.16*	0.018ns	9.88ns	559.7*	0.226**	1.413**	0.000042ns	0.002**	0.2941**
Error3	8	28.66	9.04	0.009	2.15	71.51	0.0036	0.0049	0.0001	0.00015	0.0056
CV%		6.66	12.75	8.95	5.24	11.74	14.46	25.31	36.79	33.18	26.47

* and ** mean significance at 0.01 and 0.05 levels and ns means non-significant

Flower and fruit abscission

The results showed that only the simple effect of soil was significant on flower and fruit abscission (Table 3). This trait was 6.22% lower in heavy soil than the light soil (Table 4).

Total number of blank and semi-blank fruits

The simple effects of soil and irrigation and all the interactions were significant on total blank and semi-blank fruits (Table 3). This trait was 38.27% lower in light soil than heavy soil and 20.34% lower in 48-days irrigation than 24-days irrigation (Tables 4). The results of interactions are given in Tables 5 and 6.

Nut weight
The simple effects of all three factors were significant on nut weight (Table 3). The higher weights were observed in light soil (18.33% more than heavy soil), 48-days irrigation (12.06% more than 24-days irrigation), and in cv. Kaleghoochi (35.38% more than cv. Ahmadaghaei) (Table 4). The Dual and triple interactions showed no significance.

Ounce
The simple effect of all three factors was significant on nut number in one ounce (Table 3). This number was higher in heavy soil (21.88% more than light soil), in 24-days irrigation (11.48% more than 48-days irrigation), and in cv. Ahmadaghaei (38.71% more than cv. Kaleghoochi) (Table 4). The Dual interaction of soil×cultivar was also significant. The highest and lowest nut numbers in one ounce were observed in heavy soil × cv. Ahmadaghaei (40.50 nuts) and light soil × cv. Kaleghoochi (20.21 nuts), respectively (Tables 3 and 5).

Table 4. The simple effects of soil texture, irrigation intervals, and cultivar on some nut qualities and different causes of fruit blankness in pistachio

Soil	Flower and fruit abscission (%)	Blank and semi-blank fruits (%)	Nut weight (g)	Ounce	Split nuts (%)	Parthenocarpy (%)	Endosperm only (%)	Globular embryo abortion (%)	Heart-shaped embryo abortion (%)	Cotyledonary embryo abortion (%)
Light	83.00a	18.00b	1.20a	24.52b	83.23a	0.210a	0.25a	0.002b	0.001b	0.320a
Heavy	77.83b	29.16a	0.98b	31.39a	60.80b	0.050b	0.30a	0.068a	0.730a	0.250a
Irrigation										
24-days	80.83a	26.25a	1.02b	29.60a	63.48b	0.030b	0.40a	60.030a	0.020b	0.160b
48-days	80.00a	20.91b	1.16a	26.20b	80.54a	0.230a	0.15b	30.030a	0.040a	0.400a
Cultivar										
Ahmadaghaei	79.66a	23.91a	0.84b	34.66a	72.60a	0.054b	0.43a	0.060a	0.073a	0.480a
Kaleghoochi	81.16a	23.25a	1.30a	21.24b	71.40a	0.210a	0.21b	0.002b	0.001b	0.087b

Table 5. Dual interactions of soil texture, irrigation intervals, and cultivar on some nut qualities and different causes of fruit blankness in pistachio

Soil	Irrigation	Flower and fruit abscission (%)	Blank and semi-blank fruits (%)	Nut weight (g)	Ounce	Split nuts (%)	Parthenocarpy (%)	Endosperm only (%)	Globular embryo abortion (%)	Heart-shaped embryo abortion (%)	Cotyledonary embryo abortion (%)
Light	**24-days**	82.66a	18.50c	1.10b	26.29c	77.52b	0.001d	0.500a	0.002b	0.001c	0.120c
	48-days	83.33a	17.50c	1.30a	22.76d	88.92a	0.420a	0.001c	0.002b	0.001c	0.510a
Heavy	**24-days**	79.00ab	34.00a	0.94c	33.10a	49.45c	0.070b	0.310b	0.070a	0.050b	0.200bc
	48-days	76.66b	24.33b	1.02bc	29.68b	72.17b	0.030c	0.300b	0.060a	0.090a	0.290b
Soil	**Cultivar**										
Light	**Ahmadaghaei**	81.50ab	13.50c	0.98c	28.84b	78.47a	0.001c	0.500a	0.001b	0.001b	0.460a
	Kaleghoochi	84.50a	22.50b	1.42a	20.21d	78.97a	0.400a	0.001d	0.003b	0.001b	0.170b
Heavy	**Ahmadaghaei**	77.83b	34.33a	0.70d	40.50a	57.75b	0.100b	0.370b	0.130a	0.140a	0.490a
	Kaleghoochi	77.83b	24.00b	1.27b	22.28c	63.87b	0.001c	0.240c	0.001b	0.001b	0.001c

Irrigation	Cultivar										
24-days	Ahmadaghaei	79.67a	22.00b	0.79c	36.91a	64.02b	0.070b	0.570a	0.070a	0.050b	0.200b
	Kaleghoochi	82.00a	30.50a	1.26b	22.48c	62.95b	0.001d	0.240b	0.002b	0.001c	0.120bc
48-days	Ahmadaghaei	79.67a	25.83ab	0.89c	32.43b	81.20a	0.030c	0.300b	0.060a	0.090a	0.760a
	Kaleghoochi	80.33a	16.00c	1.43a	20.01d	79.88a	0.400a	0.001c	0.002b	0.001c	0.050c

Splitting

Soil and irrigation had significant simple effects on shell dehiscence of pistachio nuts (Table 3). Light soil (26.94% more than heavy soil) and 48-days irrigation (21.18% more than 24-days irrigation) caused higher percentage of split nuts (Table 4). Among all interaction, only the triple interaction was significant. The highest rate of split nuts was observed in Ahmadaghaei cv. in light soil and 48-days irrigation (88.40%) as well as in Kaleghoochi cv. in light soil and 48-days irrigation (89.43%) (Tables 3 and 6).

Table 6. Triple interactions of soil texture, irrigation intervals, and cultivar on some nut qualities and different causes of fruit blankness in pistachio

Soil	Irrigation	Cultivar	Flower and fruit abscission (%)	Blank and semi-blank fruits (%)	Nut weight (g)	Ounce	Split nuts (%)	Parthenocarpy (%)	Endosperm only (%)	Globular embryo abortion (%)	Heart-shaped embryo abortion (%)	Cotyledonary embryo abortion (%)
Light	24-days	Ahmadaghaei	80.00ab	11e	0.93c	30.47c	86.53ab	0.001d	1.000a	0.001b	0.001c	0.001e
		Kaleghoochi	85.33a	26bc	1.28b	22.11e	68.50cd	0.001d	0.001e	0.003b	0.001c	0.240d
	48-days	Ahmadaghaei	83.00ab	16de	1.04c	27.21d	88.40a	0.001d	0.001e	0.001b	0.001c	0.930a
		Kaleghoochi	83.76ab	19cd	1.57a	18.30f	89.43a	0.840a	0.001e	0.003b	0.001c	0.001e
Heavy	24-days	Ahmadaghaei	79.33ab	33ab	0.63d	43.36a	41.50e	0.140b	0.140d	0.140a	0.110b	0.400c
		Kaleghoochi	78.67ab	35a	1.24b	22.85e	57.40d	0.001d	0.480c	0.001b	0.001c	0.001e
	48-days	Ahmadaghaei	76.33b	35a	0.75d	37.64b	74.00bc	0.070c	0.600b	0.130a	0.180a	0.590b
		Kaleghoochi	77.00b	13de	1.30b	21.71e	70.30cd	0.001d	0.001e	0.001b	0.001c	0.001e

Blank parthenocarpic fruits

The simple effect of all three factors was significant on parthenocarpy (Table 3). Light soil (76.19% more than heavy soil), 48-days irrigation (86.95% more than 24-days irrigation), and cv. Kaleghoochi (74.28% more than cv.Ahmadaghaei) revealed more parthenocarpic fruits (Table 4). All the interactions were significant on this trait (Tables 3, 5 and 6).

Blank fruits with endosperm only

Irrigation and cultivar had significant simple effects on producing fertilized seeds with no embryo (Table 3). 24-days irrigation (62.5% more than 48-days irrigation), and cv. Ahmadaghaei (51.16% more than cv. Kaleghoochi) had the highest rate of this kind of fruit blankness (Table 4). Dual interactions of soil×irrigation and soil×cultivar and the triple interaction also showed significance (Table 3, 5 and 6).

Blank fruits with globular embryo

Simple effects of soil and cultivar were significant in causing embryo abortion at globular stage (Table 3). Abortion at this stage was mostly seen in heavy soil (97.05% more than light soil) and in cv. Ahmadaghaei (96.66% more than cv. Kaleghoochi) (Table 4). Among all interactions, the dual interaction of soil×cultivar was significant. cv. Ahmadaghaei × heavy soil displayed the highest rate of this symptom (Tables 3 and 5).

Blank fruits with heart-shaped embryo

All three factors showed significant simple effects on embryo abortion at heart stage (Table 3). Heavy soil (99.86% more than light soil), 48-days irrigation (50% more than 24-days irrigation), and cv. Ahmadaghaei (98.63% more than cv. Kaleghoochi) had the greatest impact (Table 4). All the interactions were significant as well (Tables 3, 5 and 6).

Blank fruits with cotyledonary embryo

Simple effects of irrigation and cultivar were significant in causing cotyledonary embryo abortion (Table 3). Abortion at this stage was mostly seen in 48-days irrigation (60% more than 24-days irrigation) and in cv. Ahmadaghaei (81.87% more than cv. Kaleghoochi) (Table 4). All the interactions were also significant (Tables 3, 5 and 6).

Discussion

Abscission of flower and small fruits occurs normally in some plants, including pistachio, which is a determinant factor for the final fruit set. This problem can be due to the accumulation of growth regulators and nutrients in branch tips (Ayfer et al., 1990). Temperature has been suggested to influence the abscission of flower and small fruits in pistachio (Ayfer, 1959). According to Sugihara et al. (2010) moisture and temperature have higher fluctuations in sandy soils than clay soils. In this study, abscission was mostly seen in light soil. Generally, plants have a high evaporation during bloom time, therefore, if there is not enough water supply from the soil, the leaves, which have more osmotic power would, resorb water from flowers and small fruits, leading to their abscission (Ayfer, 1959). In this study, abnormal fruits showed cell degradation signs in anatomical experiments. Similarly, abscission of flower and fruit in avocado was associated initially with deterioration of the nucellus within the developing ovule in early drop, and subsequently with deterioration of the integument (seed coat) in later drop (Garner and Lovatt, 2016). The abscission rates of flower and fruit and the fruit set were also related to the pollen genotype (Kardush et al., 2009). Abscised fruit of avocado contained greater abscisic acid concentrations than persisting fruits (Garner and Lovatt, 2016).

The results showed that longer irrigation interval produces nuts with higher quality, so that, the nuts had lower blankness, higher weight and size and higher number of split ones in 48-day irrigation intervals. Generally, the plants produce better yield when they have more water supply. Because more available water helps to the plant growth and nutrient absorption and decreases the drought-induced ionic toxicity of soil. In well irrigated trees, the viability of seeds is normally increased (Verdu and Gracia-Fayos, 1998). However, research show that some plants have higher seed yield in lower water supply. In these plants, sufficient water results in an increase in chlorophyll content and vegetative and generative growth, therefore, more inflorescences, flowers, fruits and seeds are formed. In this situation a severe competition is created between the seeds which are strong sinks of photosynthetic products and chemical minerals. This ultimately results in smaller, lower-weight seeds or even in failure of some seeds to become filled and open their shell. Similar results have been reported in *Lallemantia* sp. (Maleki Farahani and Abdollahi, 2014), *Allium cepa* (Singh and Riwar, 1996) and *Foenicolum vulgar* (Koocheki et al., 2006). Specially, when high water supply interacts with heavy soil that helps its maintenance, the blankness rate is elevated. Regarding the reproduction power, the role of many other factors such as pollen genotype (Kardush et al., 2009), nutrients, alternate-bearing nature (Ferguson, 2005) and disease (Tezerji, 2009) is of great importance as well. It is also documented that pollination in suitable blooming stage of female trees leads to higher yield and quality of pistachio nuts (Sharifkhah et al., 2020).

Light soil was shown to produce larger and higher-weight nuts and higher percentage of splitting. If pistachio trees need lower water to produce high-quality nuts, it is explainable that light soil with better ventilation and permeability is a more suitable soil. Light soil showed higher percentage of blank fruits because filled fruits had larger and higher-weight seeds. In another research on pistachio, it was determined that high clay content of soil reduced the pistachio yield considerably, while the trees produced higher yields in sandy soils. The authors assumed that negative effects of high EC values of groundwater decreased partly in soils with less clay content (Salehi and Hosseinifard, 2012).

A previous research reported that cv. Kaleghoochi had larger, higher-weight nuts with higher percentage of splitting, and also higher rate of blankness than cv. Ahmadaghaei (Esmaeelpour, 2005). Similarly, the results of this study indicate that cv. Kaleghoochi produced larger and higher-weight nuts. However, the effect of cultivar was not significant on blankness rate and nut dehiscence. The weight and size of seeds seem to be more genetically determined traits because they somehow determine the morphology of the seeds. However, the rate of blankness and shell dehiscence are more variable traits that may be influenced by external factors. Similarly, Ferguson (2005) believes that blankness rate is not always constant in one cultivar and differs between individual trees and in different years. In contrary, Bolandnazar et al. (2009) showed that different pistachio cultivars had different blankness percentages in equal conditions. Some research has shown that foliar spraying of minerals does not affect the rate of fruit blankness in pistachio (Davarynejad et al., 2009; Soleimanzadeh et al. 2013). Esmaeelpour (2005) reported the fruit blankness rate in cv. Kaleghoochi and cv. Ahmadaghaei as 34-35% and 7-8% respectively. In another research, cv. Kaleghoochi had significantly higher blankness than cv. Ahmadaghaei (Tajabadipour, 2007).

Although blankness mainly happened in light soil and long irrigation intervals as mentioned above, all treatments showed some rates of blankness, happening at different developmental stages as described below. Parthenocarpy may occur as a result of egg cell failure of fertilization due to pollen shortage or pollen tube abnormality, or as the result of sperm cell failure of fertilization due to embryo sac abnormalities, including absence, degeneration or being in an incorrect place (Shuraki and Sedgley, 1996; Miyajima, 2006). Parthenocarpy is a common feature in some crops such as citrus, but it is relatively uncommon in single-seed fruits (Ferguson et al., 2005). However, some research has documented this phenomenon in pistachio (Crane, 1973; Shuraki and Sedgley, 1996; Polito, 1999), mango (Sukhvibul et al., 2005) or avocado (Hershkovitz et al., 2009). For example, only 25% of abscessed fruits were fertilized in a research on avocado. It indicates that the majority of flowers and fruits of avocado abscise due to a lack of pollen germination and a lack of fertilization (Garner and Lovatt, 2016). In this study, parthenocarpy was observed in pistachio ovule sections, and cv. Kaleghoochi, light soil, and 48-day irrigation intervals had higher effects on parthenocarpy incidence. It seems that parthenocarpy is a frugality for plants. Embryo sac or pollen tube may become degenerated in light soil and long irrigation intervals that bring more drought stress, so that ovule development to a seed does not start at all. In soil × irrigation interaction, the highest and the lowest parthenocarpy were observed in light soil with long irrigation intervals, and in light soil with short irrigation intervals, respectively. This observation may indicate that if light soil is in combination with sufficient watering, it will show lower parthenocarpy; however, if watering does not compensate for light soil potential of high evaporation, this soil type will not be a good choice. cv. Kaleghoochi produces more parthenocarp fruits than cv. Ahmadaghaei, which could be a result of its more sensitivity to abiotic stresses, such as freezing damage, which degenerates the embryo sacs. According to Verdu and Gracia-Fayos (1998) the probable stimuli of parthenocarpy are freezing damage to ovule, incitement by foreign pollen, competition imbalance between vegetative and generative structures, and imperfect auxin synthesis. Parthenocarpy is sometimes considered as a plant defense against pathogens. If insects leave their larvae in a parthenocarp fruit that lacks nutrients, they have wasted energy and time for reproduction (Travest, 1993). Frugivores cannot distinguish between blank and filled fruits as well (Janzen 1985). Parthenocarpy happens in other *Pistacia* species (Jordano, 1989) and other genera of Anacardiaceae including *Rhus* (Grimm, 1912), *Toxicodendron* (Copeland and Doyel, 1940), and *Schinopsis* (Gonzales and Vesprini 2010).

A seed containing a relatively developed endosperm but without an embryo can be the result of single fertilization of central cell or embryo abortion at very early stages, so that, no evidence of embryo would be remained in sections. Single fertilization is documented in some plants including maize (Kato, 1997) and zinnia (Miyajima, 2006). Abortion can also occur in embryos at different developmental stages, such as in globular, heart-shaped or cotyledonary stages. In mango, low temperature treatment 3 days after hand pollination significantly increased the percentage of stenospermocarpic fruit (Sukhvibul et al., 2005). The results of this study show that in cv. Ahmadaghaei, the blankness after fertilization is more common comparing parthenocarpy that is more associated with cv. Kaleghoochi. The effect of cultivar on this kind of traits has been reported in other plants like hazelnut (Mehlenbacher and Smith, 1991) and mango (Sukhvibul et al., 2005). It seems that the more tolerant cultivar acquiesces to blankness at more progressed stages of seed development. Ovules with only endosperm or with an embryo aborted at globular stage were mostly observed in light soil with short irrigation intervals or in heavy soil that bring less drought stress. While, embryo abortion at heart-shaped and cotyledonary stages were mostly associated with stressful conditions, the situation in which parthenocarpy usually occurs. According to Shuraky and Sedgley (1996) embryo abortion at cotyledonary stage results in semi-blankness of fruits. It can be assumed that the production of semi-blank fruits, which contain a non-viable seed, is not affordable, therefore, happens when the plant is forced to do it. Fruit blankness has evolutionary benefits for plants including *Pistacia* (Jordano, 1989). It occurs at different times considering the soil or water conditions and the amount of loss that the plant must undertake. Gonzales and Vesprini (2010) showed that empty fruits of *Schinopsis balancae* are the result of either embryo abortion or total absence of an embryo as the most common condition. They believe that parthenocarpy is a pleisiomorphic trait within Anacardiacea which may have adaptive value or be an evolutionary constraint.

At the end it should be noted that pistachio is an alternate-bearing species, meaning that fruit production is excessive in one year, followed by a decrease in fruit production in the following year. This is the characteristic of some species such as pistachios, apples, mangoes, and plums (Davarynejad et al., 2009). Therefore, it is suggested to investigate the rate of different types of blankness in two successive years in future projects.

Conclusion

From the obtained results of the present study it can be concluded that the nut quality of pistachio depends on the soil, irrigation, and cultivar. The blankness rate was higher in light soil texture and long irrigation interval (48-days vs 24-days), but the remaining nuts had better quality because they were higher-weight and had higher percentage of splitting. cv. Kaleghoochi had larger nuts than cv. Ahmadaghaei, but the rate of blankness was not different between two cultivars. Based on the results, parthenocarpy and embryo abortion are the symptoms that cause fruit blankness in pistachio. Light soil and long irrigation intervals showed higher parthenocarpy. In addition, cv. Kaleghoochi had higher rate of parthenocarpy while cv.

Ahmadaghaei showed higher rate of embryo abortion. It was revealed that embryo abortion could occur at different stages of embryo development depending on the soil and irrigation conditions.

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Conflict of interest

All authors agree on the content of the paper and have no conflict of interest.

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