Characterization of biochemical traits, volatile compounds, and sensorial attributes of pistachio (*Pistacia vera* L.) nuts and oil as affected by regulated deficit irrigation and roasting

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Abstract

Prolonged drought poses a critical challenge for pistachio cultivation in Mediterranean regions. Water-saving strategies and selecting adapted cultivars can help maintain sustainable production. This study was conducted in the experimental orchard of the Regional Center of Agricultural Research of Sidi Bouzid, Tunisia. Four pistachio cultivars (Mateur, Elguetar, Kerman, and Ohadi) grafted on *P. atlantica* rootstock were used to investigate the impact of regulated deficit irrigation (RDI) on yield, nut composition, volatile compounds, phenolic compounds, fatty acid profile, and sensory analysis. Three irrigation treatments were applied: control (T0) received 100% crop evapotranspiration (ETc) during all stages of nut development; RDI treatment (T1) received 50% ETc during stages I and II of nut development, followed by 100% ETc during stage III; and stressed treatment (T2) received 50% ETc during two growing seasons (2017 and 2018). Pistachio nuts were immersed in a solution of NaCl (5% w/v) for 5 min and then introduced in an oven for 2 h at 120°C to obtain 'roasted' pistachio for volatile and sensorial analysis. Results showed that RDI saved 20% of irrigation water during stages I and II of nut development while maintaining similar yield, nut composition, and fatty acid profile as that of control. Moreover, the volatile compounds content and oil yield were enhanced under drought stress. Roasting enhanced the perception of volatile compounds, especially nitrogenous ones. Cultivars Mateur and Ohadi showed high sensory quality, with Ohadi achieving the highest consumer satisfaction despite lower yield and dehiscence rate. Cultivar Mateur was suitable for high-density planting in semiarid environments. Overall, RDI proved effective for increasing water use efficiency without compromising pistachio quality, suggesting its suitability for arid and semiarid orchards.

Keywords: nut quality; pistachio; regulated deficit irrigation; roasting; volatile compounds

Introduction

Pistachios are among the most nutritious nuts consumed as raw or roasted, with or without salt (Dini *et al.*, 2019). The pistachio tree has the reputation of being drought-tolerant and saline-resistant species cultivated under rainfed conditions in its region of origin (Rieger, 1995). In Tunisia, pistachio production is around 3,190 tons with a cultivation area of 27,153 hectates (ha) (FAOSTAT, 2024). Recently, extension of

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pistachio cultivation has taken place in west-central Tunisia because of economic importance of pistachio nuts. New pistachio orchards are planted under high-density system, which increases water requirement. However, water availability for agriculture continues to decline due to changes in global climactic conditions. Therefore, great emphasis is placed on irrigation management in arid regions to increase water use efficiency (Abboud *et al.*, 2019). Regulated deficit irrigation (RDI) is a system of managing water supply by imposing water deficits in specific phenological stages, which are found to be less sensitive, without loss of economic benefits (Carbonell-Barrachina *et al.*, 2015). In pistachio production, development of nuts is characterized by three different periods (Goldhamer, 1995): stage I starts at the beginning of nut growth and ends when its maximum size is reached; during stage II, hardening of shells takes place; and finally, stage III is the period of kernel growth.

Pistachios are also considered functional food on account of their high contents of monounsaturated fatty acids, vitamins, minerals, sterols, polyphenols, and high antioxidant potential (Hojjati *et al.*, 2013; Satil *et al.*, 2003). Pistachio nuts contain about 50% of oil, with maximum of oleic acid (54.4–71.8%), linoleic acid (16.7–35.3%), palmitic acid (7.2–10.5%), stearic acid (0.9–10.5%), and linolenic acid (up to 2%) (Arena *et al.*, 2007). These fatty acids have important therapeutic properties, such as reducing triacylglycerols, low-density cholesterol (LDL), total cholesterol, and glycemic index (Taghizadeh *et al.*, 2018). Among different nuts, extraction of oil is an interesting alternative due to their high lipid content, such as almonds (53%), pistachios (50%), and walnuts (65%) (Sena-Moreno *et al.*, 2015). Nutrient oil is used in the food and cosmetics industry, adding value to products.

Raw nuts, even if well appreciated, have a rather bland aroma, because of some compounds that are responsible for characteristic flavor generated during the roasting process (Aceña *et al.*, 2010). Roasting is a key method in pistachio processing used to enhance sensory properties and aroma attributes of nuts influencing consumer's acceptance (Aceña *et al.*, 2011). It was reported that roasting of pistachio nuts increased free fatty acids, reduced total available carbohydrates, decreased moisture of nuts, produced a more crispy and fragile texture, enhanced Maillard reaction and degradation of lipids, and created desirable pigments and aroma compounds (Hojjati *et al.*, 2013).

In this context, the present study was conducted to analyze the impact of RDI on pistachio nuts and oil bioactive compounds, volatile compounds, and sensorial analysis after the roasting process of cultivars Mateur, Elguetar, Kerman, and Ohadi grown under semiarid conditions.

Material and Methods

Plant material

The trial was carried out in the Regional Center of Agriculture Research (CRRA, Sidi Bouzid) in west-central Tunisia (9°43' E, 35°01' N; altitude 354 m) during the growing seasons of 2017 and 2018. Age-wise, 17-year-old pistachio trees of cultivars (cv.) Mateur, Elguetar, Kerman, and Ohadi grafted on *P. atlantica* rootstock were studied. Trees were trained to the standard open vase system planted at a spacing of 6 × 6 m, and grown under standard conditions of fertilization, pruning, pollination, pest, and disease control. The surveyed trees were selected for uniform trunk and canopy size.

Experimental design

The trial was set in a complete randomized block design arrangement. The area assigned for the experiment was divided into three main blocks corresponding to each irrigation treatment (T0 = 100% ETc: irrigation at full water requirements; treatment T1 = RDI: irrigation at 50% water requirements during stages I and II of nut development, and 100% ETc during stage III; and treatment T2 = 50% ETc: irrigation at 50% water requirements). Each main block was then divided into four experimental units, one for each cultivar. Each cultivar (experimental plot) had on nine trees (eight females and one male). Experimental area had semi-arid Mediterranean climate with a low annual rainfall of 200 mm irregularly distributed over the growing season and a reference evapotranspiration (ETo) of 1,400 mm. The soil was aridisol, with a sandy-clay texture (clay = 13.69%, silt = 1.11%, and sand = 84.7%), 10% active $CaCO_3$, basic pH of 8.6, and slightly saline concentration (3.6 dS/m). The irrigation water was slightly saline and had a high concentration of nitrate (EC = 1.5 dS/m; SAR = 2.4; NO_3^- = 50 ppm; pH = 7.9; and HCO_3^- = 16.0 meq^{-1}) (Akrimi *et al.*, 2020).

Applied treatments

Regulated deficit irrigation treatments

The treatments consisted of three different irrigation regimes (Table 1) during the two growing seasons. The phenological stages considered during RDI treatments were those suggested by Goldhamer and Beede (2004)—stage I: from sprouting until the end of rapid nut growth; stage II: from maximum nut size until the beginning of kernel growth; and stage III: from the beginning of kernel growth until harvest.

The applied treatments were as follows:

- Treatment (T0): trees received water to cover estimated evapotranspiration losses (100% ETc), also referred to as 'control';
- Treatment (T1): trees received 50% ETc during stages I and II, and 100% ETc during stage III, also referred to as 'RDI';
- Treatment (T2): trees received 50% ETc during the growing season, also referred to as 'stressed'.

Drip irrigation was applied for 3 days every week, and was controlled and adjusted weekly according to the potential of soil matrix measured by tensiometers located 0.5 m from the drip head at depths of 30 cm and 60 cm. A drip line was utilized in each tree row, with four self-compensating drippers (4 L/h) per tree, 0.5 m apart. The amount of provided water was calculated based on crop ETc and crop coefficient (Kc) according to the FAO method: ETc = ETo × Kc (Allen *et al.*, 1998). The mean Kc values provided by Goldhamer (1995) were used: 0.39, 1.06, and 1.14 for stages I, II, and III, respectively.

Roasting treatments

After manual nut peeling, pistachio nuts were immersed in NaCl (5% w/v) solution for 5 min. Salted nuts were left to dry at room temperature for 30 min to release the excess of water and then kept in an oven for 2 h at 120°C to obtain 'roasted' pistachio for volatile and sensorial analysis (Figure 1).

Agronomical and pomological traits

Nuts were handpicked at commercial maturity and assessed by color of shells and dehiscence of nuts (Figure 2). Yield (in kg) was determined per tree. At harvest, a representative nut sample (100 nuts) was taken for pomological evaluations. Nut characteristics, such as mean nut weight (NW in g) and 100 kernel weight (g), were calculated using an electronic balance of 0.001-g sensitivity; split nuts (%), blank production (%), and infested nuts were evaluated. Nut dimensions and morphological and quality parameters of kernels were carried out at random on a sample of 100 nuts collected from trees. The color of crunched pistachios (Figure 3) was measured using a Konica Minolta CR-400 colorimeter (Tokio, Japan) to obtain CIE L^*, a^*, and b^* chromatic coordinates.

Nutritional quality of pistachio nuts

Composition of pistachio nuts

The moisture content was determined with milled pistachio nuts at 105°C for 6 h in an oven (Memmert, Model UNE 400 PA; Scheabach, Germany) (Chahed *et al.*, 2008). The ash content was determined by muffle furnace at 550°C. Concentration of proteins was determined according to the method from Bradford (1976) using bovine serum albumin (BSA) as a standard. Total protein content was expressed as mg g^{-1} of fresh weight (FW). The fiber content was determined according to Ashraf *et al.* (2011), and the fat content (FC) was determined using hexane as a solvent (Association of Official Analytical Chemists [AOAC], 1995). After calculating the moisture, ash, protein, fat, and crude fiber content in the form of a powder, the total carbohydrate content was determined using the following formula:

Total carbohydrates = 100 – (moisture [%] + ash [%] + protein [%] + fat [%] + crude fiber [%]).

Table 1. Crop evapotranspiration rate (ETc) and irrigation regimes applied to the control (treatment T0), RDI (treatment T1), and stressed (treatment T2) during the growing season 2017–2018.

Treatment		Water applied (mm)					
		Year					
		2017			2018		
		Stage I	Stage II	Stage III	Stage I	Stage II	Stage III
ET_c	T0	78.9	64.4	101.9	57.5	53.0	107.5
ET_{t1}	T1	39.4	32.2	101.9	28.7	26.5	107.5
ET_{t2}	T2	39.4	32.2	50.9	28.7	26.5	53.7
Rainfall (mm)		112.9	9.4	16.6	58.6	3.6	48.6
ET_0 (mm)		443.2	293.6	446.9	324.2	242.8	471.5

ETc: Crop evapotranspiration rate; ETt1: evapotranspiration rate under regulated deficit irrigation; ETt2: evapotranspiration rate under stressed treatments; ET_0: reference evapotranspiration of annual rainfall; Treatment: T0: well watered; T1: regulated deficit irrigation; T2: stressed; stage I: from sprouting until the end of rapid nut growth; stage II: from maximum nut size until the beginning of kernel growth; stage III: from the beginning of kernel growth up to harvest.

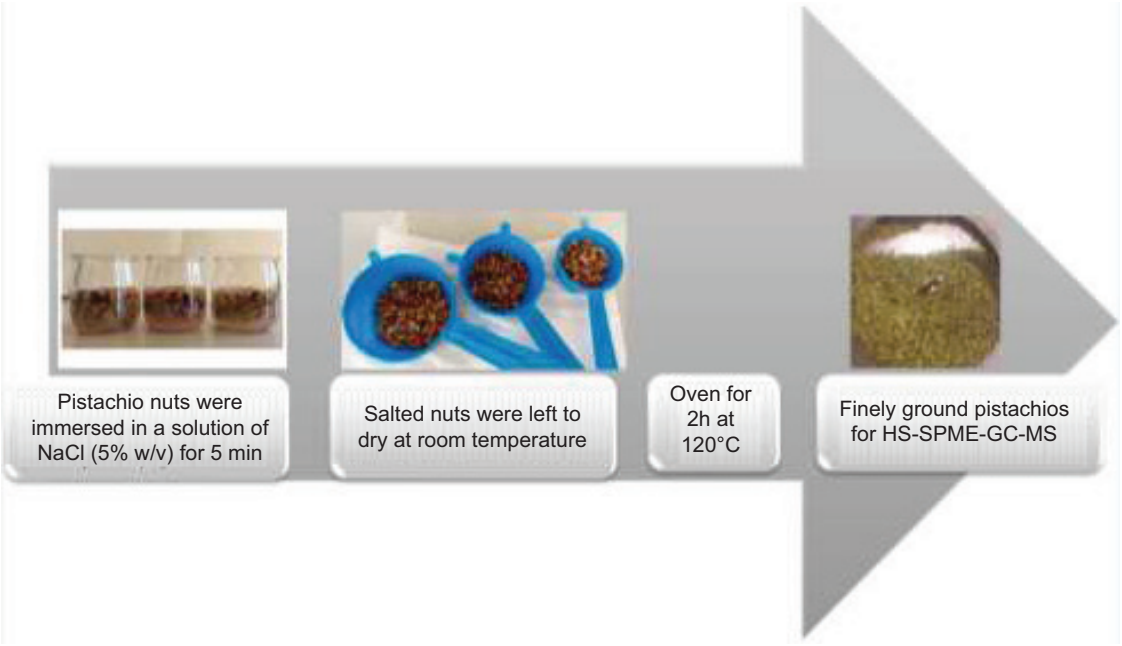

Figure 1. Outline of pistachio preparation phases for roasting and subsequent analyses.

Figure 2. Pistachio nuts of the studied cultivars (M: Mateur, K: Kerman, E: Elguetar, and O: Ohadi).

Figure 3. Color determination of pistachio nuts collected from the studied cultivars.

Analyses were made in triplicate and the results were expressed as a percentage of grams of FW (% g^{-1}). Oil yield is defined as the quotient of the weight of extracted oil and the weight of pistachio nut powder, and is expressed as percentage (%) (Uquiche *et al.*, 2008). Oil extraction was accomplished by solvent extraction technique using n-hexane according to the method described previously (Damirchi *et al.*, 2005). The prepared samples were kept at –20°C for further analysis.

Oil yield was determined using the weight of the oil extracted from 100-g pistachio samples. Free acidity was expressed as oleic acid (g 100 g^{-1} oil), and UV absorption characteristics (K_{232} and K_{270}) were determined according to the International Olive Council (Conseil Oléicole International [IOC], 2015), while the refractive index (RI) was calculated according to the AOAC (2000)

method. Carotenoid and chlorophyll from oil samples were extracted with cyclohexane, and their contents were determined according to the method described by Minguez-Mosquera *et al.* (1991). Pigments were measured at 470 nm and 670 nm, while the color of crunched pistachios was determined as described previously for nuts.

Content of bioactive compounds in pistachio nuts and oil

Samples were crunched to form powder in a mortar and pestle, separately. By weight, 20 g of pistachio kernel of each cultivar was extracted with 200 mL of 95% methanol for 48 h at room temperature. Then, the extracts were filtered and evaporated at low pressure; samples were stored at -20°C until analysis (Taghizadeh *et al.*, 2018). Total anthocyanin content (TAC) was evaluated by measuring absorbance at 535 nm and 700 nm in hydroalcoholic extract (Fuleki and Francis, 1968). Concentration of anthocyanins was calculated using the molar extinction absorptivity coefficient Ɛ = 25,965/cm M and was expressed in mg of cyanidin 3-glucoside equivalents (C3Geq) per kilogram of dry weight (C3Geq/kg DW). Total flavonoid content (TFC) was measured as described by Huang *et al.* (2004). Briefly, 5 mL of 2% aluminum trichloride ($AlCl_3$) in methanol was mixed with the same volume of extract. Absorbance was read at 367 nm and the TFC was determined by a standard curve plotted for catechin. Results were expressed as mg of catechin equivalents (mg CE/g). Total phenol content (TPC) was determined using the Folin–Ciocalteu method (Abidi *et al.*, 2011). For this purpose, 100 µL of extract was mixed with 0.5-mL Folin–Ciocalteu reagent. Then, 7 mL of distilled water was added to the solution. After 5 min incubation at room temperature, 1.5 mL 10% sodium bicarbonate (Na_2CO_3) solution was added to the mixture and left in the dark for 2 h. Absorbance was read at 725 nm against blank and results were presented as mg gallic acid equivalence for 100 g of DW (mg GAE/100 g DW). Total phenols (TP) and antioxidant capacity (AC) of pistachio oil extracts were measured as described for pistachio nuts.

Antioxidant capacity of pistachio nuts and oil

The antioxidant capacity of pistachio methanolic extracts was evaluated using modified 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), ferric reducing/antioxidant power (FRAP), and β-carotene bleaching (β-carot) activity assays. The DPPH assay was performed using the method adapted from Brand-Williams *et al.* (1995). In brief, 0.1-mM solution of DPPH in methanol was prepared and 2.9 mL of the solution was added to 0.1 mL of extract. The mixture was shaken vigorously for about 10 s and incubated in the dark at room temperature for 10 min; the absorbance was recorded at 515 nm against a blank (50 µL of sample with 950 µL of ethanol 80%). The control was a mixture of DPPH (950 µL) plus ethanol 80% (50 µL). A standard curve was drawn with Trolox (0.5–10 ppm). Results were expressed as µg of Trolox equivalence (TE) per gram of DW.

The FRAP assay was performed using 2,4,6-tripyridylS-triazine (TPTZ) solution according to the method described by Fu *et al.* (2020). In brief, 4.9 mL of FRAP solution (2.5 mL of 0.1-M acetate buffer [pH = 3.6], 250 µL of 10-mM TPTZ, and 250 µL of 20-mM FeCl3) was mixed with 0.1 mL of sample extract. Thereafter, the obtained mixture was shaken vigorously and incubated in the dark for 10 min at room temperature. Finally, the absorbance was measured at 593 nm. Results were calculated using a Trolox standard curve and expressed as µg of TE per gram of DW.

β-carot activity was determined using the method described by Kim *et al.* (2019). A mixture of 20-µL linoleic acid and 100-µL Tween 20 was dissolved in 10-mL chloroform. After removing chloroform, 10 mL of distilled water was added and stirred vigorously. Then, 240 µL of emulsion was mixed with 10 µL of extracts at various concentrations (1, 2, 3, 4, and 5 mg/mL) or butylated hydroxytoluene (BHT) as a positive control. The absorbance was measured every 15 min for 120 min at 470 nm. The antioxidant activity of extracts in terms of β-carot was calculated using the following formula:

$$\beta\text{-carot (BA \%)} = \left[1 - \frac{\text{Abs0 sample} - \text{Abs120 sample}}{\text{Abs0 control} - \text{Abs120 sample}}\right] \times 100$$

Content of volatile compounds

The volatile aroma compounds of raw and roasted pistachio nuts from each cultivar were extracted and analyzed by Head Space–Solid Phase Micro-Extraction–Gas Chromatography–Mass Spectrometry (HS-SPME-GC-MS) using the method suggested by Aceña *et al.* (2010) with slight modifications. Briefly, 1 g of finely crunched pistachio samples was placed into a 40-mL glass vial with 18 mL of NaCl saturated aqueous solution and sealed with a 'mininert' valve (Supelco; Bellefonte, PA, USA). Each sample was equilibrated for 30 min at 50°C with continuous stirring (700 rpm) in a thermostatic bath. Then, a divinylbenzene–carboxen-polydimethylsiloxane (DVB/CAR/PDMS) 2-cm fiber with 50/30-µm thickness, purchased from Supelco (Bellfonte, USA), was exposed for 1 h at 50°C in a vial headspace for the extraction of volatile compounds. After extraction, the fiber was inserted into the injection port of GC for the thermal desorption of analyte at 260°C for 3 min. The fiber was conditioned before use and thermally cleaned after each analysis at 250°C in the injector port of GC. A Shimadzu GC 2010 Plus gas chromatograph directly interfaced with a TQMS 8040 triple quadrupole mass spectrometer (Shimadzu; Milan, Italy)

was used for GC-MS analysis. Two capillary columns of different polarity were used: (1) VF-WAXms, 60 m, 0.25-mm i.d., 0.25-µm film thickness polar column (Agilent Technologies Italia S.p.A., Milan, Italy) and (2) DB-5 ms, 30 m, 0.25-mm i.d., 0.25-µm film thickness polar column (Agilent Technologies).

The GC conditions were as follows—injector temperature, 260°C; injection mode, splitless: (1) oven temperature VF-WAXms, 45°C held for 5 min, then increased from 80°C at a rate of 10°C/min to 210°C at a rate of 2°C/min and 240°C at 20°C/min; (2) oven temperature SLB-5ms, 60°C to 110°C at a rate of 2°C/min, from 110°C to 160°C at a rate of 3°C/min, and from 160°C to 260°C at a rate of 10°C/min; carrier gas, helium at a constant flow of 1 mL/min; transfer line temperature, 250°C; acquisition range, 40–400 mz^{-1}; and scan speed, 1,250 amu/s. Each compound was identified using mass spectral data, NIST' 20 (NIST/EPA/NIH Mass Spectra Library, version 2.0, NanoTech Analysis, Turin; Italy) and FFNSC 3.0 database, linear retention indices (LRI) according to the equation of Van Den Dool and Kratz (1963), literature data, and the injection of available standards, as reported previously (Cincotta *et al.*, 2018). The samples were analyzed in duplicate. The compounds were quantified using peak area, and average value was calculated.

Profile of fatty acids

The fatty acid composition of oils was analyzed using GC to determine fatty acid methyl esters (FAMEs), following the method outlined in Ghrab *et al.* (2010). FAMEs were prepared by saponification/methylation with sodium methylate according to the European Union Commission modified Regulation EEC 2568/91. A capillary column (30-m length and 0.32-mm i.d.; Stabilwax; Restek, Bellefonte, PA, USA) coated with a stationary phase formed by carbowax (0.25-mm thickness) in GC (Shimadzu GC-17A; Japan) was used. The analytical conditions were as follows: flame ionization detector (FID), nitrogen as vector gas at a flow rate of 1 mL/min. The column temperature was isothermal at 180°C and the injector and detector were at 230°C and 250°C, respectively. In all, ten fatty acids were identified by comparing retention times with standard compounds: palmitic acid (C16:0), palmitoleic acid (C16:1), margaric acid (C17:0), heptadecenoic acid (C17:1), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), linolenic acid (C18:3), arachidic acid (C20:0), and gadoleic acid (C20:1).

Sensorial analysis of pistachio nuts

This analysis was performed with salted and roasted pistachio nuts of the four studied varieties grafted on *P. atlantica* rootstock and conducted with three irrigation treatments of RDI. The sensory study was performed as suggested previously (Carbonell-Barrachina *et al.*, 2015; Noguera-Artiaga *et al.*, 2020). A consumer panel was carried out with 60 consumers selected from personal staff and students of the Faculty of Science of Sidi Bouzid (Tunisia) to study the sensory properties of pistachios. Consumers were aged 20–60 years and had no diet restrictions or allergies for any type of nut. In all, 74% of panelists were women, and 65% were aged between 20 and 35 years, 20% between 35 and 50 years, and 15% were aged between 50 and 65 years. Ten pistachio nuts were served at room temperature to each panelist in an odor-free disposable 60-mL covered plastic cups coded using two-digit numbers. Unsalted crackers and drinking water were used between samples to clean panelists' palate. Natural illumination was used during the test, and the temperature of the testing room was 20°C ± 2°C. Panelists responded using a 9-point hedonic scale, where 9 = like extremely and 1 = dislike extremely; they were asked to indicate their order of preference for samples and mark reasons for their preferences regarding the attributes under study (color, hardness, size, roasted and sweet/almond odor, sweet and sour taste, and global satisfaction).

Statistical analysis

All traits were measured or scored for each treatment separately during the two growing seasons. Mean values and mean standard error (SE) were calculated for each studied trait using SPSS 20.0 (SPSS Inc., Chicago, IL). Analysis of variance (ANOVA) was used to test the effects of water treatments and roasting on the studied parameters, and the significance was expressed as $p < 0.05$. The test Scheffe one ANOVA factor was used to compare means values. Pearson's correlation at 5% level of significance was performed between antioxidants and antioxidant capacity using the software SPSS 20. Principal components analysis (PCA) of all studied traits was carried out using SPSS 20.0. Component matrix was evaluated and orthogonal factors were rotated using variance maximization (Varimax).

Results

Agronomical parameters

During the 2-year experimental period, results showed significant differences ($p < 0.05$) between cultivars concerning yield (Table 2). Low yield was observed in treatment T2 whereas treatments T0 and T1 presented the same behavior. The highest yield (7.5 kg/tree) with control treatment was observed for cv. Mateur, followed

Table 2. Agronomical and pomological traits of four pistachio cultivars grown under RDI treatments.

Traits	Mateur			Kerman			Elguetar			Ohadi		
	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
Yield	7.1 ± $1^{a,A}$	6.4 ± $2^{a,A}$	5.1 ± $1^{b,A}$	6.4 ± $2^{a,A}$	5.4 ± $2^{b,B}$	4.8 ± $1^{b,A}$	5.1 ± $1^{a,B}$	4.7 ± $3^{a,B}$	4.0 ± $2^{b,B}$	3.8 ± $1^{a,C}$	3.1 ± $1^{b,C}$	2.1 ± $3^{c,C}$
WP	0.6 ± $0.1^{a,A}$	0.8 ± $0.2^{a,A}$	0.5 ± $0.1^{b,A}$	0.6 ± $0.1^{a,A}$	0.7 ± $0.2^{a,A}$	0.5 ± $0.1^{a,A}$	0.7 ± $0.2^{a,A}$	0.6 ± $0.2^{a,A}$	0.5 ± $0.1^{b,A}$	0.4 ± $0.2^{a,B}$	0.3 ± $0.2^{a,B}$	0.2 ± $0.1^{b,B}$
NFW	0.6 ± $0.1^{a,A}$	0.6 ± $0.5^{a,A}$	0.6 ± $0.4^{a,B}$	0.4 ± $0.4^{a,A}$	0.5 ± $0.5^{a,A}$	0.4 ± $0.5^{a,C}$	0.6 ± $0.1^{a,A}$	0.6 ± $0.6^{a,A}$	0.5 ± $0.1^{a,C}$	0.8 ± $0.1^{a,A}$	0.8 ± $0.1^{a,A}$	0.8 ± $0.4^{a,A}$
NDW	0.5 ± $0.1^{a,A}$	0.5 ± $0.5^{a,A}$	0.5 ± $0.4^{a,B}$	0.3 ± $0.4^{a,A}$	0.3 ± $0.7^{a,B}$	0.3 ± $0.4^{a,C}$	0.5 ± $0.1^{a,A}$	0.4 ± $0.7^{a,A}$	0.3 ± $0.1^{a,C}$	0.6 ± $0.1^{a,A}$	0.6 ± $0.1^{a,A}$	0.7 ± $0.4^{a,A}$
L	17.8 ± $2^{a,A}$	17.4 ± $1^{a,A}$	17.1 ± $1^{a,A}$	18.2 ± $1^{a,A}$	18.1 ± $1^{a,A}$	17.9 ± $1^{a,A}$	14.8 ± $2^{a,B}$	14.4 ± $1^{a,B}$	14.1 ± $1^{a,B}$	18.2 ± $1^{a,A}$	18.1 ± $1^{a,A}$	17.9 ± $1^{a,A}$
l	9.1 ± $1^{a,A}$	9.1 ± $1^{a,A}$	9.0 ± $1^{a,A}$	10.6 ± $1^{a,A}$	10.4 ± $1^{a,A}$	10.1 ± $1^{a,A}$	8.1 ± $1^{a,B}$	8.1 ± $1^{a,B}$	8.0 ± $1^{a,B}$	11.6 ± $1^{a,A}$	11.4 ± $1^{a,A}$	11.1 ± $1^{a,A}$
H	7.9 ± $1^{a,A}$	7.7 ± $1^{a,A}$	7.5 ± $1^{a,B}$	8.9 ± $1^{a,A}$	8.8 ± $1^{a,A}$	8.7 ± $1^{a,A}$	6.8 ± $1^{a,B}$	6.7 ± $1^{a,B}$	6.5 ± $1^{a,B}$	10.9 ± $1^{a,A}$	10.8 ± $1^{a,A}$	10.7 ± $1^{a,A}$
Split nut	76 ± $5^{a,A}$	70 ± $3^{a,A}$	68 ± $4^{b,A}$	70 ± $3^{a,A}$	65 ± $2^{a,A}$	72 ± $3^{a,A}$	71 ± $5^{b,A}$	75 ± $2^{a,A}$	70 ± $3^{b,A}$	55 ± $6^{a,B}$	48 ± $4^{b,B}$	46 ± $2^{b,B}$
Blanks	7 ± $2^{c,B}$	12 ± $2^{b,B}$	19 ± $1^{a,B}$	10 ± $3^{b,B}$	12 ± $3^{b,B}$	18 ± $2^{a,B}$	9 ± $3^{c,B}$	13 ± $3^{b,B}$	16 ± $2^{a,B}$	25 ± $5^{c,A}$	29 ± $2^{b,A}$	35 ± $2^{a,A}$
Infested	6 ± $1^{b,A}$	7 ± $2^{b,A}$	10 ± $1^{a,A}$	5 ± $2^{b,A}$	4 ± $2^{b,A}$	7 ± $1^{a,A}$	6 ± $2^{b,A}$	7 ± $2^{b,A}$	11 ± $3^{a,A}$	5 ± $2^{a,A}$	4 ± $1^{b,A}$	7 ± $2^{a,A}$

Notes. Values are means (n = 3) ± SE (mean standard error). Different superscripted lowercase letters a, b, and c indicate difference ($p < 0.05$) among three irrigations treatments (T0: control; T1: regulated deficit irrigation; T2: stressed) in the same cultivar. Superscripted uppercase letters A, B, and C indicate differences ($p < 0.05$) among cultivars in the same treatment.
Yield: kg/tree; WP = water productivity (kg /m^3); NDW = nut dry weight (g); NFW = nut fresh weight (g); L = length (mm); l = width (mm); and H = thickness (mm).

by cv. Kerman (6.4 kg/tree) and Elguetar (5.1 kg/tree) whereas cv. Ohadi showed the lowest yield (3.8 kg/tree). Results showed that the RDI treatment presented a similar yield as that observed with control treatment when 20% of water was saved during stages I and II of fruit development that increased water productivity. In this sense, Galindo *et al.* (2018) reported that RDI could benefit water productivity by increasing irrigation water savings, minimizing or eliminating negative impacts on yield and crop revenue, and even improving harvest quality. Findings of the present study agreed with the study conducted by Memmi *et al.* (2015), reporting that the water restriction applied to pistachio trees at stages I and II of nut development did not affect the final yield. Nut's FW showed different patterns depending on the genotype. Hence, cv. Ohadi with full irrigated regime (T0) showed the highest nut FW (0.77 g) whereas the lowest value (0.44 g) was shown in cv. Elguetar. Nut weight was not affected by irrigation strategy. These findings were in accordance with the study conducted by Carbonell-Barrachina *et al.* (2015), reporting that the RDI treatment did not significantly affect the weight of whole pistachio, its edible portion, and its shell.

Pomological parameters

Pomological parameters showed statistically significant differences ($p < 0.05$) between stated cultivars (Table 2). The physical properties of nuts revealed that cv. Ohadi had the highest dimensions of length, L (18.2 mm) and width, l (11.6 mm). Ohadi nuts were thicker, larger, and longer than three other cultivars whereas the kernel of cv. Elguetar had the lowest dimensions (L = 14.8 mm, and l = 8.1 mm). In an experiment conducted in Tunisia, Ghrab *et al.* (2004) reported that cv. Ohadi produced nuts with a higher weight and a larger size. Nut dimensions presented significant differences between cultivars, mainly explained by the genotype. Carbonell-Barrachina *et al.* (2015) reported that the size of pistachio nuts was not affected by the RDI irrigation treatment. Cv. Mateur, Kerman, and Elguetar recorded the highest split nut rate of fruit dehiscence (76%, 70%, and 71%, respectively, with control treatment; Table 2). Cv. Ohadi showed the lowest split nut rate (55% with treatment T0, 48% with treatment T1, and 46% with treatment T2) and the highest rate (25%) of blanks. The split and blank proportions of nuts were also affected by the genotype. Present results were in accordance with Zribi *et al.* (2006), showing that cv. Ohadi presented a low split proportion of 49% whereas cv. Mateur had the higher split proportion (67%). Ghrab *et al.* (2004) reported that the high proportion of non-split nuts observed between cv. Ohadi and other varieties could be due to the cultivar and the season. The proportion of blanks was higher under stressed treatment (T2). These results were in accordance with

the findings of Galindo *et al.* (2018), reporting that irrigation increased yield, nut size, and splitting, and reduced alternate bearing pattern and incidence of blank nuts. An explanation of blanks proportion in pistachio nuts could be attributed to lack of pollination, poor nutrition, rainfall during anthesis, and water deficit during seed development (Crane and Iwakiri, 1981). Present results showed lower proportions of infested nuts under different irrigation regimes. The observed fungal decay and insect infestation of the kernel was generally low in the present conditions.

Nut color parameters (L*, a*, b*, and C*) presented statistically significant differences ($p < 0.05$) among genotypes (Figure 4). L* varied from 40.7 in cv. Ohadi to 43.5 in cv. Kerman with control treatment. The a* value ranged from 22.9 in cv. Elguetar to 28.4 in cv. Mateur. The b* value ranged from 16.9 in cv. Mateur to 21.5 in cv. Elguetar. Similar results were reported by Carbonell-Barrachina *et al.* (2015) and Galindo *et al.* (2015), stating that the RDI treatments applied did not significantly affect pistachio nut color.

Regarding the effect of water regimes on pistachio nut color, results of the present study were in accordance with Guerrero *et al.* (2005), showing that irrigation increased kernel weight but did not show significant impact on shell and kernel colors. The obtained values in the present study were consistent with those observed by Dini *et al.* (2019), studying the kinetics of color degradation, chlorophylls, and xanthophylls loss in pistachio nuts during roasting.

Composition of Nuts

Nut composition (moisture, carbohydrates, ash, protein, fiber, and oil yield) varied between cultivars, depending

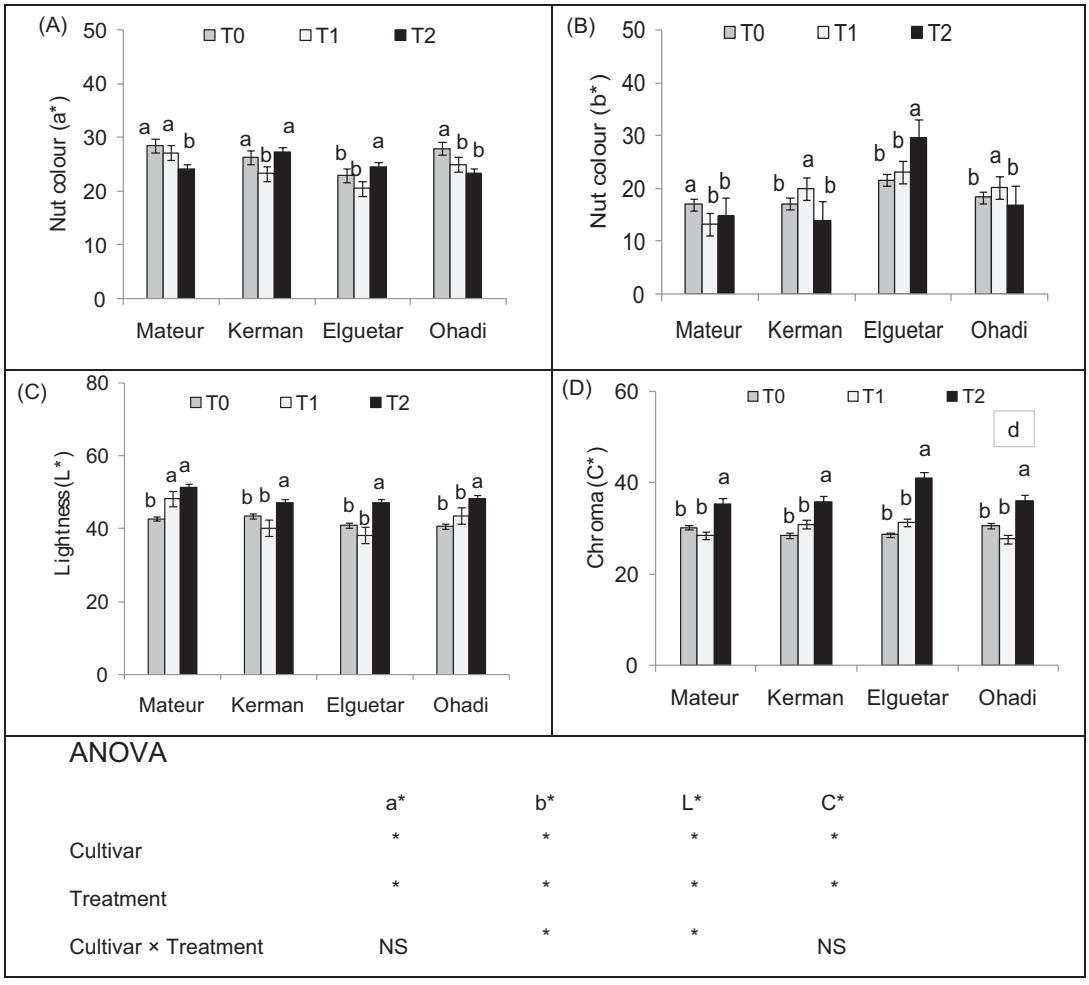

Figure 4. Variation in nut color from the pistachio cultivars (C) under irrigation treatments (T). L* means the brightness of the sample while a* and b* represent color directions, and C* = chroma. Values are mean values of three measurements (n = 3) ± SE. Different letters a, b, and c indicate significant differences between the storage periods of each cultivar (NS: not significant; *$p < 0.05$, **$p < 0.01$) according to Duncan's multiple range test.

on RDI treatments (Table 3). Hence, treatment T2 presented significant ($p < 0.05$) lower values of carbohydrates, compared to the control and RDI treatments. Ash content also decreased under stressed treatment (T2), showing a statistically significant ($p < 0.05$) difference between cv. Mateur, Kerman, and Ohadi. The protein content ranged from 18.6% in cv. Mateur to 25.1% in cv. Ohadi. This trait was also affected by water restriction, showing significant ($p < 0.05$) lower values with treatment T2. The fiber content presented a similar trend showing significantly lower values with treatmentr T2 whereas treatments T0 and T1 presented the same content. Moisture in nuts decreased with decrease in water supply, showing significant ($p < 0.05$) lower values under stressed treatment T2.

Regarding oil yield, cv. Mateur, Elguetar, and Kerman presented similar values under three water regimes. Cv. Ohadi presented higher oil content under RDI treatment, showing a significant difference between treatments T0 and T2. These results were in accordance with those reported by Carbonell-Barrachina *et al.* (2015), stating that the nuts from treatment T1 showed the highest oil content, followed by control and treatment T2. Yahyavi *et al.* (2020) reported that differences in oil contents of pistachio cultivars could be due to differences in factors, such as growing conditions, harvesting, and climate.

As expected, irrigation regimes significantly affected nut composition, except for oil yield, which was consistent with water treatments. Nut composition identified cv. Ohadi with high carbohydrates, ash, protein, fiber, and moisture contents. In the present study, nut composition was affected by drought stress, showing lower contents in treatment T2. Kola *et al.* (2018) reported that irrigation increased crude fiber, ash, and oil contents of pistachio nuts, but decreased protein content. Oil yield showed the same pattern under three water regimes, showing that water restriction did not affect oil content.

Biochemical parameters of nuts

Contents of anthocyanins, flavonoids, and total phenolics and the antioxidant capacity of pistachio nuts are shown in Table 4. Treatments T0 and T1 presented the same values of anthocyanins, flavonoids, total phenols, and RAC, showing statistically significant differences ($p < 0.05$) with treatment T2. Cv. Elguetar showed low flavonoid content, compared to other three cultivars. Cv.

Table 3. Nut composition (%) for the studied pistachio cultivars grown under RDI treatments.

Traits		Mateur	Elguetar	Kerman	Ohadi
Carbohydrates	T0	$9.20 \pm 2^{a,A}$	$8.70 \pm 1^{a,B}$	$7.80 \pm 2^{a,B}$	$10.20 \pm 1^{a,A}$
	T1	$8.10 \pm 2^{a,A}$	$8.10 \pm 1^{a,A}$	$7.23 \pm 2^{a,B}$	$9.83 \pm 1^{a,A}$
	T2	$7.85 \pm 2^{b,B}$	$7.73 \pm 1^{b,B}$	$7.00 \pm 2^{b,B}$	$9.35 \pm 1^{b,A}$
Ash	T0	$0.50 \pm 0.2^{a,A}$	$0.43 \pm 0.1^{a,B}$	$0.46 \pm 0.1^{a,B}$	$0.52 \pm 0.1^{a,A}$
	T1	$0.45 \pm 0.2^{a,A}$	$0.37 \pm 0.1^{b,B}$	$0.45 \pm 0.1^{a,A}$	$0.48 \pm 0.1^{a,A}$
	T2	$0.36 \pm 0.2^{b,B}$	$0.40 \pm 0.1^{a,A}$	$0.38 \pm 0.1^{b,B}$	$0.42 \pm 0.1^{b,A}$
Proteins	T0	$20.5 \pm 0.1^{a,B}$	$22.5 \pm 0.1^{a,A}$	$21.4 \pm 0.1^{a,B}$	$25.1 \pm 0.2^{a,A}$
	T1	$19.3 \pm 0.1^{a,B}$	$20.1 \pm 0.1^{a,B}$	$20.4 \pm 0.1^{a,B}$	$23.1 \pm 0.2^{a,A}$
	T2	$18.6 \pm 0.1^{b,B}$	$19.5 \pm 0.1^{b,B}$	$19.1 \pm 0.1^{b,B}$	$22.3 \pm 0.2^{b,A}$
Fiber	T0	$1.23 \pm 0.5^{a,B}$	$1.35 \pm 0.2^{a,B}$	$1.52 \pm 0.5^{a,A}$	$1.60 \pm 0.2^{a,A}$
	T1	$1.20 \pm 0.5^{a,B}$	$1.15 \pm 0.2^{b,B}$	$1.34 \pm 0.5^{a,A}$	$1.56 \pm 0.2^{a,A}$
	T2	$1.13 \pm 0.5^{b,B}$	$1.05 \pm 0.2^{b,B}$	$1.12 \pm 0.5^{b,B}$	$1.21 \pm 0.2^{b,A}$
Moisture	T0	$28.26 \pm 0.6^{a,B}$	$29.94 \pm 0.5^{a,A}$	$30.07 \pm 0.6^{a,A}$	$35.61 \pm 0.1^{a,A}$
	T1	$24.52 \pm 0.4^{b,B}$	$30.16 \pm 0.4^{a,A}$	$29.47 \pm 1.0^{a,A}$	$33.54 \pm 0.6^{a,A}$
	T2	$22.92 \pm 0.5^{b,B}$	$24.66 \pm 0.7^{b,B}$	$26.41 \pm 0.9^{b,B}$	$32.1 \pm 0.6^{b,A}$
Oil yield (%)	T0	$54.45 \pm 0.3^{a,A}$	$53.62 \pm 0.2^{a,A}$	$56.63 \pm 0.1^{a,A}$	$46.84 \pm 0.3^{b,B}$
	T1	$54.07 \pm 0.9^{a,A}$	$52.77 \pm 0.2^{a,A}$	$55.76 \pm 0.3^{a,A}$	$54.45 \pm 0.3^{a,A}$
	T2	$54.38 \pm 0.3^{a,A}$	$53.24 \pm 0.1^{a,A}$	$57.11 \pm 0.3^{a,A}$	$47.57 \pm 0.2^{b,B}$

FW: fresh weight; DW: dry weight, FC: fat content.
Data are presented as mean ± SE (n = 3). Different superscripted lowercase letters a, b, and c indicate difference ($p < 0.05$) among three irrigation treatments (T0: control; T1: regulated deficit irrigation; and T2: stressed) in the same cultivar. Uppercase superscripted letters A and B indicate differences ($p < 0.05$) among cultivars in the same treatment. Mean separation within columns by Scheffe´s test ($p \leq 0.05$). In each column, values with the same letter are not significantly different.

Table 4. Phenolic compounds in pistachio nuts under RDI.

Traits		Mateur	Elguetar	Kerman	Ohadi
Pistachio fresh nuts					
Anthocyanins	T0	7.72 ± 2^{a,A}	6.63 ± 1^{a,B}	6.38 ± 2^{a,B}	8.25 ± 1^{a,A}
	T1	6.78 ± 2^{a,A}	5.98 ± 1^{a,B}	5.82 ± 2^{a,B}	7.51 ± 1^{a,A}
	T2	4.85 ± 2^{b,A}	4.38 ± 1^{b,A}	3.40 ± 2^{b,B}	4.33 ± 1^{b,A}
Flavonoids	T0	12.18 ± 0.2^{a,B}	10.63 ± 0.1^{a,B}	15.38 ± 0.1^{a,A}	14.25 ± 0.1^{a,A}
	T1	13.28 ± 0.2^{a,A}	8.68 ± 0.1^{a,B}	12.82 ± 0.1^{a,A}	13.51 ± 0.1^{a,A}
	T2	8.75 ± 0.2^{b,B}	7.38 ± 0.1^{b,B}	9.40 ± 0.1^{b,A}	10.33 ± 0.1^{b,A}
Total phenols	T0	410.50 ± 0.1^{a,A}	323.63 ± 0.1^{a,B}	365.38 ± 0.1^{a,B}	334.25 ± 0.2^{a,B}
	T1	385.50 ± 0.1^{a,A}	300.20 ± 0.1^{a,B}	305.58 ± 0.1^{b,B}	344.51 ± 0.2^{a,A}
	T2	311.50 ± 0.1^{b,A}	207.38 ± 0.1^{b,C}	257.40 ± 0.1^{c,B}	237.33 ± 0.2^{b,A}
RAC	T0	121.90 ± 0.5^{a,B}	131.20 ± 0.2^{a,B}	162.43 ± 0.5^{a,A}	153.00 ± 0.2^{a,A}
	T1	112.40 ± 0.5^{a,C}	123.08 ± 0.2^{a,B}	142.99 ± 0.5^{a,A}	132.69 ± 0.2^{a,B}
	T2	84.31 ± 0.5^{c,B}	92.75 ± 0.2^{b,A}	73.46 ± 0.5^{b,C}	102.47 ± 0.2^{b,A}
FRAP	T0	125.00 ± 1.5^{a,B}	123.00 ± 0.5^{a,B}	150.00 ± 1.5^{a,A}	140.00 ± 0.5^{a,A}
	T1	110.00 ± 1.0^{b,C}	120.00 ± 2.0^{a,B}	140.00 ± 1.5^{a,A}	143.00 ± 1.0^{a,A}
	T2	100.50 ± 0.5^{b,B}	123.00 ± 1.0^{a,A}	115.00 ± 1.0^{b,A}	98.00 ± 2.0^{b,B}
β-carot (%)	T0	60.50 ± 2.0^{a,A}	56.50 ± 1.0^{a,A}	40.00 ± 2.0^{a,A}	42.50 ± 2.0^{b,B}
	T1	55.0 ± 3.0^{a,A}	52.0 ± 2.0^{a,A}	45.50 ± 2.0^{a,A}	57.10 ± 3.0^{a,A}
	T2	40.60 ± 2.0^{b,B}	43.60 ± 3.0^{b,B}	37.20 ± 1.0^{b,B}	52.20 ± 2.0^{a,A}
ANOVA	C	*	*	*	*
	T	**	**	**	**
	C*T	*	*	*	*

Anthocyanin: mg C3Geq kg^{-1} of DW; flavonoids: mg CE/100 g of DW; total phenols: mg GAE/100 g of DW; RAC: relative antioxidant capacity (μg TE/g of DW). C3Geq: Cyanidin-3-glucoside equivalents; CE: catechin equivalents; GAE: gallic acid equivalence; β-carot: β-carotene bleaching activity; DW: dry weight.
Values are means (n = 3) ± SE. Different superscripted lowercase letters a, b, and c indicate difference ($p < 0.05$) among the irrigation treatments in the same cultivar. Superscripted uppercase letters A, B, and C indicate differences ($p < 0.05$) among cultivars (C) in the same treatment (T)
(T0: control [100% ETc]; T1: treatment RDI [50% ETc during stage I and stage of nut development and 100% ETc during the stage III]; T2: stressed treatment (50% ETc).

Mateur presented high TPC (410.5 mg GAE/100 g of DW), followed by cv. Kerman (365.38 mg GAE/100 g of DW). Changes in the antioxidant capacity of pistachio nuts were consistent with changes in flavonoid and TPC. The observed values of RAC with DPPH, FRAP, and β-carotene assays showed that DPPH scavenging ability was stronger, which could be due to specific antioxidant compounds discovered in pistachio nuts. In the present study, TPC in pistachio nuts presented high variability between cultivars under three water regimes. It was observed that treatments T0 and T1 presented high values of bioactive compounds whereas treatment T2 presented lower values. As stated by Ojeda-Amador *et al.* (2019), the observed variability in phenolic compounds was explained by different factors, such as cultivar, geographical origin, ripening stage, and industrial processing. Our findings were in line with the results of Noguera-Artiaga *et al.* (2020a), reporting that moderate RDI (T1 treatment) produced nuts with good functional quality (high values of TPC and antioxidant capacity), without affecting their sensory quality.

Physicochemical and biochemical parameters of pistachio oil

Physicochemical parameters of pistachio oil

Pistachio oil samples were investigated for acidity, chlorophyll, carotenoid pigments, and specific extinction coefficient (K_{232}, and K_{270}) as shown in Table 5. Physicochemical parameters varied between cultivars whereas water regimes did not show significant differences. Acidity showed a statistically significant difference ($p < 0.05$) between the studied cultivars. Cv. Ohadi showed the highest value (0.55 g/100 g) of acidity with treatment T2 whereas the lowest value (0.32 g/100 g) was observed in cv. Mateur with treatment T1. The lower values of acidity in oil samples of raw kernels indicated that hydrolytic rancidity had not

occurred. Oil acidity observed in the present study was in the range of 0.37–0.62 meq O_2/kg of oil, as also reported by Daneshmandi *et al.* (2014).

Arena *et al.* (2007) found 6.8 meq O_2/kg of oil as peroxide number in Iranian pistachio oil. Yahyavi et al (2020) reported that the peroxide number was the main indicator of fat oxidation, measuring the concentration of hydroperoxide formed during lipid oxidation. The specific extinction index is often used to evaluate the presence of primary (K_{232}) or secondary (K_{270}) oxidation products. The K_{232} values in pistachio oil were higher in cv. Ohadi (2.17, 2.31, and 2.05 for treatments T0, T1, and T2, respectively) followed by cv. Elguetar. Interestingly, no significant variation of RI, even at 270 nm, was observed in pistachio oil of the studied cultivars. RI of pistachio oil samples was the same between cultivars (1.47) and years of study. These results were consistent with the results of the previous studies, reporting that the RI of pistachio oil was around 1.4 for different varieties and regions without any significant changes (Yahyavi *et al.*, 2020; Yildiz *et al.*, 1998). Results further showed that cv. Ohadi showed the most considerable content of chlorophyll for three irrigation regimes (7.35, 8.11, and 7.8 mg/kg for treatments T0, T1, and T2, respectively). However, carotenoids content showed a significant difference ($p < 0.05$) between cultivars. Hence, carotenoid dominated in cv. Ohadi (38.04, 38.66, and 36.37 mg/kg for treatments T0, T1, and T2, respectively), followed by cv. Elguetar. Analysis revealed that the oil extracted from cv. Mateur had the lowest content of carotenoids (25.38 mg/kg) for treatment T0. Treatment T0 showed lower values of carotenoids, compared to treatments T1 and T2. Bellomo and Fallico (2007) reported that the content of pigments in pistachio oils was in the range of 18–52 mg/kg of DW. These values were linked to genotype, degree of ripeness, environmental conditions, and geographical origin (Giuffrida *et al.*, 2006).

Biochemical parameters of pistachio oil

The TPC of the extracted pistachio oil in control and treatment T1 was the same, showing a statistically significant difference ($p < 0.05$) with the treatment T2 (Table 5). Among cultivars studied, TPC of pistachio oil samples showed statistically significant differences ($p < 0.05$). Cv. Ohadi had the highest values of TPC, followed by cv. Mateur and Elguetar, while cv. Kerman presented the lowest values of TPC for three irrigation treatments. Irrigation treatments significantly affected the TPC, with treatment T2 presenting lower values for the four studied cultivars. These results were in line with the study done by Miraliakbari and Shahidi (2008), showing a TPC of 158 mg/kg oil for commercial pistachio. Irrigation treatments affected significantly the TPC, with treatment T2 presenting the lowest values in the four studied cultivars.

The RAC values conducted with DPPH assay showed values of DPPH ranging from 22.40 µg TE/g to 53.63 µg TE/g of oil. Pistachio oil from treatment T2 always presented lower values of RAC, compared to treatment T0 and RDI (treatment T1). Extracted oil from cv. Kerman showed lower values for AC and presented statistically significant difference ($p < 0.05$) compared to cv. Mateur, Ohadi, and Elguetar. The AC values were consistent within the range of 20.7–87.4 µg TE/g of oil as reported in a previous paper on fatty acid composition, antioxidant, and antibacterial activities of Pistacia fruit oils (Mezni *et al.*, 2020).

Correlations between antioxidant compounds

Pearson's correlation between antioxidants showed a strong positive association between total phenols and DPPH (r = 0.45), flavonoids and anthocyanin (r = 0.56), flavonoids and FRAP (r = 0.52), and flavonoids and β-carot (r = 0.40) (Table 6). A low positive correlation was observed between anthocyanin and β-carot (r = 0.32). Negative correlations were observed between total phenols and flavonoids (r = -0.50), total phenols and anthocyanin (r = -0.62), total phenols and FRAP (r = -0.68), and anthocyanin and β-carot (r = -0.70). Moreover, a positive relationship (r = 0.45) that manifested between total phenols and DPPH implied the contribution of phenols in DPPH capacity. However, total phenols showed a negative correlation with FRAP and β-carot. Meanwhile, flavonoids and anthocyanin had a positive correlation with FRAP and β-carot but a negative association with DPPH. These demonstrated their contributions to radical scavenging in pistachio nuts, but they were not key components of DPPH activity.

Content of volatile compounds in nuts

The analysis of volatile compounds in raw pistachio nuts identified 76 volatiles belonging to the chemical classes of acids, aldehydes, alcohols, terpenes, ketones, esters, aromatics, and nitrogen compounds as shown in Table 7. Water regime affected the volatile content of the studied cultivars, showing high values in treatment T2 whereas treatments T0 and T1 presented similar volatile compounds content. The most abundant compounds were terpenes, such as α-pinene, terpinolene, and limonene, followed by 1-methyl-pyrrole. Terpenes and 1-methyl-pyrrole (nutty and sweet) constituted 80% of volatile compounds. The results revealed statistically significant differences ($p < 0.05$) in the contents of volatile compounds of the studied cultivars under three water regimes. The amount of terpenes and 1-methyl-pyrrole in raw pistachio nuts was higher with T2 stressed treatment in all studied cultivars. In the same manner, aliphatic

Table 5. Physicochemical and biochemical parameters of pistachio oil of the four studied cultivars grown with RDI treatments.

Cultivar	Treatment	Acidity	Chlorophyll	Carotenoids	K_{232} (1%)	K_{270} (1%)	Total phenols	RAC	FRAP	β-carot
Mateur	T0	$0.35 \pm 0.1^{a,B}$	$3.89 \pm 0.05^{a,C}$	$27.38 \pm 2.0^{a,C}$	$1.85 \pm 0.14^{a,B}$	$0.17 \pm 0.04^{a,A}$	$128.26 \pm 0.1^{a,B}$	$48.80 \pm 0.5^{a,B}$	$52.50 \pm 1.0^{a,B}$	$47.20 \pm 2.0^{a,B}$
	T1	$0.32 \pm 0.2^{b,B}$	$4.20 \pm 0.01^{a,B}$	$26.59 \pm 1.6^{a,B}$	$1.88 \pm 0.25^{a,B}$	$0.15 \pm 0.05^{a,A}$	$127.21 \pm 0.1^{a,B}$	$42.40 \pm 0.5^{b,A}$	$40.10 \pm 0.5^{b,B}$	$35.70 \pm 1.5^{b,B}$
	T2	$0.40 \pm 0.1^{a,B}$	$3.93 \pm 0.27^{a,C}$	$27.27 \pm 0.7^{a,B}$	$1.84 \pm 0.11^{a,B}$	$0.17 \pm 0.01^{a,A}$	$113.79 \pm 0.1^{b,B}$	$30.20 \pm 0.5^{c,A}$	$50.50 \pm 1.0^{a,A}$	$45.30 \pm 2.0^{a,A}$
Elguetar	T0	$0.44 \pm 0.1^{a,A}$	$4.91 \pm 0.96^{a,B}$	$31.61 \pm 2.1^{a,B}$	$1.98 \pm 0.19^{a,A}$	$0.14 \pm 0.03^{a,A}$	$109.58 \pm 0.1^{a,C}$	$53.63 \pm 0.2^{a,A}$	$62.20 \pm 0.5^{a,A}$	$57.10 \pm 1.5^{a,A}$
	T1	$0.37 \pm 0.2^{a,B}$	$4.71 \pm 0.40^{a,B}$	$34.74 \pm 1.4^{a,A}$	$2.12 \pm 0.11^{a,A}$	$0.15 \pm 0.04^{a,A}$	$113.36 \pm 0.1^{a,B}$	$40.98 \pm 0.2^{b,A}$	$53.50 \pm 1.0^{b,A}$	$48.20 \pm 1.0^{b,A}$
	T2	$0.40 \pm 0.1^{a,B}$	$4.63 \pm 0.64^{a,B}$	$32.43 \pm 0.3^{a,A}$	$2.01 \pm 0.41^{a,A}$	$0.14 \pm 0.07^{a,A}$	$101.55 \pm 0.1^{b,B}$	$27.38 \pm 0.2^{c,B}$	$45.50 \pm 0.5^{c,B}$	$40.30 \pm 1.5^{c,B}$
Ohadi	T0	$0.49 \pm 0.1^{a,A}$	$7.35 \pm 0.05^{b,A}$	$38.04 \pm 2.0^{a,A}$	$2.17 \pm 0.10^{a,A}$	$0.18 \pm 0.04^{a,A}$	$138.85 \pm 0.2^{a,A}$	$47.25 \pm 0.2^{a,B}$	$45.55 \pm 0.5^{a,C}$	$40.25 \pm 1.5^{a,C}$
	T1	$0.42 \pm 0.1^{b,A}$	$8.11 \pm 0.05^{a,A}$	$38.66 \pm 2.0^{a,A}$	$2.31 \pm 0.11^{a,A}$	$0.19 \pm 0.01^{a,A}$	$137.25 \pm 0.2^{a,A}$	$37.51 \pm 0.2^{b,B}$	$47.20 \pm 1.5^{a,B}$	$42.70 \pm 2.5^{a,B}$
	T2	$0.55 \pm 0.1^{a,A}$	$7.80 \pm 0.95^{a,A}$	$36.37 \pm 2.0^{b,A}$	$2.05 \pm 0.10^{b,A}$	$0.17 \pm 0.01^{a,A}$	$125.41 \pm 0.2^{b,A}$	$27.33 \pm 0.2^{c,B}$	$47.15 \pm 2.0^{a,B}$	$44.55 \pm 1.0^{a,A}$
Kerman	T0	$0.43 \pm 0.1^{b,A}$	$5.07 \pm 0.31^{a,B}$	$29.28 \pm 4.2^{a,C}$	$1.67 \pm 0.06^{b,C}$	$0.15 \pm 0.03^{b,A}$	$73.25 \pm 0.1^{b,C}$	$40.80 \pm 0.5^{a,C}$	$50.20 \pm 1.5^{a,C}$	$45.50 \pm 2.5^{a,C}$
	T1	$0.43 \pm 0.1^{b,A}$	$5.35 \pm 0.09^{a,B}$	$29.21 \pm 6.4^{a,B}$	$1.86 \pm 0.05^{a,B}$	$0.18 \pm 0.03^{a,A}$	$76.67 \pm 0.1^{a,C}$	$32.82 \pm 0.5^{b,C}$	$30.10 \pm 1.0^{b,C}$	$25.50 \pm 2.0^{b,C}$
	T2	$0.54 \pm 0.1^{a,A}$	$5.34 \pm 0.42^{a,B}$	$29.39 \pm 1.2^{a,B}$	$1.71 \pm 0.04^{a,B}$	$0.16 \pm 0.04^{a,A}$	$68.29 \pm 0.1^{c,C}$	$22.40 \pm 0.5^{c,C}$	$32.20 \pm 0.5^{b,C}$	$27.50 \pm 1.5^{b,C}$
ANOVA	C	*	*	*	*	NS	*	*	*	*
	T	*	*	*	*	NS	*	*	*	*
	C*T	*	NS	NS	NS	NS	**	**	**	**

Acidity: g 100 g^{-1}; chlorophyll: mg kg^{-1}; carotenoids: mg kg^{-1}; K_{232} = absorbance at a wavelength of 232 nm; K_{270} = absorbance at a wavelength of 270 nm; total phenols: mg kg^{-1}; RAC: relative antioxidant capacity (μg TEg^{-1} of DW). T0: control (100% ETc); T1: regulated deficit irrigation (RDI; 50% ETc during stage I and stage of nut development and 100% ETc during stage III); T2: stressed treatments (50% ETc).
Values are means (n = 3) ± SE. Different superscripted lowercase letters a, b, and c indicate difference ($p < 0.05$) among three irrigation treatments (T0, T1, and T2) in the same cultivar. Different superscripted uppercase letters A, B, and C indicate differences ($p < 0.05$) among cultivars in the same treatment.

Table 6. Correlation between antioxidants and antioxidant activity in pistachio nuts.

	TP	Flav	Anth	FRAP	DPPH	β-carot
TP	1	–0.50**	–0.62**	–0.68**	0.45**	–0.70**
Flav		1	0.56**	0.52**	–0.32*	0.40*
Anth			1	0.60**	–0.42**	0.32**
FRAP				1	–0.10NS	0.60**
DPPH					1	–0.37**
β-carot						1

*, **, and *** indicate significance at $p < 0.05$, 0.01, and 0.001, respectively.
NS = not significant; TP: total phenols; Flav: flavonoids; Anth: anthocyanin; FRAP: ferric-reducing antioxidant power; DPPH: 1,1-diphenyl-2-picrylhydrazyl capacity; β-carot: β-carotene bleaching activity assay.

alcohols, aldehydes, and 1-methyl-pyrrole also increased with decrease in water regime. Hence, the amount of 1-methyl-pyrrole increased by about 50% in cv. Mateur and Ohadi with stressed treatment T2. Alcohols were the second most represented class consisting mainly of 1-hexanol, 1-nonanol, and 1-dodecanol. Among the aldehydes, nonanal (nonanaldehyde) had the highest content, especially in cv. Ohadi and Elguetar.

Seventy volatiles were identified in pistacho nuts after the roasting process, including acids, aldehydes, alcohols, terpenes, ketones, esters, aromatic compounds, pyridine, pyrazines, pyrimidines, and furan derivatives (Table 8). The predominant volatile compounds were α-pinene and limonene, which are terpenes. Terpenes constituted the primary class of substances, comprising 50% of all volatile compounds, followed by aldehydes and nitrogenous compounds. The roasted pistachio showed an evident increase in pyridine, pyrazines, pyrimidines, furan derivatives, and aldehydes arising from Maillard reaction during roasting (Table 8).

Irrigation treatments have similar effects on the content of volatile compounds of raw and roasted pistachio nuts. Results showed that terpenes were the most abundant compounds. Kendirci and Onoğur (2011), studying raw pistachio nuts of different cultivars in Turkey, observed that terpenes and mainly α-pinene (pine-like, resinous) were the major volatile compounds contributing to flavor. These authors suggested that terpenes and 1-methyl-pyrrole were the key odorants found in the highest amount in all cultivars grown under the T2 stressed treatment. Key aroma compounds, such as terpenes, aldehydes, and nitrogenous compounds, were improved in raw and roasted nuts grown under the T2 irrigation treatment. Galindo *et al.* (2018) reported that severe RDI during stage II increased the contents of aldehydes and reduced those of pyrazines and terpenes. These findings were in accordance with the results shown by Şahan and Bozkurt (2020), reporting that flavoring compounds were higher in rain-fed pistachios than irrigated trees and the concentration of terpenes, the most abundant volatile compounds in dried pistachio nuts, decreased with irrigation. Increase in pyridines, pyrazines, pyrimidines, and furan derivatives as well as aldehydes in roasted pistachio was evident. This behavior is related to the roasting process, as these volatiles arise from Maillard reactions as well as from the Strecker degradation of α-amino acids, producing aldehydes and α-aminoketones, as reported by Rodríguez-Bencomo *et al.* (2015).

Composition of fatty acids

In the present study, the RDI irrigation treatments did not affect the fatty acid profile, and the fatty acid composition didn't show a consistent behavior with irrigation treatments (Table 9). Moreover, Noguera-Artiaga *et al.* (2020b) showed that pistachios obtained under moderate RDI (treatment T1) had the highest content of oleic acid and the lowest content of α-linolenic, compared to those of control (T0) and treatment T2. In the same manner, Carbonell-Barrachina *et al.* (2015) reported that moderate RDI increased the content of linoleic acid. Moreover, 50% ETc water regime (treatment T2) contributed to higher fatty acid content for all cultivars in both years, compared to control (100% ETc) and RDI (T1) treatments. It was clear from the results of this investigation that the fatty acid content appeared to be insensitive to water deficit. This finding confirmed the results of previous investigations under deficit irrigation, showing that deficit irrigation allowed the maintenance of higher fatty acids, compared to full irrigation (Ahumada-Orellana *et al.*, 2018; Motilva *et al.*, 2000). This contrasting behavior could be attributed to the higher influence of varietal factors and climatic conditions on the composition of fatty acids than to water status (Fernandes-Silva *et al.*, 2021).

Analysis of the fatty acid profile revealed four main fatty acids: oleic acid (C18:1), linoleic acid (C18:2), palmitic

Table 7. Amount* of volatile aroma compounds for classes of substances in raw pistachio samples of the four studied pistachio cultivars subjected to different irrigation treatments.

Compounds	LRI		Mateur			Kerman			Ohadi			Elguetar		
	VF-Vax	SLB-5	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
Acids														
Acetic	1,448	596	195^{b}	201^{b}	176^{a}	273^{b}	284^{b}	142^{a}	174^{a}	172^{a}	314^{b}	157^{a}	143^{a}	296^{b}
Isobutyric	1,566	742	54^{b}	60^{b}	0^{a}	10^{a}	15^{a}	18^{a}	103^{b}	111^{b}	88^{a}	46^{b}	50^{b}	35^{a}
Pentanoic	1,740	894	101^{b}	105^{b}	36^{a}	40^{a}	38^{a}	43^{a}	161^{b}	180^{b}	70^{a}	35^{a}	36^{a}	53^{b}
Hexanoic	1,849	983	200^{a}	206^{a}	225^{b}	372^{b}	315^{a}	325^{a}	342^{a}	349^{a}	387^{a}	361^{a}	386^{a}	526^{b}
2-Ethyl-hexanoic	1,952	1,123	32^{a}	33^{a}	38^{a}	75^{b}	79^{b}	25^{a}	53^{a}	52^{a}	47^{a}	20^{a}	29^{a}	48^{b}
Octanoic	2,062	1,180	173^{b}	159^{b}	84^{a}	79^{a}	96^{b}	77^{a}	150^{a}	172^{a}	163^{a}	214^{b}	244^{b}	136^{a}
Nonanoic	2,149	1,280	119^{a}	125^{a}	208^{b}	162^{b}	120^{a}	135^{a}	389^{b}	355^{b}	319^{a}	172^{a}	170^{a}	230^{b}
All			874^{b}	889^{b}	767^{a}	1011^{c}	947^{b}	765^{a}	1,372^{a}	1,391^{a}	1,388^{a}	1,005^{a}	1,058^{a}	1,324^{b}
Aldehydes														
2-Methyl-butanal	915	646	55^{a}	53^{a}	78^{b}	71^{a}	71^{a}	96^{b}	33^{a}	25^{a}	87^{b}	23^{a}	29^{a}	48^{b}
3-Methyl-butanal	919	652	20^{a}	17^{a}	44^{b}	28^{a}	22^{a}	39^{b}	12^{a}	19^{a}	30^{b}	13^{a}	19^{a}	38^{b}
Hexanal	1,076	810	850^{a}	871^{a}	1218^{b}	356^{a}	359^{a}	579^{b}	165^{a}	166^{a}	374^{b}	504^{a}	578^{a}	842^{b}
Heptanal	1,175	912	410^{a}	428^{a}	531^{b}	180^{a}	235^{a}	295^{b}	121^{a}	133^{a}	289^{b}	146^{a}	143^{a}	267^{b}
Octanal	1,279	1,006	120^{a}	132^{a}	245^{b}	30^{a}	26^{a}	56^{b}	60^{a}	58^{a}	254^{b}	235^{a}	241^{a}	320^{b}
(Z)-2-Heptenal	1,316	964	129^{a}	144^{a}	172^{b}	29^{a}	35^{a}	50^{b}	95^{a}	93^{a}	184^{b}	79^{a}	84^{a}	188^{b}
Nonanal	1,377	1,107	410^{a}	432^{a}	552^{b}	495^{a}	545^{a}	968^{b}	1,732^{a}	1,681^{a}	3,819^{b}	2,491^{a}	2,556^{b}	3,344^{c}
(E)-2-Octenal	1,419	1,057	33^{a}	34^{a}	40^{a}	80^{a}	79^{a}	203^{b}	63^{a}	66^{a}	124^{b}	24^{a}	27^{a}	31^{a}
Decanal	1,491	1,209	168^{a}	177^{a}	264^{b}	175^{a}	157^{a}	246^{b}	216^{a}	230^{a}	351^{b}	128^{a}	155^{a}	258^{b}
Benzaldehyde	1,520	953	166^{a}	167^{a}	189^{b}	133^{a}	131^{a}	238^{b}	132^{a}	133^{a}	281^{b}	75^{a}	84^{a}	186^{b}
(E)-2-Nonenal	1,530	1,161	144^{a}	136^{a}	240^{b}	160^{a}	122^{a}	273^{b}	180^{a}	226^{a}	337^{b}	145^{a}	104^{a}	270^{b}
1-Methyl-pyrrole-2-carboxaldehyde	1,621	993	39^{a}	41^{a}	84^{b}	27^{a}	21^{a}	47^{b}	26^{a}	21^{a}	102^{b}	26^{a}	24^{a}	72^{b}
All			2,544^{a}	2,632^{a}	3,657^{b}	1,764^{a}	1,803^{a}	3,090^{b}	2,835^{a}	2,851^{a}	6,232^{b}	3,889^{a}	4,044^{b}	5,864^{c}
Alcohols														
2-Methyl-1-butanol	1,201	730	289^{a}	275^{a}	394^{b}	97^{a}	107^{a}	209^{b}	88^{a}	99^{a}	150^{b}	99^{a}	100^{a}	143^{b}
1-Pentanol	1,240	768	92^{a}	90^{a}	254^{b}	168^{a}	199^{b}	618^{c}	603^{a}	622^{a}	859^{b}	323^{a}	360^{a}	786^{b}
Heptan-2-ol	1,307	900	125^{a}	129^{a}	266^{b}	80^{a}	76^{a}	120^{b}	112^{a}	116^{a}	380^{b}	81^{a}	111^{a}	144^{b}
Hexanol	1,340	871	364^{a}	344^{a}	750^{b}	1,574^{a}	1,523^{a}	2,683^{b}	2,202^{a}	2,209^{a}	2,861^{b}	3,064^{a}	3,066^{a}	4,025^{b}
2-Butoxy-ethanol	1,393	910	160^{a}	175^{a}	219^{b}	330^{a}	344^{a}	578^{b}	308^{a}	302^{a}	411^{b}	253^{a}	279^{a}	324^{b}

(*continues*)

Table 7. Continued.

Compounds	LRI		Mateur			Kerman			Ohadi			Elguetar		
	VF-Vax	SLB-5	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
2-Octanol	1,406	997	77[a]	89[a]	132[b]	32[a]	47[a]	68[b]	53[a]	86[a]	124[b]	58[a]	55[a]	137[b]
1-Octen-3-ol	1,437	985	240[a]	220[a]	331[b]	177[a]	156[a]	321[b]	174[a]	163[a]	240[b]	223[a]	236[a]	290[b]
1-Heptanol	1,443	972	270[b]	201[a]	633[c]	275[a]	284[a]	511[b]	350[a]	363[a]	383[a]	337[a]	339[a]	778[b]
6-Methyl-hept-5-en-2-ol	1,451	994	87[a]	90[a]	161[b]	105[a]	120[a]	277[b]	105[a]	101[a]	154[b]	79[a]	106[a]	183[b]
2-Ethyl-1-hexanol	1,477	1,038	271[a]	293[a]	335[b]	449[a]	474[a]	597[b]	510[a]	501[a]	584[b]	340[a]	376[a]	476[b]
Nonan-2-ol	1,507	1,088	53[a]	41[a]	90[b]	45[a]	53[a]	87[b]	60[a]	62[a]	118[b]	52[a]	67[a]	139[b]
1-Octanol	1,548	1,075	328[a]	377[a]	643[b]	1,311[a]	1,297[a]	2,773[b]	631[a]	637[a]	950[b]	851[a]	868[a]	938[b]
1-Nonanol	1,653	1,172	387[a]	417[a]	532[b]	727[a]	785[a]	899[b]	955[a]	958[a]	1,112[b]	1,039[a]	1,047[a]	1,494[b]
(Z)-3-Nonen-1-ol	1,680	1,160	43[a]	40[a]	124[b]	56[a]	53[a]	151[b]	46[a]	42[a]	92[b]	46[a]	56[a]	79[a]
1-Decanol	1,760	1,267	102[a]	99[a]	216[b]	72[a]	85[a]	167[b]	81[a]	87[a]	101[a]	109[a]	138[a]	222[b]
Benzylalchohol	1,879	1,029	176[a]	173[a]	240[b]	175[a]	173[a]	241[b]	216[a]	213[a]	245[b]	361[a]	343[a]	480[b]
Phenylethylalchohol	1,913	1,112	80[a]	92[a]	190[b]	165[a]	135[a]	294[b]	132[a]	184[a]	257[b]	313[a]	317[a]	397[b]
1-Dodecanol	1,967	1,475	317[a]	378[a]	991[b]	205[a]	184[a]	292[b]	148[a]	114[a]	765[b]	112[a]	139[a]	472[b]
All			3,461[a]	3,523[a]	6,501[b]	6,043[a]	6,095[a]	10,886[b]	6,774[a]	6,859[b]	9,786[c]	7,740[a]	8,003[b]	11,507[c]
Terpenes														
Tricyclene	1,005	922	129[a]	119[a]	246[b]	76[a]	78[a]	180[b]	112[a]	102[a]	200[b]	131[a]	140[a]	268[b]
α-Pinene	1,019	940	1,6103[b]	15,895[a]	17,433[c]	11,018[a]	12,897[b]	15,450[c]	13,458[a]	13,357[a]	16,501[b]	15,071[a]	15,602[b]	16,309[c]
α-Thujene	1,023	932	76[a]	83[a]	96[a]	222[a]	201[a]	390[b]	224[a]	217[a]	402[b]	81[a]	100[a]	123[a]
α-Fenchene	1,052	953	53[a]	43[a]	79[a]	59[a]	54[a]	70[a]	38[a]	37[a]	47[a]	59[a]	61[a]	74[a]
Camphene	1,058	955	473[a]	502[a]	654[b]	393[a]	362[a]	1034[b]	500[a]	529[a]	661[b]	522[b]	474[a]	637[c]
β-Pinene	1,094	980	808[a]	807[a]	934[b]	399[a]	530[b]	1483[c]	1780[a]	1774[a]	1851[b]	663[a]	639[a]	750[b]
Sabinene	1,107	978	40[a]	38[a]	57[a]	138[a]	134[a]	202[b]	91[a]	91[a]	111[a]	42[a]	30[a]	61[a]
2-Carene	1,119	1006	80[a]	82[a]	113[a]	108[a]	114[a]	137[b]	87[a]	104[a]	245[b]	46[a]	42[a]	149[b]
3-Carene	1,128	1,012	445[a]	456[a]	483[a]	215[a]	234[a]	340[b]	514[a]	487[a]	670[b]	138[a]	173[b]	571[c]
Myrcene	1,138	991	809[a]	806[a]	1420[b]	818[a]	849[a]	2,575[b]	1,113[a]	1,114[a]	1,325[b]	1,954[a]	2,232[b]	3,817[c]
α-Phellandrene	1,141	1,005	106[a]	117[a]	320[b]	217[a]	255[a]	278[a]	192[a]	183[a]	282[b]	138[a]	146[a]	274[b]
α-Terpinene	1,153	1,018	158[a]	144[a]	250[b]	212[a]	192[a]	600[b]	250[a]	288[a]	356[b]	284[a]	258[a]	860[b]
Limonene	1,183	1,032	2,215[a]	2,243[a]	4,088[b]	12,618[a]	13,499[b]	16,691[c]	11,528[a]	11,842[b]	17,707[c]	10,768[a]	10,943[b]	12,120[c]
β-Phellandrene	1,194	1,030	210[a]	261[a]	356[b]	369[a]	318[a]	553[b]	423[a]	429[a]	385[b]	132[a]	187[a]	328[b]
γ-Terpinene	1,231	1,064	335[a]	327[a]	456[b]	1351[b]	1292[a]	1516[c]	632[a]	640[a]	1211[b]	742[a]	754[a]	938[b]

β-Ocimene	1,236	1,050	50^{a}	43^{a}	73^{a}	208^{a}	183^{a}	326^{b}	49^{a}	37^{a}	82^{b}	489^{a}	532^{a}	937^{b}
p-Cymene	1,246	1,022	1,778^{a}	1,786^{a}	1,813^{b}	2,365^{a}	2,500^{b}	3,202^{c}	1,448^{a}	1,997^{b}	3,029^{c}	2,206^{a}	2,292^{b}	2,957^{c}
o-Cymene	1,250	1,021	47^{a}	50^{a}	105^{b}	344^{a}	360^{a}	429^{b}	207^{a}	209^{a}	316^{b}	15^{a}	37^{a}	79^{b}
Terpinolene	1256	1088	9421^{a}	9394^{a}	10058^{b}	2119^{a}	2159^{a}	5743^{b}	2612^{a}	2789^{b}	3664^{c}	6958^{b}	6875^{a}	7794^{c}
p-Mentha-1,5,8-triene	1,410	1,113	180^{a}	197^{a}	330^{b}	61^{a}	52^{a}	80^{a}	69^{a}	76^{a}	80^{a}	101^{a}	128^{a}	282^{b}
p-Cymenene	1,423	1,091	1,078^{a}	1,016^{a}	1,498^{b}	512^{a}	503^{a}	614^{b}	599^{a}	580^{a}	966^{b}	1,404^{a}	1,438^{a}	2,669^{b}
m-Cymenene	1,431	1,085	68^{a}	79^{a}	139^{b}	352^{a}	314^{a}	402^{b}	243^{a}	255^{a}	412^{b}	152^{a}	134^{a}	233^{b}
Camphor	1,509	1,143	78^{a}	95^{a}	154^{b}	137^{a}	124^{a}	255^{b}	99^{a}	118^{a}	271^{b}	128^{a}	127^{a}	310^{b}
Linalool	1,536	1,098	117^{a}	111^{a}	285^{b}	242^{a}	283^{a}	363^{b}	129^{a}	109^{a}	227^{b}	173^{a}	158^{a}	314^{b}
α-Terpineol	1,694	1,191	38a	30^{a}	89^{b}	105^{a}	109^{a}	242^{b}	38^{a}	37^{a}	62^{b}	26^{a}	39^{a}	86^{b}
m-Cymen-8-ol	1,850	1,185	179^{a}	187^{a}	389^{b}	161^{a}	168^{a}	208^{b}	162^{a}	187^{a}	206^{b}	294^{a}	287^{a}	423^{b}
Nerylacetone	1,855	1,435	90^{a}	87^{a}	219^{b}	23^{a}	29^{a}	50^{b}	19^{a}	25^{a}	53^{b}	80^{a}	62^{a}	142^{b}
Eucalyptol	1,190	1,032	44^{a}	35^{a}	75^{b}	870^{a}	872^{a}	902^{b}	113^{a}	106^{a}	143^{b}	38^{a}	53^{a}	114^{b}
Bornylacetate	1,575	1,280	20^{a}	25^{a}	58^{b}	38^{a}	37^{a}	51^{b}	35^{a}	32^{a}	48^{a}	18^{a}	16^{a}	112^{b}
All			35,228^{a}	35,058^{a}	42,270^{b}	35,750^{a}	38,702^{b}	54,366^{c}	36,764^{a}	37,751^{b}	51,513^{c}	42,853^{a}	43,959^{b}	53,731^{c}
Ketones														
6-Methyl-5-hepten-2-one	1,326	986	113^{a}	156^{b}	220^{c}	208^{a}	235^{a}	391^{b}	136^{a}	151^{a}	321^{b}	320^{a}	305^{a}	691^{b}
Oct-3-en-2-one	1,399	1,040	34^{a}	46^{a}	176^{b}	89^{a}	83^{a}	177^{b}	55^{a}	60^{a}	134^{b}	119^{a}	141^{a}	235^{a}
Acetophenone	1,651	1,068	43^{a}	37^{a}	131^{b}	32^{a}	54^{a}	137^{b}	41^{a}	62^{a}	152^{b}	48^{a}	39^{a}	138^{b}
All			190^{a}	239^{a}	527^{b}	329^{a}	372^{a}	705^{b}	232^{a}	273^{a}	607^{b}	487^{a}	485^{a}	1,064^{b}
Others														
Toluene	1,038	761	83^{a}	94^{a}	79^{a}	148^{b}	100^{a}	84^{a}	183^{a}	163^{a}	155^{a}	145^{b}	99^{a}	121^{b}
1-Methyl-pyrrole	1,133	750	3,917^{a}	3,952^{a}	6,925^{b}	5,462^{a}	5,612^{b}	7,415^{c}	2,648^{a}	2,700^{b}	5,901^{c}	2,790^{a}	2,863^{a}	5,374^{b}
Styrene	1,242	889	35^{a}	28^{a}	25^{a}	22^{a}	20^{a}	55^{b}	36^{a}	18^{a}	32^{a}	41^{a}	31^{a}	49^{a}
Octylacetate	1,465	1,213	15^{a}	24^{a}	48^{b}	105^{b}	105^{b}	67^{a}	44^{a}	40^{a}	55^{a}	36^{a}	35^{a}	71^{b}
Benzothiazole	1,956	1,224	351^{a}	347^{a}	428^{b}	279^{a}	270^{a}	432^{b}	361^{a}	388^{a}	410^{b}	340^{a}	355^{a}	417^{b}
Phenol	2,011	992	212^{a}	204^{a}	354^{b}	270^{a}	263^{a}	320^{b}	244^{a}	276^{a}	348^{b}	250^{a}	230^{a}	355^{b}
γ-Nonalactone	2,032	1,344	36^{a}	20^{a}	124^{b}	13^{a}	20^{a}	52^{b}	35^{a}	42^{a}	143^{b}	35^{a}	45^{a}	85^{b}
All			4,649^{c}	4,677^{c}	8,031^{a}	6,301^{b}	6,390^{b}	8,425^{a}	3,551^{c}	3,627^{c}	7,044^{b}	3,637^{c}	3,658^{c}	64,72^{b}

Peak area, arbitrary scale; T0: control; T1: regulated deficit irrigation (RDI); T2: stressed; different lowercase superscripted letters in the same row indicate difference ($p < 0.05$) among three irrigation treatments (T0, T1, and T2) and cultivars by Scheffe´s test.

Table 8. Amount* of volatile compounds and classes of substances in roasted pistachio samples of the four studied pistachio cultivars subjected to different irrigation treatments.

Compounds	LRI		Mateur			Kerman			Ohadi			Elguetar		
	VF-Vax	SLB-5	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
Acids														
Acetic	1,448	596	584[a]	591[a]	649[b]	514[b]	548[b]	437[a]	261[a]	395[b]	372[b]	220[a]	252[a]	339[b]
Pentanoic	1,740	894	55[a]	50[a]	55[a]	49[a]	57[a]	71[b]	41[a]	43[a]	48[a]	73[a]	89[a]	135[b]
Hexanoic	1,849	983	755[b]	784[b]	703[a]	328[b]	273[a]	305[b]	547[a]	564[a]	559[a]	1,309[a]	1,399[b]	1,322[a]
Heptanoic	1,956	1,083	336[a]	363[b]	316[a]	219[a]	210[a]	238[a]	204[a]	235[b]	238[b]	442[a]	410[a]	580[b]
Octanoic	2,062	1,180	286[a]	269[a]	332[b]	89[a]	76[a]	85[a]	117[a]	126[a]	144[b]	378[a]	357[a]	395[b]
Nonanoic	2,149	1,280	351[b]	327[a]	320[a]	119[a]	118[a]	165[b]	217[a]	249[b]	213[a]	221[a]	220[a]	225[a]
All			2,367[a]	2,384[a]	2,375[a]	1,318[b]	1,282[a]	1,301[b]	1,387[a]	1,612[c]	1,574[b]	2,643[a]	2,727[b]	2,996[c]
Aldehydes														
2-Methyl-butanal	915	646	2,148[a]	2,604[b]	2,847[c]	1,674[a]	1,975[b]	3,412[c]	1,858[a]	1,856[a]	5,229[b]	4,733[a]	4,733[a]	6,105[b]
3-Methyl-butanal	918	652	972[a]	977[a]	1083[b]	684[a]	688[a]	890[b]	449[a]	495[a]	631[b]	155[a]	180[a]	348[b]
Pentanal	919	715	307[a]	316[a]	445[b]	248[a]	273[a]	478[b]	170[a]	147[a]	509[b]	129[a]	126[a]	345[b]
Hexanal	1,076	810	1,658[a]	1,617[a]	2,404[b]	1,073[a]	1,016[a]	2,436[b]	1,388[a]	1,381[a]	1,783[b]	1,300[a]	1,356[a]	2,675[b]
Heptanal	1,175	912	378[a]	373[a]	423[b]	113[a]	92[a]	501[b]	746[a]	791[a]	948[b]	584[a]	589[a]	813[b]
Octanal	1,279	1,006	748[a]	725[a]	1514[b]	742[a]	699[a]	822[b]	919[a]	918[a]	2,705[b]	1,444[a]	1,440[a]	2,189[b]
Nonanal	1,377	1,107	5,250[a]	5,166[a]	8,844[b]	2,580[a]	2,573[a]	4,084[b]	2,81[a]	2,70[a]	398[b]	56[a]	64[a]	780[b]
(E)-2-Octenal	1,419	1,057	19[a]	65[b]	91[c]	32[a]	24[a]	76[b]	55[a]	91[a]	276[b]	272[a]	261[a]	315[b]
Decanal	1,491	1,209	45[a]	56[a]	98[b]	12[a]	18[a]	54[b]	154[a]	172[a]	360[b]	60[a]	76[a]	122[b]
Benzaldehyde	1,520	953	467[a]	418[a]	611[b]	609[a]	655[a]	758[b]	890[a]	848[a]	1,082[b]	769[a]	761[a]	1,494[b]
(E)-2-Nonenal	1,530	1,161	292[a]	350[b]	540[c]	11[a]	16[a]	23[b]	69[a]	70[a]	199[b]	39[a]	44[a]	77[b]
1-Methy-pyrrole-2-carboxaldehyde	1,621	993	154[a]	146[a]	385[b]	112[a]	122[a]	295[b]	129[a]	139[a]	424[b]	322[a]	307[a]	465[b]
Benzeneacetaldehyde	1,644	1,043	74[a]	78[a]	199[b]	156[a]	167[a]	300[b]	232[a]	231[a]	430[b]	54[a]	67[a]	154[b]
Pyrrole-2-carboxaldehyde	2,028	1,015	45[a]	56[a]	123[b]	51[a]	75[b]	90[c]	59[a]	82[a]	134[b]	78[a]	99[a]	236[b]
All			12,557[a]	12,947[a]	19,607[b]	8,097[a]	8,393[a]	14,219[b]	7,399[a]	7,491[a]	15,108[b]	9,995[a]	10,103[b]	16,118[c]
Alcohols														
2-Methyl-1-butanol	1,201	730	178[a]	201[b]	369[c]	312[a]	325[a]	426[b]	163[a]	165[a]	542[b]	160[a]	187[a]	255[b]
Hexanol	1,340	871	1,435[a]	1,433[a]	2,395[b]	1,066[a]	1,087[a]	1,941[b]	1,739[a]	1,762[a]	2,380[b]	963[a]	1,116[a]	2,451[b]
2-Octanol	1,406	997	71[a]	82[a]	124[b]	61[a]	40[a]	120[b]	103[a]	110[a]	261[b]	398[a]	421[a]	564[b]
1-Heptanol	1,443	972	487[a]	481[a]	710[b]	251[a]	221[a]	599[b]	341[a]	447[a]	644[b]	165[a]	184[a]	295[b]

2-Ethyl-1-hexanol	1,478	1,038	165^{a}	219^{b}	375^{c}	330^{a}	302^{a}	473^{b}	257^{a}	276^{a}	894^{b}	357^{a}	365^{a}	723^{b}
1-Octanol	1,548	1,548	1,114^{a}	1,180^{a}	1,575^{b}	1,156^{a}	1,178^{a}	2,106^{b}	1,073^{a}	1,072^{a}	2,111^{b}	87^{a}	85^{a}	180^{b}
1-Nonanol	1,653	1,653	539^{a}	615^{b}	824^{c}	534^{a}	554^{a}	680^{b}	599^{a}	601^{a}	791^{b}	419^{a}	467^{a}	606^{b}
Benzylalchohol	1,879	1,029	56^{a}	59^{a}	143^{b}	179^{a}	144^{a}	214^{b}	176^{a}	168^{a}	602^{b}	420^{a}	452^{a}	676^{b}
Phenylethylalchohol	1,913	1,112	167^{a}	162^{a}	209^{b}	300^{a}	335^{a}	410^{b}	516^{a}	547^{a}	702^{b}	170^{a}	179^{a}	739^{b}
1-Dodecanol	1,967	1,475	1,193^{a}	1,200^{b}	1,738^{c}	70^{a}	132^{b}	274^{c}	94^{a}	90^{a}	163^{b}	61^{a}	67^{a}	99^{b}
Pentadecanol	2,151	1,778	352^{a}	298^{a}	451^{b}	69^{a}	64^{a}	80^{b}	42^{a}	41^{a}	100^{b}	29^{a}	32^{a}	75^{b}
All			5,757^{a}	5,930^{a}	8,913^{b}	4,328^{a}	4,382^{a}	7,323^{c}	5,103^{a}	5,279^{a}	9,190^{b}	3,229^{a}	3,582^{a}	6,663^{b}
Terpenes														
Tricyclene	1,005	922	127^{a}	132^{a}	303^{b}	124^{a}	100^{a}	208^{b}	154^{a}	161^{a}	268^{b}	105^{a}	108^{a}	129^{b}
α-Pinene	1,019	940	14,739^{a}	1,5114^{b}	16,556^{c}	10,193^{a}	10,997^{b}	13,215^{c}	14,984^{a}	15,700^{b}	16,259^{c}	13,722^{a}	14,159^{b}	16,063^{c}
α-Thujene	1,023	932	111^{a}	103^{a}	228^{b}	198^{a}	192^{a}	303^{b}	161^{a}	167^{a}	346^{b}	309^{a}	370^{a}	910^{b}
Camphene	1,058	955	669^{a}	613^{a}	768^{b}	851^{a}	857^{a}	1043^{b}	693^{a}	695^{a}	757^{b}	659^{a}	652^{a}	789^{b}
β-Pinene	1,094	980	859^{a}	870^{a}	1020^{b}	1015^{a}	1020^{a}	1240^{b}	980^{a}	1074^{b}	2079^{c}	491^{a}	538^{a}	679^{b}
Sabinene	1,107	978	24^{a}	30^{a}	44^{a}	35^{a}	55^{a}	105^{b}	130^{a}	123^{a}	168^{b}	109^{a}	118^{a}	236^{b}
Myrcene	1,138	991	1,296^{a}	1,323^{a}	1,582^{b}	1,077^{a}	1,080^{a}	1,406^{b}	1,281^{a}	1,465^{b}	3,278^{c}	2,328^{a}	2,883^{b}	4,570^{c}
α-Terpinene	1,153	1,018	291^{a}	297^{a}	378^{b}	424^{a}	444^{a}	792^{b}	251^{a}	283^{a}	366^{b}	1,729^{a}	1,770^{a}	2,917^{b}
Limonene	1,183	1,032	6,313^{a}	6,867^{b}	9,348^{c}	9,266^{a}	9,366^{b}	10,613^{c}	10,855^{a}	10,852^{a}	15,004^{b}	1,4888^{a}	15,821^{b}	17,002^{c}
β-Phellandrene	1,194	1,030	201^{a}	170^{a}	309^{b}	388^{a}	420^{a}	540^{b}	381^{a}	417^{a}	638^{b}	359^{a}	439^{b}	664^{c}
γ-Terpinene	1,231	1,064	612^{a}	669^{a}	909^{b}	613^{a}	627^{a}	836^{b}	846^{a}	870^{a}	1123^{b}	626^{a}	666^{a}	860^{b}
p-Cymene	1,260	1,022	1,610^{a}	1,632^{a}	2,541^{b}	2,455^{a}	2,480^{a}	2,728^{b}	3,158^{b}	2,907^{a}	7,239^{c}	9,618^{a}	9,784^{b}	11,656^{c}
Terpinolene	1,273	1,088	5,063^{a}	5,101^{b}	6,664^{c}	1,365^{a}	2,155^{b}	3,659^{c}	2,406^{a}	2,420^{a}	3,641^{b}	1,709^{a}	1,720^{a}	3,275^{b}
p-Mentha-1,5,8-triene	1,410	1,113	128^{a}	169^{a}	212^{b}	33^{a}	35^{a}	89^{b}	76^{a}	70^{a}	138^{b}	105^{a}	148^{a}	229^{b}
p-Cymenene	1,423	1,019	185^{a}	170^{a}	282^{b}	204^{a}	201^{a}	291^{b}	366^{a}	336^{a}	432^{b}	319^{a}	320^{a}	665^{b}
Linalool	1,537	1,191	71^{a}	80^{a}	142^{b}	129^{a}	191^{a}	295^{b}	93^{a}	131^{a}	732^{b}	222^{a}	227^{a}	412^{b}
Bornylacetate	1,575	1,280	34^{a}	39^{a}	80^{b}	59^{a}	67^{a}	132^{b}	37^{a}	27^{a}	91^{b}	52^{a}	60^{a}	179^{b}
m-Cymen-8-ol	1,850	1,185	521^{a}	521^{a}	722^{b}	273^{a}	276^{a}	400^{b}	357^{a}	443^{b}	553^{c}	447^{a}	477^{a}	770^{b}
All			32,854^{a}	33,900^{b}	42,088^{c}	28,702^{a}	30,563^{b}	37,895^{c}	37,259^{a}	38,141^{b}	53,112^{c}	47,797^{a}	50,260^{b}	62,005^{c}
Nitrogenous														
2,6-Diethyl-pyrazine	1,426	1,093	87^{a}	90^{a}	199^{b}	78^{a}	95^{a}	132^{b}	82^{a}	107^{a}	261^{b}	32^{a}	36^{a}	68^{b}
3,5-Diethyl-2-methyl-pyrazine	1,486	1,166	543^{a}	571^{a}	763^{b}	430^{a}	441^{a}	540^{b}	162^{a}	230^{b}	348^{c}	45^{a}	47^{a}	173^{b}

(*continues*)

Table 8. Continued.

Compounds	LRI		Mateur			Kerman			Ohadi			Elguetar		
	VF-Vax	SLB-5	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
(E)-2-Methyl-5-(1-propenyl)-pyrazine	1,712	1,133	81[a]	82[a]	127[b]	58[a]	62[a]	83[b]	103[a]	144[a]	258[b]	124[a]	129[a]	332[b]
2-Ethyl-5-methyl-pyrazine	1,378	998	359[a]	360[a]	514[b]	202[a]	259[a]	374[b]	335[a]	354[a]	615[b]	283[a]	311[a]	536[b]
Trimethyl-pyrazine	1,398	1005	393[a]	411[a]	618[b]	244[a]	317[b]	496[c]	444[a]	467[a]	687[b]	760[a]	769[a]	913[b]
2,5-Dimethyl-pyrazine	1,318	927	1,369[a]	1,395[a]	1,662[b]	1,060[a]	1,130[b]	1,525[c]	1,099[a]	1,339[b]	2,741[c]	1,169[a]	1,180[a]	2,648[b]
4,6-Dimethyl-pyrimidine	1,323	928	71[a]	80[a]	179[b]	45[a]	57[a]	87[b]	162[a]	175[a]	471[b]	149[a]	197[a]	424[b]
2-Ethyl-3,5-dimethyl-pyrazine	1,437	1,082	1,542[a]	1,557[a]	2,011[b]	1,067[a]	1,072[a]	1,662[b]	1,901[a]	1,966[a]	2,725[b]	4,987[a]	4,990[a]	6,164[b]
N-acetyl-4(H)-pyridine	1,721	1,038	184[a]	185[a]	270[b]	84[a]	102[a]	137[b]	156[a]	217[b]	282[c]	101[a]	120[a]	206[b]
All			4,629[a]	4,731[b]	6,343[c]	3,268[a]	3,535[b]	5,036[c]	4,444[a]	4,999[b]	8,388[c]	7,650[a]	7,779[b]	11,464[c]
Furans														
2-Pentyl-furan	1,220	992	56[a]	61[a]	78[a]	29[a]	30[a]	82[b]	75[a]	77[a]	183[b]	66[a]	69[a]	166[b]
Furfural	1,460	836	628[a]	669[a]	890[b]	479[a]	515[b]	742[c]	600[a]	614[a]	800[b]	89[a]	94[a]	145[b]
5-Methyl-furfural	1,572	964	73[a]	75[a]	86[b]	39[a]	49[a]	154[b]	55[a]	71[a]	684[b]	533[a]	537[a]	757[b]
2-Furanmethanol	1,659	864	90[a]	91[a]	200[b]	120[a]	126[a]	244[b]	59[a]	79[a]	111[b]	58[a]	76[a]	189[b]
All			847[a]	896[a]	1254[b]	667[a]	720[b]	1222[c]	789[a]	841[b]	1778[c]	746[a]	776[a]	1257[b]
Ketones														
2,3-Pentanedione	1,055	702	123[a]	131[a]	166[b]	103[a]	135[a]	324[b]	139[a]	142[a]	248[b]	113[a]	148[a]	194[b]
2-Heptanone	1,174	889	538[a]	552[a]	700[b]	217[a]	266[a]	455[b]	409[a]	420[a]	647[b]	237[a]	264[a]	338[b]
2-Octanone	1,276	986	803[a]	816[a]	1077[b]	580[a]	589[a]	830[b]	1037[a]	1041[a]	1934[b]	395[a]	433[a]	780[b]
2-Nonanone	1,380	1,093	99[a]	120[a]	184[b]	64[a]	68[a]	112[b]	78[a]	98[a]	187[b]	70[a]	78[a]	135[b]
Oct-3-en-2-one	1,401	1,040	318[a]	319[a]	240[b]	137[a]	139[a]	272[b]	116[a]	155[a]	289[b]	238[a]	241[a]	309[b]
Acetophenone	1,650	1,068	34[a]	43[a]	97[b]	86[a]	94[a]	180[b]	68[a]	78[a]	92[b]	12[a]	24[a]	113[b]
All			1,915[a]	1,981[a]	2,464[b]	1,187[a]	1,291[b]	2,173[c]	1,847[a]	1,934[b]	3,397[c]	1,065[a]	1,188[b]	1,869[c]
Pyrroles														
1-methyl-pyrrole	1,133	750	3,098[a]	3,173[b]	5,064[c]	8,174[a]	8,260[b]	10,632[c]	4,067[a]	4,099[a]	4,725[b]	4,187[a]	4,190[a]	5,164[b]
Others														
Phenol	2,011	992	234[a]	268[a]	432[b]	15[a]	35[a]	86[b]	249[a]	267[a]	374[b]	143[a]	154[a]	327[b]

*Peak area, arbitrary scale; T0: control; T1: regulated deficit irrigation (RDI); T2: stressed; different lowercase superscripted letters in the same row indicate difference ($p < 0.05$) among three irrigation treatments (T0, T1, and T2) and different cultivars by Scheffe's test. Each compound was identified using mass spectral data, NIST' 20 and FFNSC 3.0 database, linear retention indices (LRI) according to the Van Den Dool and Kratz equation, calculated on VF-Wax 60 m and SLB-5ms 30-m capillary columns.

Table 9. Fatty acids profile of four pistachio nuts grown under RDI treatments.

Cultivar	Trt	C16:0	C16:1	C17:0	C17:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1
Mateur	T0	9.25±0.17^{aA}	0.55±0.01^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.45±0.04^{aA}	68.23±1.03^{aA}	19.88±1.22^{aA}	0.24±0.01^{aA}	0.07±0.01^{aA}	0.27±0.04^{aA}
	T1	9.48±0.16^{aA}	0.61±0.06^{aA}	0.02±0.0^{aA}	0.04±0.01^{aA}	1.47±0.12^{aA}	68.13±1.29^{aA}	19.70±1.56^{aA}	0.24±0.01^{aA}	0.07±0.01^{aA}	0.26±0.04^{aA}
	T2	9.42±0.31 ^{Aa}	0.62±0.03^{aA}	0.02±0.0^{aA}	0.04±0.01^{aA}	1.45±0.04^{aA}	68.3 ±0.87^{aA}	19.53±1.24^{aA}	0.24±0.02^{aA}	0.07±0.01^{aA}	0.29±0.02^{aA}
Elguetar	T0	8.47±0.53^{aB}	0.68±0.14^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.52±0.01^{aA}	68.7 ±0.66^{aA}	19.84±0.01^{aA}	0.30±0.08^{aA}	0.08±0.01^{aA}	0.32±0.06^{aA}
	T1	8.85±0.91^{aB}	0.74±0.09^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.40±0.02^{aA}	68.7 ±0.89^{aA}	19.63±0.01^{aA}	0.29±0.01^{aA}	0.07±0.01^{aA}	0.21±0.08^{aA}
	T2	8.86±0.69^{aB}	0.71±0.19^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.51±0.16^{aA}	68.7 ±0.73^{aA}	19.49±0.14^{aA}	0.3±0.02^{aA}	0.06±0.03^{aA}	0.24±0.13^{aA}
Ohadi	T0	9.92±0.15^{aA}	0.81±0.01^{aA}	0.02±0.0^{aA}	0.04±0.01^{aA}	0.95±0.04^{aB}	59.0 ±1.00^{aB}	28.62±1.20^{aB}	0.34±0.00^{aA}	0.05±0.00^{aA}	0.22±0.01^{aA}
	T1	10.13±0.15^{aA}	0.97±0.01^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	0.8±0.01^{aB}	58.7 ±1.00^{aB}	28.75±1.02^{aB}	0.28±0.01^{aA}	0.05±0.01^{aA}	0.20±0.01^{aA}
	T2	9.67±0.75^{aA}	0.72±0.18^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	0.93±0.06^{aB}	59.4 ±0.37^{aB}	28.52±0.41^{aB}	0.31±0.01^{aA}	0.07±0.01^{aA}	0.27±0.04^{aA}
Kerman	T0	9.35±0.12^{aA}	0.68±0.06^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.44±0.11^{aA}	68.7 ±0.05^{aA}	19.88±0.22^{aA}	0.26±0.01^{aA}	0.06±0.01^{aA}	0.27±0.01^{aA}
	T1	9.72±0.55^{aA}	0.69±0.01^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.44±0.01^{aA}	68.35±0.1^{aA}	19.24±0.64^{aA}	0.24±0.01^{aA}	0.06±0.02^{aA}	0.21±0.01^{aA}
	T2	9.51±0.4^{aA}	0.62±0.13^{aA}	0.02±0.0^{aA}	0.05±0.01^{aA}	1.44±0.04^{aA}	68.23± 1.0^{aA}	19.88 ± 1.2^{aA}	0.24±0.01^{aA}	0.07±0.01^{aA}	0.27±0.04^{aA}
ANOVA	C	*	ns	ns	ns	*	*	*	ns	ns	ns
	T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	C*T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

palmitic acid (C16:0); palmitoleic acid (C16:1); margaric acid (C17:0); Heptadecenoic acid (C17:1); stearic acid (C18:0); oleic acid (C18:1); linoleic acid (C18:2); linolenic acid (C18:3); arachidic acid (C20:0) and gadoleic acid (C20:1)

acid (C16:0), and stearic acid (C18:0) (Table 8). Oleic acid was dominant (68% of the total content), followed by linoleic (19% of the total content), palmitic (9% of the total content), and steric acids (1% of the total content). Our findings matched with Acar *et al.* (2017), reporting that main fatty acids found in pistachio were oleic, linoleic, and palmitic acids. Oleic acid ranged from 58.75% in cv. Ohadi to 68.70% in cv. Elguetar. Our results for the oleic acid content (58–68%) in pistachio samples were confirmed by previous studies (Arena *et al.*, 2007; Noguera-Artiaga *et al.*, 2020a). In the same line, Ghrab *et al.* (2010) reported that oleic acid was the main monounsaturated fatty acid, the total contents of saturated and unsaturated fatty acids being constant at 10% and 89%, respectively, and other fatty acids were determined in traces. Cv. Ohadi showed the lowest value of oleic acid (59.0; 58.7, and 59.4 with treatments T0, T1, and T2, respectively). Linoleic acid was the dominant polyunsaturated fatty acid, varying from 19.49% in cv. Elguetar to 28.75% in cv. Ohadi. Hence, the extracted oil from cv. Ohadi had higher content of linoleic acid (28.62%, 28.75%, and 28.52% with treatment T0, T1, and T2, respectively). Palmitic acid was the main saturated fatty acid ranging from 8.85% in cv. Elguetar to 10.13% in cv. Ohadi. Regarding stearic acid, it was found as a minor saturated fatty acid in pistachio kernels, ranging from 0.8% in cv. Ohadi to 1.52% in cv. Elguetar. Our results revealed that both cv. Ohadi and Elguetar had the most interesting fatty acid compositions among the studied cultivars. Statistically, neither of the treatments nor the 'cultivar × treatment' interaction (C × T) showed significant results; the only significant differences ($p < 0.05$) observed among cultivars were for four main FAMEs (oleic acid, linoleic acid, palmitic acid, and stearic acid).

Sensorial analysis

Sensory attributes of nuts, such as color, odor, size, sweetness, acidity, and hardness, were studied to assess their organoleptic quality and meet consumer preferences (Figure 5). These attributes influence the consumer's sensory experiences, contributing to the overall perception of product. As expected, irrigation treatments significantly ($p < 0.05$) affected the sensory features and consumer's global preferences. Pistachios grown with treatments T0 and T1 gained higher values of the most studied attributes, showing statistically significant differences ($p < 0.05$) with treatment T2. Our findings matched with those of Noguera-Artiaga *et al.* (2020a), studying sensorial properties of pistachios under RDI and reporting that pistachios under treatment T1 were the most appreciated ones. In addition, an international consumer study on the same topic indicated that the kernels resulting from moderate RDI applied during stage II had a higher intensity of sensory attributes and a greater level of satisfaction among consumers than the kernels obtained from well-watered trees or from those exposed to severe RDI during stage II (Noguera-Artiaga *et al.*, 2016).

Regarding nut color (Figure 5A), cv. Ohadi showed the highest values with irrigation treatments T2 and T0. Cv. Mateur with treatment T0 (7.5) had the highest value of sweet taste (Figure 5B). In the present study, sour taste (Figure 5C) showed a different trend, with treatments T0 and T1 having less sour taste than treatment T2 samples. The highest value of sour taste (6.5) was observed in cv. Mateur for treatment T2.

The nut size was cultivar-dependent, with cv. Ohadi demonstrated the highest value for treatment T0 (Figure 5D). Cv. Ohadi showed the highest value of nut hardness (Figure 5e) for treatment T0, with no significant difference compared to treatment T1.

The highest score for the roasted odor resulted in cv. Mateur grown for two water regimes of T0 and T1 (Figure 5f). The sweet/almond odor was also noted in cv. Mateur for two water regimes of T0 and T1 (Figure 5g). Considering global satisfaction (Figure 5h), which defines the final opinion of consumers about the overall quality of samples, all the studied cultivars grown under treatment T0 obtained the highest score, followed by treatment T1, which received water restriction during stages I and II of nut development, whereas treatment T2 was statistically different from both treatments T0 and T1.

The sensorial analysis performed in this study showed that cv. Mateur and Ohadi grown with treatments T0 and T1 were the most appreciated varieties among consumers. The roasting process had a significant impact on the sensorial quality of pistachio nuts. Roasted nuts from cv. Ohadi and Mateur grown under 100% ETc water regime were the most appreciated nuts, followed by treatment T1 nuts. Rodríguez-Bencomo *et al.* (2015) reported that the roasting process makes the pistachio commercially viable and valuable as it improved nut's hallmark sensory characteristics, such as flavor, color, odor, and texture.

Nuts of local cv. Mateur were highly appreciated by consumers. Ojeda-Amador *et al.* (2018) reported that cv. Mateur presented a marked green appearance and higher intensity of the roasted nuts attribute and were appreciated for their flavor, intensity, and the persistence of pistachio aroma in the mouth. Regarding the roasted and sweet/almond odor, the resulting acceptability was confirmed by Noguera-Artiaga *et al.* (2016) and Ojeda-Amador *et al.* (2018).

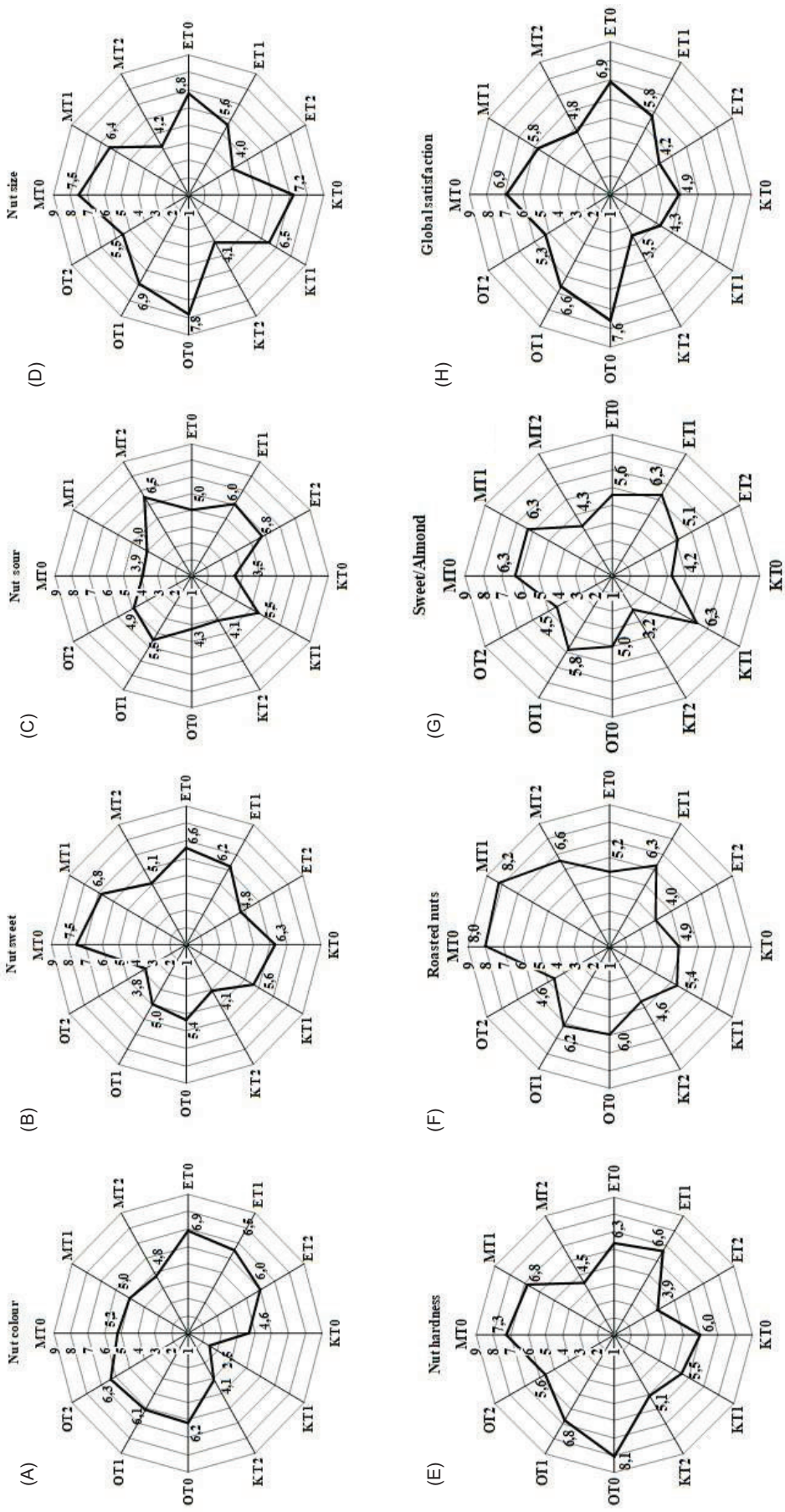

Figure 5. Sensorial analysis of salted and roasted (SRP) nuts of four pistachio cultiars grown under RDI treatments. Abbreviations: M = Mateur, E = Elguetar, K = Kerman, O = Ohadi. T0 = well watered, T1 = regulated deficit irrigation treatment, and T2 = stressed treatment.

Analysis of principal components

The multivariate analysis of data permitted the reduction of variables to two principal components, PC1 and PC2, revealing an interesting grouping of the studied cultivars under RDI strategy (Figure 6a). Depending on the water regime, the studied cultivars were distributed into four groups. Cv. Mateur, Elguetar, and Ohadi, grown with treatments T0 and T1, occupied the positive side of PC1 and PC2. These cultivars occupied the negative side of PC2 if subjected to severe drought stress (treatment T2). Cv. Kerman subjected to treatments T0 and T1 occupied the positive side of PC2 and the negative side of PC1. Cv. Kerman under severe drought stress (treatment T2) occupied the negative side of both PC1 and PC2.

The two principal components presented 61.0% of total variability. The first principal component PC1 showed 35.52% of the observed variability and separated the

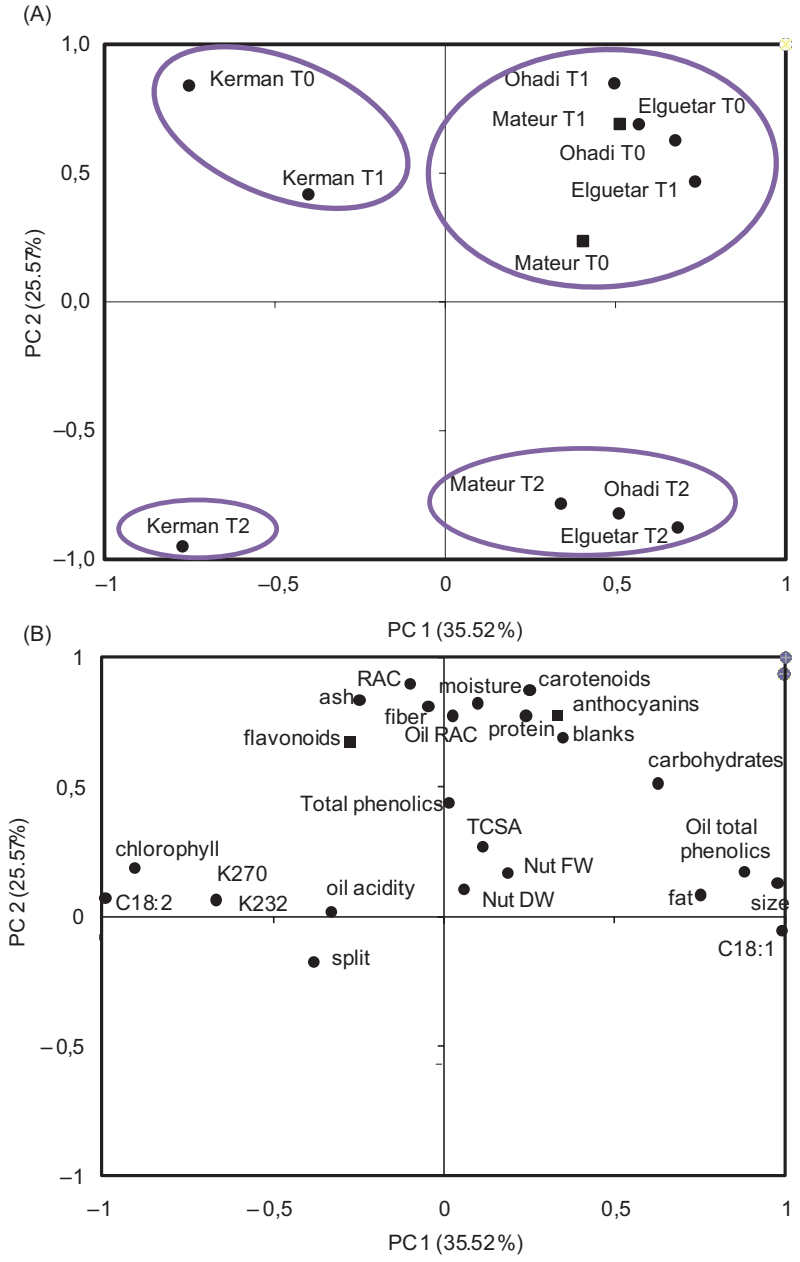

Figure 6. Principal component analysis of main agronomical and biochemical pistachio nuts and oil quality of the four studied cultivars under RDI treatments: (treatment T0) control (100% ETc); (treatment T1) regulated deficit irrigation RDI (50% ETc during stage I and stage of nut development and 100% ETc during stage III); (T2) stressed treatment (50% ETc). Values are means (n = 3) ± SE. Abbreviations: TCSA = trunk cross-sectional area; FW = fresh weight; DW = dry weight.

cultivars based on biochemical traits, fatty acid profile, composition, and size of nuts.

According to a PCA biplot, size, fat content (FC), C18:1 content, total phenols in oil, and carbohydrates of nuts were positively correlated to PC1 whereas absorbance at a wavelength of 270 nm (K_{270}), chlorophylls, and C18:2 content were negatively correlated to PC1. Parameters such as biochemical traits, oil quality, and composition of nuts explained PC1 separation in a better way (Figure 6b). Principal component PC2, explaining 25.57% of total variability, was able to separate cultivars depending on water regime. Hence, treatment T2 occupied the negative side of PC2 whereas treatments T0 and T1 occupied its positive side. Among all the traits that contributed mostly to PC2 separation were phenolic compounds and the nutritional components of pistachios, with split nut and C18:1 being the only two parameters showing a negative correlation (Figure 6B).

Conclusions

The moderate water stress generated by RDI (treatment T1; 50% ETc during fruit development stages I and II, followed by full irrigation at 100% ETc during stage III) maintained nut organoleptic quality as compared to control trees. Water restriction applied in treatment T2 (50% ETc) during all growing seasons decreased nut composition and biochemical compounds. Cv. Ohadi presented nuts with higher dimensions and higher content of carbohydrates, ash, fiber, and proteins under three water regimes. Cv. Mateur and Ohadi presented high sensorial quality and were more accepted by consumers. Cv. Mateur appeared suitable for high-density planting under semiarid conditions. In the present study, the RDI irrigation treatments did not affect fatty acid profile. Oleic, linoleic, palmitic, and steric acids were the main components. Higher contents of volatile compounds were observed in pistachios roasted under stressed treatment T2 (50% ETc); hence, terpenes were abundantly found in non-irrigated pistachios. Oil yield of pistachio nuts was improved under treatment T2. Treatment T1 (RDI) reduced water supply by 20% during stages I and II of nut development, thus increasing water use efficiency without compromising yield and nut quality. Our results suggested that the RDI water management strategy could be applied in pistachio orchards grown under arid and semiarid conditions.

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Author Contributions

Walid Abidi and Rawaa Akrimi: conceptualization, data curation, formal analysis, and writing of original draft and review & editing. Valeria Rizzo: formal analysis, and writing of original draft and review & editing. Fabrizio Cincotta: data curation, formal analysis, and writing of original draft. Antonella Verzera: resources, supervision and writing and review & editing. Giuseppe Muratore: resources, supervision, and writing and review & editing. All authors read and approved the final manuscript.

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Ethics and Consent

Panellists were informed about the conducted study and they agreed to the publication of the results of their sensorial modules. They were fully aware of the implications of publication and accepted any associated risk. All collected forms were anonymous. None of the participants was identified based on the details or images contained in the paper.

Conflict of Interest

The authors declared that they had no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data are available on request.

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