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Deficit Irrigation and Its Implications for HydroSOStainable Almond Production

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Abstract: Deficit irrigation (DI) strategies are considered essential in many arid and semi-arid areas of Mediterranean countries for proper water management under drought conditions. This fact is even more necessary in crops such as almond (*Prunus dulcis* Mill.), which in the last recent years has been progressively introduced in irrigated areas. An essential aspect to be considered would be the ability to improve fruit-quality parameters when DI strategies are imposed, which can boost the final almond price and ensure the sustainability and competitiveness of this crop. This work examines the effects of sustained deficit irrigation (SDI) on three almond cultivars (Marta, Guara, and Lauranne) on parameters related to almond functionality, aroma and sensory profile, which consequently influence its marketability and consumers acceptance. SDI strategies allowed the improvement of physical parameters such as unit weight, kernel length, kernel thickness or color. Moreover, higher total phenolic compounds, organic acids and sugars were found in SDI almonds. Finally, the highest concentrations of volatile compounds were obtained under SDI, this being a clear advantage in relation to almond flavor. Thus, moderate SDI strategy offered relevant improvements in parameters regarding the marketability, by enhancing the final added value of hydroSOStainable almonds with respect to those cultivated under full irrigation conditions.

Keywords: almond quality; sustainability; marketability; semiarid Mediterranean environment; water stress

1. Introduction

Water is the most limiting natural resource for sustainable agricultural development in arid and semi-arid areas of Mediterranean and more specifically under climate change scenarios [1]. In this regard, several works have reported the impact of climate change on agriculture [2,3], concluding that crop water demand will increase substantially due to higher evapotranspiration rates, temporal variability of rainfall or heat weaves events [4].

Within these scenarios, implementing drought-tolerant crops in irrigated zones and the application of deficit irrigation (DI) strategies are being considered, especially in the last few years [5,6]. Developing water-saving strategies in Mediterranean woody crops involves many considerations relative to environmental constraints, sustainable yields, and product marketability. However, these must be deeply studied, establishing the most profitable strategies to maximize the fruit production, minimizing the irrigation water consumption and maintaining (or even improving) the fruit quality.

Almond (*Prunus dulcis* Mill.) is the largest tree nut crop, and the world surface dedicated to its cultivation during 2018 amounted to 2,071,884 ha, with Spain being the country with the largest area devoted to this crop, with 657,768 ha, followed by the USA, with 441,107 ha [7]. However, in production terms, relevant differences are found, with 1,872,500 and 339,033 t for the USA and Spain, respectively. Moreover, for the period 2010–2018 in the USA (3500–5608 kg ha^{-1}) and Spain (279–515 kg ha^{-1}), the production per area were highly different. In 2018, the Mediterranean basin (Spain, Italy, Greece, Syria, Tunisia, Argelia and Morocco) produced roughly 29% of the world almond production, with most plantations under rainfed conditions and located in marginal areas. In Spain, the almond cultivation is mainly concentrated in Andalusia (S Spain) (31% of total area), and since approximately 85% of almond crops are rainfed, this provokes important fluctuations in productivity [8].

Today, the increase in almond prices from 2014 to 2019, when it reached an average price of 5€ per kg [9], has resulted in an increase of surface devoted to almond cultivation with different techniques [10], explicitly in irrigated areas that were traditionally occupied by other crops (cereals, cotton and sunflower, among others) [11]. This increase in cultivated area under irrigation from 2014 to 2018 amounted to 25% by using new cultivars [12], which allows to obtain higher yields (>1500 kg ha^{-1}) than those from traditional rainfed plantations (150–500 kg ha^{-1}) [13].

By taking into consideration the advantage of the positive adaptation of almond to drought scenarios [14,15], and its sharp phenology, many authors have reported the positive responses and opportunities of DI for almond cultivation, obtaining competitive yields under moderate-to-severe water stress situations [16–19].

Recently, a novelty research line, focused on food production under hydro-sustainable strategies (hydroSOStainable products), has been successfully developed [20–22]. This also showed advantages of different Mediterranean crops, with significant improvements in the fruit quality, sensory profile and consumer acceptance in crops such as pistachios [23], olives [24] and almonds [25]. In this context, there is in an interest in those characteristics or parameters of raw almonds related to their marketability that could be affected by DI strategies. In other words, the main limitation of DI implementation is ultimately the yield reduction (in comparison to the potential rate when almond is grown under full-irrigated conditions), affecting the plantation viability and its competitiveness. In this regard, Lipan et al. [25,26] reported relevant results, concluding that some fruit-quality parameters could be improved (or at least not affected) when DI strategies are imposed. If that is the case, these kinds of strategies would encourage the product marketability and the consumer acceptance, allowing a recovering in terms of final price, minimizing the losses when these are analyzed in monetary terms. In addition, many aspects are still not clear, such as if these effects would be similar for the new high-yielding cultivars or the dependence in relation to the irrigation strategy imposed or crop physiological status during the water stress period.

On the other hand, consumer appreciation, and hence, almond marketability, can be determined by a wide number of variables that could be classified into physical and chemical parameters, all of them determining the sensory appreciation and the almond appeal. Raw almonds are mainly composed by fats (44–61%), proteins (16–23%) and dietary fiber (11–14%) and high concentrations of vitamin E [27,28]. Despite these being the main compounds of raw almonds, their influence in taste receptors is negligible. In this line, other compounds, more related to flavor properties and sensory and chemical characteristics, can be found. According to Civille et al. [29] the main taste properties of raw almonds are mainly defined by astringency and sweetness degree, and to a lesser extent, the tactile dimensions (almond texture) [30]; this is the highest variability in almond flavor related to odor-active volatiles compounds. That is, volatile compounds are responsible of characteristic flavor properties of raw and processed almonds and contribute to their high consumer acceptance [25,31]. In particular, benzaldehyde is one of the main volatiles in bitter almonds, but its presence in sweet almonds is very variable (highly cultivar dependent), and, overall, it is found in very low concentrations [32]. Despite these low concentrations, its presence is responsible of the typical almond flavor and derivates such as marzipan [33].

Considering that the hydroSOStainable almond production could be a key factor for sustainable development in a semiarid Mediterranean environment; the objective of this study was to evaluate the effects of sustained deficit irrigation strategies and almond cultivars on the main physico-chemical parameters involved in nut sensory profile and improvements in marketability.

2. Material and Methods

2.1. Plant Material, Growing Conditions and Experimental Design

The trial was conducted during 2019 in a commercial orchard of almonds (*Prunus dulcis* Mill., *cvs* Guara, Marta and Lauranne), grafted onto GN15 rootstock, and located in the Guadalquivir river basin (37°30′27.4′′ N; 5°55′48.7′′ O) (Seville, SW Spain) (Figure 1). The plantation contained seven-year-old almond trees, 8 × 6 m spaced and drip irrigated by using two pipelines with emitters of 2.3 L h^{-1}. The soil is a silty loam typical Fluvisol [34], more than 2 m deep, fertile and with an organic matter content of 15.0 g kg^{-1}. Roots were located predominately in the first 50 cm of soil, corresponding to the intended wetting depth, although these exceed more than one meter in depth. The climatology in the study area is attenuated meso-Mediterranean, with an annual reference evapotranspiration rate (ET_0) of 1400 mm and an annual rainfall of 540 mm, mainly distributed from October to April. More details about the experimental site can be found in Gutiérrez-Gordillo et al. [35].

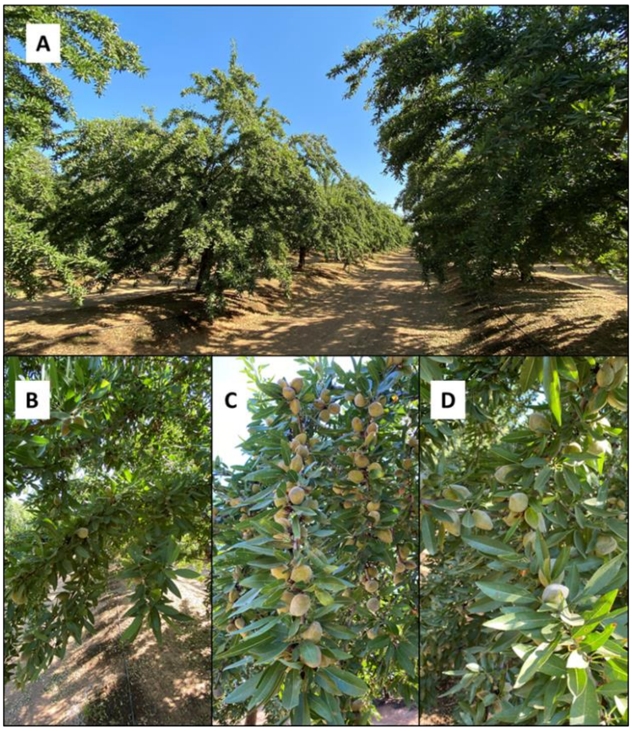

Figure 1. Experimental almond orchard (**A**) and *cvs.* Marta (**B**), Guara (**C**) and Lauranne (**D**).

Three irrigation treatments were designed: (i) a full-irrigated treatment (FI), which received 100% of irrigation requirements (IR) during the irrigation period, and two sustained-deficit irrigation treatments, which received 75% (SDI_{75}) and 65% (SDI_{65}) of IR. Irrigation was applied from April to

October, the IR being estimated according to the methodology proposed by Allen et al. [36], obtaining the values of ET_0 by using a weather station installed in the same experimental orchard (Davis Advance Pro2, Davis Instruments, Valencia, Spain). The local crop coefficients used during the experimental period ranged from 0.4 to 1.2, according to the results obtained by García-Tejero et al. [37].

2.2. Field Measurements

Physiological response to different irrigation doses was evaluated throughout measurements of leaf water potential (Ψ_{leaf}) in shaded leaves, these readings being taken between 12:00 and13:30 GTM, and on a weekly basis. Measurements of Ψ_{leaf} were developed by using a pressure chamber (Soil Moisture Equipment Corp., Sta. Barbara, CA, USA), monitoring eight trees per irrigation treatment (two leaves per tree), located in the north side of the tree and being totally mature, fresh and shaded, at 1.5 m of height. These readings were used to quantify the water stress supported by the crop for each week and the whole kernel-filling period by means of the stress integral (Ψ_{Int}), following the methodology proposed by Myers [38] (Equation (1)). This index allows to quantify the effect of water stress provided by the water restriction beyond its temporal distribution, integrating the global stress supported by the crop in comparison to the punctual measurements:

$$\psi_{Int} = \left| \sum \left(\psi_{leaf}^{av} - \left(\psi_{leaf}^{max} \right) \right) \cdot \mathrm{n} \right|. \quad (1)$$

where Ψ_{Int} is the stress integral in terms of Ψ_{leaf} values, ψ_{leaf}^{av} is the average leaf water potential for any interval (in our case, for each week), ψ_{leaf}^{max} is the maximum value of Ψ_{leaf} weekly registered, during the experimental period and n is the days numbers within each interval, in our case $n = 7$.

At the end of each season, monitored trees (eight per cultivar and irrigation strategy) were harvested. This process was carried out by using a mechanic vibrator to throw the almond on the ground (previously covered with a plastic mesh). Collected almonds were processed with a mechanic peeling to remove the hull. Finally, once cleaned, almonds were left to air dry and weighed once reached a humidity content around 6%. Around 3 kg of in-shell almonds were sent to Miguel Hernández University for quality and sensory analysis, where the main morphological, physical and chemical parameters were analyzed (Figure 2).

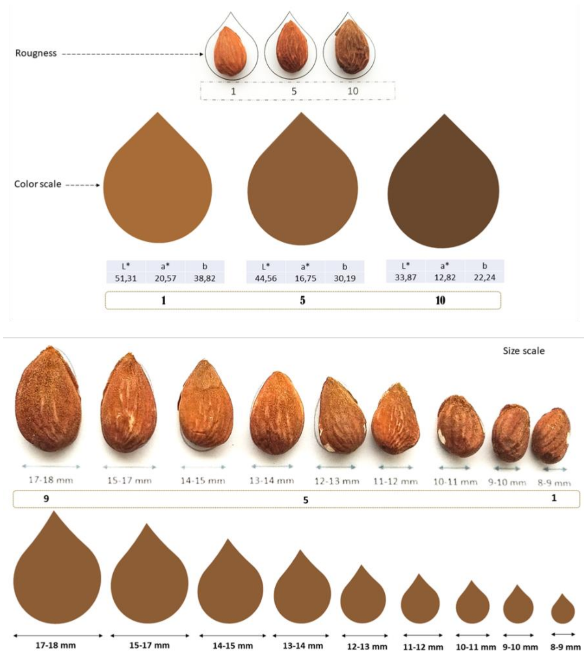

Figure 2. Scales reference used by trained panel to evaluate the almond appearance in this study.

2.3. Morphological and Physical Parameters

The ratio between the mass of in-shell almonds and kernel was calculated from ~1 kg of nuts per cultivar and irrigation treatment. Additionally, 225 almonds (25 samples × 3 varieties × 3 treatments) were randomly selected and analyzed by measuring the weight and size (length, width and thickness) of almonds (both in-shell and kernel) using a digital caliper (Mitutoyo 500-197-20, Kawasaki, Japan) and a scale (Mettler Toledo model AG204, Barcelona, Spain), respectively.

A Minolta Colorimeter CR-300 (Minolta, Osaka, Japan) was used to perform the color measurements in 75 kernels per each variety. This colorimeter uses a D_{65} illuminant and a 10° observer as references. The color was provided as CIE*L*a*b** coordinates defining the color in a three-dimensional space and it was expressed in three numerical values, which includes L^* for the lightness (L^* = 0 black; L^* = 100 white), a^* for the green-red (a^* = red; $-a^*$ = green) and b^* for the blue-yellow components (b^* = yellow; $-b^*$ = blue).

2.4. Chemical Composition

2.4.1. Total Sugars

Sugars were determined using a high-performance liquid chromatography (HPLC) equipment. The extraction consisted of 1 g of grinded almond in a Moulinex grinder (AR110830) for 10 s, homogenized with 5 mL of phosphate buffer with an homogenizer (Ultra Turrax T18 Basic) over 2 min at 11.3 rpm, while the tube was maintained in an ice bath and after it was centrifuged for 20 min at 15,000 rpm and 4 °C (Sigma 3–18 K; Sigma Laborzentrifugen, Osterode and Harz, Germany) followed by filtration and injection in the HPLC equipment. Sugar content was determined by using a Supelcogel TM C-610H column (30 cm × 7.8 mm) with a pre-column (Supelguard 5 cm × 4.6 mm; Supelco, Bellefonte, PA, USA) and it was detected by a refractive index detector (RID). Organic acid absorbance was measured at 210 nm in the same HPLC condition using a diode-array detector (DAD). Analyses were triplicated and results were expressed as g kg^{-1} dry weight.

2.4.2. Volatile Compounds

For the extraction of the volatile compounds, headspace solid phase microextraction (HS-SPME) was used. Ground almond (1 g) was added to a hermetic vial with polypropylene cap and PTFE (polytetrafluoroethylene)/silicone septa, together with 500 µL salty water (12.5% NaCl) and 2.5 µL of 2-acethylthiazole (1000 mg L^{-1}) internal standard, needed for the semi-quantification of the volatile compounds. To simulate the mouth temperature, the vial was heated in a laboratory hot plate up to 50 °C. When the temperature was reached and was stable, a 50/30 µm Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS) fiber was introduced in the headspace of the vial for 35 min. A gas chromatograph Shimadzu GC-17A (Shimadzu Corporation, Kyoto, Japan) coupled with mass spectrometer (MS) detector Shimadzu QP-5050A were used for isolation and identification of the volatile compounds. The Gas Chromatography—Mass Spectrometry (GC-MS) was equipped with a SLB-5ms Fused Silica Capillary Column of 30 m × 0.25 mm × 0.25 µm film thickness, 5% diphenyl and 95% dimethyl siloxane (Supelco Analytical). Helium was used as gas carrier at a flow rate of 0.9 mL min^{-1} in a split ratio of 1:5. The oven program was: (a) initial temperature 50 °C, (b) rate of 4.0 °C min^{-1} to 130 °C, (c) rate of 10 °C min^{-1} from 130 °C to 180 °C, (d) rate of 20 °C from 180 °C to 280 °C. The injector and the detector were held at 250 °C. The identification of the volatile compounds was performed using three methods: (a) retention indices, (b) GC-MS retention times of authentic chemicals and (c) mass spectra compounds were extracted using HS-SPME.

Simultaneously, the quantification of the volatile compounds was done on a gas chromatograph, Shimadzu 2010, with a flame ionization detector (FID). The column and chromatographic conditions were those previously reported for the GC-MS analysis. The injector temperature was 200 °C and nitrogen was used as carrier gas (1 mL min^{-1}). The quantification was obtained from electronic integration measurements using flame ionization detection (FID). 2-Acethylthiazole (2.5 μL of 1000 mg L^{-1}) was used as internal standard.

2.5. Descriptive Sensory Analysis

The descriptive sensory analysis was held by a trained panel with a 10 highly qualified panelists from the Food Quality and Safety Group (Miguel Hernández University of Elche, Orihuela, Alicante, Spain). The descriptive sensory analysis was performed to estimate if the significant differences among treatments were found. Although the panelists were highly trained, having more than 600 h of experience with different types of food products, three orientation sessions were done prior to almond tasting, where the panelists were trained with reference products for each attribute according to the lexicon previously described by Lipan et al. [25]. The samples were served in odor-free 30 mL covered plastic cup and randomly coded with three digits. To clean the palate between samples, water and unsalted crackers were served. The descriptive test was performed in a special tasting room with individual booths (controlled temperature of 21 ± 1 °C and combined natural/artificial light), and to collect panelists' evaluations, ballot charts were used. The samples were presented based on a randomized block design to avoid biases. Numerical scale from 0 to 10 was used by the panelists to quantify the intensity of the almond attributes, where 0 represents no intensity and 10 extremely strong with a 0.5 increment (Figure 2).

2.6. Statistical Analysis

The stress integral of Ψ_{leaf} and yield were analyzed by Sigma Plot statistical software (version 12.5, Systat Software, Inc., San Jose, CA, USA). Initially, a descriptive analysis for each treatment and cultivar was done, applying a Levene's test to check the variance homogeneity of the whole of data. Once completed, a one-way analysis of variance (ANOVA) was performed to determine whether there were statistical differences ($p < 0.05$) between irrigation treatments and within each cultivar, applying a Tukey's test to find the differences among them.

Relating to the quality and sensorial parameters, a two-way analysis of variance (ANOVA) was performed, with the cultivar and irrigation being the two factors. Moreover, a Tukey's multiple range test was carried out to establish the means that were significantly different from each other. XLSTAT Premium 2016 (Addinsoft, New York, NY, USA) was used to perform statistically significant differences, with a significant level $p < 0.05$.

3. Results and Discussion

3.1. Irrigation Doses, Crop Physiological and Yield Response

Table 1 summarizes the climatic conditions throughout the experiment with cumulative rainfall and crop evapotranspiration (ET_C) of 85 and 840 mm, respectively. According to the registered data, the water irrigation amount for FI, SDI_{75} and SDI_{65} was 770, 574 and 516 mm, respectively.

The irrigation doses imposed different physiological responses and yield reductions were observed in the SDI strategies with respect to FI (Table 2). The *cv.* Marta reported higher values of Ψ_{Int} in SDI_{65} (197 MPa) compared to that registered in FI (179 MPa), with intermediate values for SDI_{75} (188 MPa). These differences were even more pronounced for *cv.* Guara with Ψ_{Int} values in SDI treatments (~210 MPa) significantly higher than in FI (194 MPa). Finally, *cv.* Lauranne did not register variations among treatments for Ψ_{Int} with values of 194 MPa.

Table 1. Monthly average values of weather parameters and irrigation doses during the study period.

Parameters	April	May	June	July	August	September	October
T_{max} (°C)	22.2	30.4	31.3	34.5	36.5	32.4	27.6
T_{min} (°C)	7.2	12.2	17.5	17.9	17.9	16.3	11.7
T_{av} (°C)	19.8	21.5	22.7	25.8	26.9	23.8	18.9
RH_{max} (%)	97.8	85.2	83.2	84.0	77.2	81.9	90.7
RH_{min} (%)	39.8	23.3	23.4	25.3	18.7	27.6	32.9
RH_{av} (%)	72.2	52.3	51.4	55.4	45.9	54.4	63.2
Rad (MJ m^{-2})	1.9	2.1	2.1	2.9	0.8	0.9	0.7
Rainfall (mm)	71.2	0.0	0.0	0.0	0.0	3.4	10.4
ET_o (mm)	111.0	198.0	202.9	238.7	170.1	121.0	76.4
ET_C (mm)	44	119	135	215	179	97	46
				Irrigation (mm)			
FI	25	115	140	210	170	80	30
SDI_{75}	18	85	104	157	127	61	22
SDI_{65}	16	77	95	141	114	53	20

T_{max}, T_{min}, T_{av}, maximum, minimum and average air temperature; RH_{max}, RH_{min}, RH_{av}, maximum, minimum and average relative humidity; Rad, solar radiation; ET_0, reference evapotranspiration; ET_C, crop evapotranspiration rate; FI, SDI_{75}, SDI_{65}, full-irrigated and sustained-deficit irrigation at 75 and 65% of irrigation requirements, respectively.

Table 2. Integral stress (Ψ_{Int}) values and almond yield for the different cultivars and irrigation treatments.

	FI	SDI_{75}	SDI_{65}
Cultivar		Ψ_{Int} (MPa day)	
Marta	179b	188ab	197a
Guara	194b	209a	210a
Lauranne	194a	198a	191a
		Almond yield (kg ha^{-1})	
Marta	2218a	2208a	2243a
Guara	2254a	2081ab	1872b
Lauranne	2325a	2104a	2195a

Values (average of eight replications; n = 8) within a same row, and followed by different letters, show significant differences between treatments and within each cultivar, according to Tukey's test ($p < 0.05$). FI, SDI_{75} and SDI_{65}, full-irrigated and sustained-deficit irrigation at 75 and 65% of irrigation requirements, respectively.

In line with the physiological pattern previously described, the studied cultivars also presented yield reductions. In this regard, *cvs*. such as Marta and Lauranne did not showed significant variations among treatments, while *cv*. Guara was reduced about 8 and 17% in SDI_{75} and SDI_{65}, respectively (Table 2).

Taking into consideration the obtained results, the water stress promoted different physiological and yield responses depending on the studied cultivar. In this regard, Gomes-Laranjo et al. [39] also reported different physiological responses of almond cultivars when they were subjected to deficit-irrigation strategies, concluding that *cv*. Lauranne would be less sensitive to irrigation restrictions than other cultivars. More recently, Gutiérrez-Gordillo et al. [17] revealed that *cv*. Marta evidenced a stronger stomatal control as compared to *cvs*. Guara and Lauranne, when subjected to regulated deficit-irrigation strategies. On the contrary, *cv*. Guara would show a minor conservative behavior, being able to maximize the gas-exchange rates when subjected to water restriction.

However, as observed in the present study, Guara was the most sensitive cultivar growth under SDI conditions. This point is especially remarkable considering that this cultivar presented very positive responses when water restrictions were applied during the kernel-filling period [40,41]. This means that the final response to water stress would be determined by the effect of water restriction, cultivar and deficit-irrigation strategy. Similar results were also reported by Alegre et al. [42], who obtained higher yield reductions in *cv*. Guara as compared to *cv*. Lauranne, when they were subjected to severe SDI (~2500 m^3 ha^{-1}). Moreover, Miarnau et al. [43] suggested that under SDI strategies, with irrigation applications around 2000 m^3 ha^{-1}, *cv*. Marta would be able to reach higher productions (1850 kg ha^{-1}) than those obtained by *cv*. Guara (1200 kg ha^{-1}) when using similar irrigation doses. Thus, these results would reinforce the statement that *cv*. Marta would be able to activate a physiological prevention mechanism to mitigate the water stress, leading to a higher yield than *cv*. Guara.

3.2. Morphological and Physical Parameters

Table 3 displays the main results related to the effects of irrigation doses and cultivar on the physical and morphological properties of raw almonds. Both irrigation treatments and cultivars offered significant differences on the weight, size and physical parameters. In relation to the almond weight, *cv.* Marta stood out, comparing to *cvs*. Guara and Lauranne. More evident were the improvements fixed in the almond weight from SDI_{65} trees regarding to SDI_{75} and FI treatments. These differences were also found in the morphological parameters, with higher values in SDI_{65} for kernel length, the whole thickness and kernel thickness. As was expected, these morphological differences were even more pronounced between cultivars. Thus, *cvs*. Marta and Lauranne offered a more lengthened morphology in comparison to *cv*. Guara. In relation to the kernel color coordinates, significant differences between cultivars and treatments were observed. Thus, SDI_{75} and SDI_{65} registered higher values of *L**, *a** and *b** that evidenced lighter, redder and yellower almonds than FI and with even greater values of chroma, which means a higher color intensity of samples perceived by humans. Instrumental color was also affected by the cultivar, with Guara being the cultivar with the highest values of *L**, *a**, *b** and *chroma*, whereas *cvs*. Lauranne and Marta showed a higher similarity between them for these parameters.

In relation to the interaction between irrigation dose × cultivar, all the studied parameters reported significant differences. For *cv.* Marta, the most notable effects related to the irrigation doses were found for the almond size, with higher values of kernel thickness and length. Moreover, this cultivar registered lower values of *L**, *a**, *b** and *chrom*a for SDI_{65}, while SDI_{75} was mainly similar to FI almonds. More interesting were the irrigation effects in *cv*. Guara with significant improvements in the almond and kernel weight for SDI_{65} compared to SDI_{75} and FI. Within this cultivar, SDI_{65} presented higher values of *L**, *b** and *chroma*, while SDI_{75} generated almonds with a greater hardness and crispiness. Finally, regarding *cv*. Lauranne, higher values of almond weight and color on SDI_{65} were observed, although the weight improvements were more pronounced in the almond shell.

Table 3. Morphology and instrumental color of raw almonds as affected by deficit treatment and almond cultivar.

	Weight (g)			**Size (mm)**						**Kernel Color Coordinates**				
	Whole	**Kernel**	**Shell**	**WL**	**KL**	**WW**	**KW**	**WT**	**KT**	**L***	**a***	**b***	**C**	**Hue**
Irrigation	**	**	**	NS	***	NS	NS	***	***	***	***	***	***	NS
Cultivar	**	**	**	**	***	***	***	***	***	***	***	***	***	NS
Irrigation × Cultivar	**	**	**	**	***	***	***	***	***	***	***	***	***	NS
Tukey Multiple Range Test ‡														
Irrigation														
FI	3.19ab	1.08b	2.11ab	30.7	22.2b	21.4	13.3	15.0b	8.30a	45.9b	19.1a	29.9b	35.6b	60.4
SDI_{75}	3.07b	1.08b	1.98b	30.0	22.2b	21.5	13.1	14.9b	8.03b	48.7a	18.9ab	34.9a	39.7a	61.3
SDI_{65}	3.38a	1.16a	2.22a	30.1	22.7a	21.5	13.3	15.4a	8.44a	48.7a	18.2b	34.5a	39.0a	61.8
Cultivar														
cv. Marta	3.49a	1.19a	2.30a	30.2ab	23.1a	20.3c	12.8b	14.8b	8.34a	47.3b	17.9b	32.1b	36.8b	60.4
cv. Guara	2.92b	1.07b	1.85c	29.8b	21.6c	22.7a	13.5a	15.9a	8.43a	49.4a	19.2a	35.0a	40.1a	64.1
cv. Lauranne	3.22ab	1.05b	2.17b	30.9a	22.4b	21.5b	13.4a	14.6b	7.97b	46.6b	19.1a	32.2b	37.5b	58.9
Irrigation × Cultivar														
cv. Marta														
FI	3.55a	1.21a	2.34a	29.7b	22.5abc	20.0d	12.7c	14.3c	8.13abcd	48.5abc	18.2bc	32.6bcd	37.4bcd	60.6
SDI_{75}	3.47a	1.18a	2.29a	30.2ab	23.2ab	20.4cd	13.0abc	14.9bc	8.49abc	48.2abc	18.5abc	34.1abc	38.9abc	61.1
SDI_{65}	3.46a	1.18a	2.28a	30.6ab	23.7a	20.5cd	12.8bc	15.2b	8.49abc	45.1cd	17.0c	29.6de	34.2de	59.6
cv. Guara														
FI	2.91d	0.99b	1.92bc	30.4ab	21.6cd	22.7ab	13.7a	16.0a	8.72a	47.2bc	20.0a	30.2cde	36.5cde	66.1
SDI_{75}	2.56d	1.00b	1.56c	29.5b	21.2d	22.7ab	13.2abc	15.4ab	7.96cd	49.6ab	19.1ab	36.6ab	41.3ab	62.3
SDI_{65}	3.30b	1.22a	2.08b	29.6b	22.0bcd	22.8a	13.6ab	16.2a	8.6ab	51.5a	18.6abc	38.2a	42.5a	63.9
cv. Lauranne														
FI	3.12c	1.02b	2.09b	32.1a	22.4bcd	21.7abc	13.4abc	14.7bc	8.05bcd	42.0d	19.0ab	26.9e	33.0e	54.5
SDI_{75}	3.18c	1.05b	2.13b	30.3ab	22.1bcd	21.5abc	13.3abc	14.3b	7.63d	48.2abc	19.2ab	34.0abc	39.0abc	60.6
SDI_{65}	3.38b	1.08b	2.30a	30.2ab	22.5abc	21.3bcd	13.4abc	14.9bc	8.22abcd	49.5ab	19.0ab	35.7ab	40.5abc	61.8

NS, not significant at $p < 0.05$; ** and *** significant at $p < 0.01$, and 0.001, respectively. ‡ Values (average of 25 replication) followed by the same letter, within the same column and factor, were not significantly different ($p < 0.05$), according to Tukey's least significant difference test. WL, Whole Length; KL, Kernel Length; WW, Whole Width; KW, Kernel Width; WT, Whole Thickness; KT, Kernel Thickness; *L**, *a**, *b**, Color coordinates; C, Chroma. FI, SDI_{75}, SDI_{65}, full-irrigated and sustained-deficit irrigation at 75 and 65% of irrigation requirements, respectively.

3.3. Total Sugars and Phenolic Content

The total sugars (TSC) and total phenolic (TPC) contents are shown in Table 4. High significant effects were observed in response to the studied cultivars and irrigation dose imposed. Regarding the TSC, the highest values were reached in almonds under water stress conditions, with SDI_{75} and SDI_{65} having a TSC of 62.9 and 62.2 g kg^{-1}, respectively, which increased ~19% with regard to almonds growth under full-irrigated conditions. The *cvs*. Guara and Lauranne registered the highest values of sugars with ~1.4-fold higher than *cv*. Marta. Comparing all cultivars and irrigation treatments the highest values were reached by *cv*. Guara under SDI_{75} (76.1 g kg^{-1}), followed by *cv*. Guara under SDI_{65} (68.4 g kg^{-1}) and *cv*. Lauranne under SDI_{75} and SDI_{65} (65.1 and 64.7 g kg^{-1}, respectively). Thus, SDI conditions led to higher total contents of sugar in all cultivars as compared to fully irrigated trees. As previously reported, raw almonds contain a variable amount of sugars, highlighting sucrose, glucose and fructose [27], whose concentrations are significantly affected by both water stress and cultivar [26]; and hence, their concentrations can vary depending on the water management applied during the fruit development. The increase of sugars in the fruits under stress circumstances is mainly related to the osmotic adjustment, initiated to adapt the plant to dry and saline stress by accumulation of solutes rich in hydroxyl (-OH) groups (sugars, proline etc.) in the cytoplasm [44] and to the induction of the growth inhibitor abscisic acid, inducing the accumulation of osmotically active compounds, which help to protect the cells from harm [45]. Sugars are key compounds in the basic sweet taste of almonds, this fact being important for consumer acceptance [25,46] and essential in the aroma profile of toasted almonds, because these are precursors of aroma compounds formation during thermal processing [47].

Table 4. Impact of deficit irrigation on total phenolic (TPC) and sugars contents (TSC).

	TSC (g kg^{-1})	**TPC (g GAE kg^{-1})**
	ANOVA †	
Irrigation	***	***
Cultivar	***	***
Irrigation × Cultivar	***	***
	Tukey Multiple Range Test ‡	
	Irrigation	
FI	52.6b	2.97b
SDI_{75}	62.9a	3.81a
SDI_{65}	62.2a	3.80a
	Cultivar	
Marta	48.5b	3.40b
Guara	65.5a	3.50b
Lauranne	63.7a	3.68a
	Irrigation × Cultivar	
	cv. Marta	
FI	44.4f	2.79de
SDI_{75}	47.6ef	3.44cd
SDI_{65}	53.6d	3.98bc
	cv. Guara	
FI	52.1de	2.29e
SDI_{75}	76.1a	3.14cde
SDI_{65}	68.4b	5.06a
	cv. Lauranne	
FI	61.3c	3.82c
SDI_{75}	65.1bc	4.86ab
SDI_{65}	64.7bc	2.37e

†—Analysis of variance test (ANOVA), *** significant at $p < 0.001$; GAE, Gallic Acid Equivalent; ‡ Values (average of three replications) followed by the same letter, within the same column and factor, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test. FI, SDI_{75}, SDI_{65}, full-irrigated and sustained-deficit irrigation at 75 and 65% of irrigation requirements, respectively.

On the other hand, the total phenolic content (TPC) expressed as gallic acid equivalent (GAE) was significantly raised by the SDI treatments with an increase of 28% regarding the FI almonds. Additionally, *cv*. Lauranne registered the highest values (3.68 g GAE kg^{-1}), followed by *cv*. Guara (3.50 g GAE kg^{-1}) and *cv*. Marta (3.40 g GAE kg^{-1}), proving the cultivar effect for the TPC. Focusing on the interaction between the irrigation dose and cultivar, the highest TPC values were reached by *cv*. Guara in SDI_{65} and *cv*. Lauranne in SDI_{75} conditions (5.06 g GAE kg^{-1} and 4.86 g GAE kg^{-1}, respectively), being the lowest values obtained by *cvs.* Marta and Guara under FI (2.79 and 2.29 g GAE kg^{-1}) and *cv*. Lauranne under SDI_{65} conditions (2.37 g GAE kg^{-1}). These results agreed with the study by Lipan et al., who found a positive correlation between TPC and water stress in almonds [31]. Moreover, Horner [48] reported that water stress in trees generates an increase in phenolic compounds precursors (free phenylalanine) and their synthesis could be more sensitive in moderate water stress circumstances.

Overall, the water stress in plants decrease the turgor pressure, increase the ion toxicity and inhibits the photosynthesis [49], which leads to the activation of the antioxidant defense system to deal with reactive oxygen species (ROS). The trigger of many defense mechanisms, including the increase in antioxidants to enhance plant tolerance to water stress is mainly done by plant phytohormones [49]. Almond polyphenols are mostly found in skin and are responsible of the kernel color and astringency [50]. In this line, Monagas et al. [51] identified flavonol monomers as well as oligomers up to seven units as the most abundant type of flavonoids in almond skin; moreover, the intensity of the astringency depended on the polymerization degree [52].

3.4. Volatile Compounds

Using NIST libraries and Kovats Index values (REF), a total of 35 volatile compounds were identified and presented in Table 5, together with their retention times, retention indices, and their odor descriptors. These include 10 alcohols, 13 alkanes, five terpenes, four aldehydes, one ketone, one acid and one ester. Significant differences ($p < 0.001$) were promoted by the effect of both irrigation and cultivar (Table 6) factors, with the highest values for V2 and V16 to V34 under SDI_{65} treatment, whereas V4–V9, V12, V14, V15, V17 and V35 reached the highest values under SDI_{75} treatment. According to this and attending to the sum (total volatile compounds content), SDI_{75} was able to increase the volatile compounds. By contrast, the SDI_{65} strategy reflected a reduction in the whole amount, which is significantly lower than that obtained under moderate SDI_{75}, which confirms the theory about the quadratic equation of Horner [48], who reported a reduction in fruit chemical compounds when the stress threshold is exceeded. Additionally, differences among cultivars were also found, with Marta and Guara being the cultivars that registered the highest values of the total volatiles. However, focusing the attention in the most abundant compounds (V15 and V17), the highest amounts of benzaldehyde (V15) were registered for SDI_{75} (in terms of irrigation treatment) and Guara (in terms of cultivar) (Table 6). Regarding to pentamethyl heptane, which might be a degradation product of fatty acids, the highest amounts were found for the SDI strategies and *cv*. Marta.

Regarding the interaction irrigation × cultivar the highest contents of benzaldehyde were reached by *cvs.* Marta and Guara both under RDI_{75}. For the case of pentamethyl heptane the highest values were found for *cv*. Marta under SDI_{75}, *cv*. Guara under FI, and *cv*. Lauranne under SDI_{65}. Finally, and considering the total volatiles, the highest values were registered by *cv*. Marta under RDI_{75}, followed by *cv*. Guara under FI and *cv*. Lauranne under SDI_{65}.

Alcohols were the most abundant volatile compounds found in the present experiment. In this line, Kwak et al. [32] reported that alcohols are the main volatiles in raw almonds (*cv.* Nonpareil) and are released by enzymatic reactions. These compounds might contribute to the typical raw sweet aroma of almonds and an increase in its concentration may improve consumer acceptance [31,32]. In the present study, the highest content of alcohols was reached by the SDI_{75} treatment (296 μg kg^{-1}), followed by FI (288 μg kg^{-1}) and it was reduced by SDI_{65} (243 μg kg^{-1}). Regarding the cultivar effect, *cv*. Lauranne recorded the highest values of alcohols followed by *cvs*. Marta and Guara with 310, 296 and 220 μg kg^{-1}, respectively.

Table 5. Volatile compounds profile in raw studied almonds cultivars, retention index and main odor and aroma descriptors.

Code	Compound	Chemical Family	RT (min)	Retention Index †		Odor Descriptor
				Experimental	Literature ‡	
V1	3-Methyl-2-butanol	Alcohol	1.65	699	700	Musty, alcoholic, vegetable, cider, cocoa, cheesy [1]
V2	Acetoin	Ketone	1.765	702	707	Sweet, buttery, creamy, dairy, milky, fatty [1]
V3	Acetic acid [¥]	Acid	2.083	717	630	Pungent, acidic, cheesy, vinegar[1]
V4	3-Hexenol	Alcohol	2.548	739	746	Green, leafy, floral, petal, oily, earthy [1]
V5	1-Pentanol	Alcohol	3.053	764	762	Pungent, fermented, bready, yeasty, winey, solvent-like [1]
V6	2-Pentenol	Alcohol	3.097	767	767	Fermented, ripe banana, apple [1]
V7	α-Octene	Alkene	3.677	794	788	
V8	Octane	Alkane	3.805	800	800	
V9	Hexanal	Aldehyde	3.905	805	804	Fresh green fatty aldehydic grassy leafy fruity sweaty [1]
V10	*(2E)*-2-Octene	Alkene	4.057	812	815	
V11	*(2E)*-2-Hexenal	Aldehyde	4.457	831	825	Green, banana, aldehydic, fatty, cheesy [1]
V12	Nonane	Alkane	5.903	900	900	Gasoline [1]
V13	α-Pinene	Terpene	6.924	934	933	Sharp, warm, resinous, fresh, pine [1]
V14	Citronellene	Terpene	7.241	945	945	Citronellol, herbal, citrus, terpenic [1]
V15	Benzaldehyde	Aldehyde	7.963	970	967	Almond, fruity, powdery, nutty, cherry, sweet, bitter [1]
V16	Heptanol	Alcohol	8.435	986	977	Musty, leafy green, fruity, apple, banana and nutty and fatty notes [1]
V17	2,2,4,6,6-Pentamethyl heptane [¥]	Alkane	8.627	991	997	
V18	Decane	Alkane	8.87	1000	1000	
V19	2-Octanol	Alcohol	9.192	1010	1010	Fresh, spicy, green, woody, herbal earthy [1]
V20	Limonene	Terpene	9.97	1032	1034	Citrus, orange, sweet, fresh, peely [1]
V21	2-Ethyl-hexanol	Alcohol	10.044	1034	1030	Citrus, fresh, floral oily sweet [1]
V22	3,5,5-Trimethyl-hexanol	Alcohol	10.513	1048	1048	Green, floral, camphoreous, woody, melon, berry.
V23	Butanoate	Ester	10.839	1058	1054	Fruity, pineapple odor [1]
V24	Undecane	Alkane	12.333	1100	1100	Waxy, fruity, creamy, fatty, orris, floral, pineapple [1]
V25	Linalool	Terpene	12.525	1106	1106	Citrus, orange, floral, terpy, rose [1]
V26	Nonanal	Aldehyde	12.862	1115	1107	Waxy, aldehydic, citrus, green lemon peel, orange peel [1]
V27	Octyl-formate	Alkane	13.683	1136	1128	Fruity, rose, orange, waxy, cumber [1]
V28	1-Nonanol	Alcohol	15.425	1185	1181	Fresh, clean, fatty, floral, rose, orange, dusty, wet, oily [1]
V29	*(2Z)*-2-Dodecene	Alkene	15.701	1193	1193	Pleasant odor [2]
V30	Dodecane	Alkane	15.979	1200	1200	
V31	3,7-Dimethyl-1-octanol [¥]	Alcohol	16.283	1209	1190	Aldehydic citrus, rosy and green woody notes [1]
V32	Tridecane	Alkane	19.525	1301	1300	
V33	Tetradecane	Alkane	22.5	1401	1400	Mild waxy [1]
V34	Pentadecanol	Alcohol	27.993	1770	1772	Mild alcohol odor [2]
V35	Geranyl linalool	Terpene	29.933	2039	2034	Mild floral rose balsam [1]

[¥] tentatively identified (identification only based on spectral database); † RT, retention time; ‡ NIST [53]; [1] Company [54]; [2] NCBI [55].

Table 6. Volatile compounds are based on the use of 2-acethyl thiazole as internal standard in raw almonds.

ANOVA †				Irrigation			Cultivar			Irrigation × Cultivar								
										cv. Marta			*cv.* Guara			*cv.* Lauranne		
Code	Irrigation	Cultivar	Irrigation × Cultivar	F_I	RDI_{75}	RDI_{65}	Marta	Guara	Lauranne	FI	SDI_{75}	SDI_{65}	FI	SDI_{75}	SDI_{65}	FI	SDI_{75}	SDI_{65}
				(μg kg^{-1})														
V1	***	***	***	17.2a	6.07b	5.19b	3.25c	8.43b	16.7a	4.08d	4.14d	1.54d	21.2b	2.04d	2.01d	26.2a	12.0c	12.0c
V2	***	***	***	6.61c	9.71b	11.2a	9.17b	4.34c	14.0a	7.53cd	14.3b	5.71de	3.86e	5.94cde	3.23e	8.44cd	8.91c	24.7a
V3	***	***	***	15.4a	4.11b	3.18b	3.75b	4.79b	14.2a	2.32c	5.33bc	3.60c	8.35b	3.58c	2.43c	35.6a	3.43c	3.53c
V4	***	***	***	1.89b	3.24a	1.84b	3.36a	1.29c	2.32b	2.45a	5.76a	1.88d	1.54d	1.35c	0.97d	1.67ab	2.61bc	2.67abc
V5	***	***	***	109a	119a	73.2b	117a	59.5b	124a	149a	151a	52.1d	40.7d	94.9c	42.8d	136ab	111bc	125abc
V6	***	***	***	35.4b	51.4a	22.9c	51.4a	22.7c	35.6b	35.1b	103a	16.2c	31.4b	19.0c	17.6c	39.7b	32.2b	35.0b
V7	***	***	***	83.2b	100a	61.3c	84.4a	68.9b	91.3a	110ab	86.4bc	57.1de	79.2cd	87.7bc	40.0e	60.6d	126a	87.0bc
V8	***	***	***	168b	223a	141c	227a	152b	153b	228b	305a	147de	170cb	203bc	83.4f	107ef	161cd	191bcd
V9	***	***	***	54.6a	50.1a	43.2b	56.2a	50.4a	41.2b	66.6a	48.3bc	53.7ac	67.9a	58.4ab	24.9e	29.2de	43.6cd	50.9bc
V10	***	***	***	16.2b	16.4b	30.2a	36.2a	13.3b	13.3b	28.3b	12.8cde	67.5a	12.0de	19.0c	8.83e	8.31e	17.2de	14.4cd
V11	***	***	***	46.1a	38.9b	31.2c	50.8a	38.9b	26.5c	57.0a	52.3ab	43.2bc	62.5a	37.7cd	16.4e	18.8e	26.7de	34.0cd
V12	***	***	***	30.8a	30.5a	27.2b	35.1a	24.2c	29.2b	39.1ab	45.0a	21.3c	33.7b	23.0c	15.8c	19.6c	23.6c	44.4a
V13	***	***	***	7.85a	4.80b	3.62c	3.82c	7.59a	4.86b	4.88c	5.46bc	1.13e	16.1a	4.11cd	2.54de	2.54de	4.84c	7.20b
V14	***	***	***	8.42b	9.14a	8.78b	8.99a	7.84b	9.51a	7.91c	12.7ab	6.42c	10.6b	7.62c	5.31c	6.76c	7.16c	14.6a
V15	***	***	***	292b	465a	235c	419b	542a	31.3c	260b	686a	310b	587a	686a	353b	28.8c	21.9c	43.3c
V16	***	***	***	24.5a	21.2b	24.0ab	20.7b	28.8a	20.3b	20.5cde	24.1cd	17.4def	38.2a	26.7bc	21.6cde	14.9ef	12.9f	33.0ab
V17	***	***	***	1423b	1482a	1461ab	1534a	1413b	1418b	1328b	2090a	1185b	1809a	1323b	1108b	1131b	1033b	2091a
V18	***	***	***	30.4b	28.1b	37.2a	27.5b	34.1a	34.2a	24.5de	34.9bc	23.1e	40.7b	28.0cde	33.6bc	26.1cde	21.5b	55.1a
V19	***	***	***	11.3ab	11.0b	11.8a	12.1a	10.7c	11.2b	10.2b	17.3a	8.84b	16.7a	8.25b	7.17b	6.99b	7.37b	19.3a
V20	***	***	***	22.9ab	21.5b	24.5a	20.6b	21.3b	27.1a	22.5abc	21.5bc	17.7c	17.7c	17.6c	28.6a	28.6a	25.5ab	27.2ab
V21	***	***	***	73.5b	71.4b	83.4a	75.4b	73.0c	79.9a	66.9c	95.4b	63.7c	96.9b	63.6c	58.5c	56.6c	55.3c	128a
V22	***	***	***	56.0b	51.2b	70.5a	52.3b	56.4b	69.0a	47.0c	67.1b	42.7c	74.3b	48.2c	46.7c	46.6c	38.3c	122a
V23	***	***	***	9.08b	9.18ab	9.59a	9.07b	8.36b	10.4a	7.44de	11.9bc	7.88de	12.8b	9.83cd	2.47f	7.03de	5.81e	18.4a
V24	***	***	***	12.5a	3.95b	11.1a	2.53b	12.4a	12.7a	3.27cd	2.61cd	1.70d	7.67b	5.66bc	23.7a	26.7a	3.56cd	7.89bc
V25	***	***	***	3.99b	2.54c	11.9a	3.10c	10.7a	4.61b	2.41de	3.93cd	2.97cde	4.34cd	2.41de	25.4a	5.21bc	1.29e	7.32b
V26	***	***	***	30.1b	23.6c	37.8a	25.3c	30.3b	35.9a	23.1cde	31.4c	21.5de	40.9b	22.0cde	27.8cd	26.3cde	17.3e	63.9a
V27	***	***	***	4.16b	3.86b	5.48a	3.73c	4.51b	5.27a	2.33d	5.75b	3.12cd	6.17b	3.35cd	4.02c	4.00c	2.49d	9.31a
V28	***	***	***	4.89b	3.89c	6.35a	4.04c	4.97b	6.12a	3.63cd	5.07c	3.41d	6.75b	3.60cd	4.54cd	4.28cd	2.98d	11.1a
V29	***	***	***	3.50b	3.64ab	3.84a	2.80b	4.02a	4.16a	1.42e	4.96b	2.01de	5.67ab	3.48c	2.92cd	3.41c	2.48cde	6.58a
V30	***	***	***	8.79a	5.39b	9.49a	5.10c	8.74b	9.83a	4.67cd	6.95bc	3.68d	8.85b	4.74cd	12.6a	12.8a	4.48cd	12.2a
V31	***	***	***	8.60b	6.73c	11.6a	6.77c	8.79b	11.4a	6.10cd	9.06b	5.14d	11.0b	6.12cd	9.28b	8.70bc	5.00d	20.4a
V32	***	***	***	9.91a	7.69b	10.2a	6.32c	8.99b	12.4a	5.29d	9.48c	4.21e	7.84cd	6.17de	13.0b	16.6a	7.42cd	13.3b
V33	***	***	***	2.94ab	2.68b	3.28a	3.20a	2.40b	3.31a	3.12b	4.26a	2.22cd	3.10b	1.53d	2.57bc	2.60bc	2.27bcd	5.06a
V34	***	***	***	1.69b	2.38a	2.65a	2.11b	1.99b	2.61a	1.93c	3.23b	1.17d	1.80cd	2.69b	1.49cd	1.32cd	1.22cd	5.29a
V35	***	***	***	1.09b	1.42a	0.97b	1.21a	1.10b	1.18ab	1.09b	1.79a	0.75c	1.02bc	1.19b	1.07bc	1.16b	1.27b	1.10b
Σ	***	***	***	2,636ab	2,894a	2,536b	2,928a	2,751a	2,387b	2,588bcd	3,989a	2,206cd	3,358ab	2,842bc	2,054d	1,961d	1,853d	3,347ab

†—Analysis of variance test (ANOVA), ***, significant at $p < 0.001$; Values (mean of three replications) followed by the same letter within the same row were not significantly different ($p < 0.05$), according to Tukey's least significant difference test. FI, SDI_{75} and SDI_{65}, full-irrigated and sustained-deficit irrigation at 75 and 65% of irrigation requirements, respectively.

The presence of alkanes, alkenes, acids and aldehydes are mainly related to the oxidative decomposition of the triglyceride and fatty acid components [56]. The oxidation of polyunsaturated fatty acids generates monohydroperoxides, which are precursors of volatile aldehydes such as hexanal, octanal, nonanal and decanal [57]. In the present study, only hexanal, hexenal and nonanal were identified, with values between 112 and 131 μg kg^{-1} with the lowest content corresponding to the SDI_{65} and SDI_{75} treatments and the highest one to the FI treatment. In this way, Yang et al. [54] when studying the roasted almond shelf life concluded that hexanal and nonanal concentrations should be less than 2140 and 5970 μg kg^{-1}, respectively, at the endpoint of shelf life to be suitable for their consumption. Thus, the relatively low experimental contents of hexanal and nonanal are indicative of the freshness of the samples under study.

Benzaldehyde is released from amygdalin, its precursor, by enzymatic hydrolysis, which is a cyanogenic glycoside naturally produced in almond [32]. Moreover, benzaldehyde is a characteristic aroma compound of wild/bitter almonds with a low odor threshold and it is found in a lower concentration in sweet almonds, but it is cultivar dependent [47,58]. In this context, the concentration of benzaldehyde in *cvs.* Vairo and Nonpareil was reported to be below that needed to affect the aroma of the almonds [31,47]. In the present study, the benzaldehyde content for *cv*. Lauranne (31 μg kg^{-1}) was similar to that reported for *cv*. Vairo [31]. However, a greater content of this compound was registered by *cv*. Marta (419 μg kg^{-1}) and even higher by *cv*. Guara (542 μg kg^{-1}). Thus, DI strategies significantly affected the benzaldehyde concentration, which was increased by SDI_{75} (465 μg kg^{-1}), but decreased in more severe conditions of water stress such as SDI_{65} (235 μg kg^{-1}) when compared to FI almonds (292 μg kg^{-1}). This fact suggests that the benzaldehyde was cultivar and irrigation treatment dependent, which convert it in an alleged marker for cultivar and hydroSOStainable identification.

3.5. Descriptive Sensory Profile

Descriptive sensory analysis was conducted to quantify the hypothetical effects of cultivars and irrigation doses on the almond sensory profiles. In this sense, 15 attributes were considered, and in general, significant differences both affected by cultivar and irrigation were found (Table 7). Regarding the DI treatments, panelists found that FI and SDI_{75} almonds had an intense red-brown color, which agreed with instrumental data, which also showed the highest values for the *a** coordinate (FI = 19.1a; SDI_{75} = 18.9ab; SDI_{65} = 18.2b), indicating that almonds from FI and SDI_{75} were more reddish than those from SDI_{65}. Regarding the size, even though the instrumental measurements were statistically significant the trained panel did not detect significant differences for these parameters among irrigation treatments. Similar findings were revealed by Lipan et al. [46] and Carbonell-Barrachina et al. [23] on hydroSOStainable almonds and pistachios, respectively, where no significant differences on sensory size were detected.

Regarding the flavor attributes, higher intensity of sweetness, aromatics reminiscent of almond (almond ID) and benzaldehyde-like notes were found for SDI_{65} almonds; these results proved that these particular almonds are those having the most intense, typical almond flavor. As shown, the benzaldehyde perception by human was in the contrast with the volatile compound concentration, which was higher in the SDI_{75} in comparison to FI. However, the human perception regarding the sweetness was in agreement with the results of total sugar (Table 4), showing a higher sweetness and sugar content in almonds cultivated under deficit irrigation conditions.

Table 7. Descriptive sensory analysis of raw almonds as affected by deficit irrigation. Scale used ranged from 0 = no intensity to 10 = extremely strong intensity.

	Outer Color	Size	Roughness	Sweetness	Bitterness	Astringency	Overall Nuts	Almond ID	Benzaldehyde Like	Woody
					ANOVA Test †					
Irrigation	***	NS	***	***	NS	NS	NS	***	***	NS
Cultivar	***	***	NS	***	NS	NS	***	***	***	NS
Irrigation × Cultivar	***	***	***	***	NS	NS	***	***	***	NS
					Tukey's Multiple Range Test ‡					
					Irrigation					
FI	3.9a	2.8	4.2a	3.7b	1.2	0.5	4.5	3.4b	2.0a	1.9
SDI_{75}	1.8b	2.7	4.5a	3.7b	1.1	0.6	4.4	3.9ab	1.8b	1.5
SDI_{65}	2.0b	2.8	2.4b	4.2a	1.0	0.7	4.5	4.4a	2.1a	2.2
					Cultivar					
Marta	2.2b	3.2a	3.7	1.9c	1.0	0.6	2.8c	1.9b	1.4b	2.2
Guara	2.5ab	2.4b	3.8	4.4b	1.5	0.7	4.7b	4.8a	2.9a	1.7
Lauranne	3.0a	2.7b	3.7	5.3a	0.9	0.6	5.7 a	5.2a	1.7b	1.6
					Irrigation × Cultivar					
					cv. Marta					
FI	2.1bc	3.1ab	4.6ab	2.1c	1.4	0.5	3.4bc	2.3cd	1.7bc	1.9
SDI_{75}	2.0bc	3.5a	4.4ab	1.4c	0.6	0.4	2.6c	1.4d	1.1c	1.7
SDI_{65}	2.4bc	3.0abc	2.0c	2.3c	0.6	0.8	2.5c	1.9cd	1.3c	3.1
					cv. Guara					
FI	4.9a	2.8abc	4.1ab	4.0b	1.2	0.5	4.4ab	3.6bc	2.4 abc	2.1
SDI_{75}	1.5bc	2.1c	5.1a	4.1b	1.8	0.9	4.9ab	4.8ab	2.9 ab	1.3
SDI_{65}	2.16b	2.1c	2.1c	5.0ab	1.6	0.8	4.8ab	5.8a	3.5a	1.6
					cv. Lauranne					
FI	4.8a	2.5bc	4.0ab	4.9ab	1.0	0.5	5.5a	4.4ab	2.1bc	1.7
SDI_{75}	1.8bc	2.3bc	4.0ab	5.7a	0.9	0.6	5.6a	5.4ab	1.5c	1.5
SDI_{65}	2.66b	3.1ab	3.1bc	5.3ab	0.6	0.6	6.0a	5.6ab	1.5c	1.7

† NS, not significant at $p < 0.05$; *** significant at $p < 0.001$; ‡ Values (mean of 10 trained panelists) followed by the same letter, within the same column, were not significantly different ($p > 0.05$), according to Tukey's least significant difference test. FI, SDI_{75} and SDI_{65}, full-irrigated and sustained-deficit irrigation at 75 and 65% of irrigation requirements, respectively. Almond ID, aromatics reminiscent of almond.

Although not many affective studies have been conducted using almond, Lipan et al. [25] concluded that both Spanish and Romanian consumers considered the almond ID (aromatics reminiscent of almond) and sweetness as the main attributes that control the consumer preferences. Moreover, sweetness, flavor, texture and price were the most relevant parameters in the CATA questionnaire when consumers were asked about their buying drivers. Taking into consideration the obtained results in this work, almond ID and sweetness were parameters that reached significant improvements when SDI was imposed, and it would reinforce the statement that water savings strategies in almond crop would help to obtain a final product with a higher acceptance by consumers. Thus, hydroSOStainable almonds with a final added value would allow to recover the economic losses caused by yield reductions, offering a product with a higher competitiveness and marketability (Figure 3), as has been corroborated by authors such as Lipan et al. [46], who concluded that consumers were willing to pay an extra amount of money for the hydroSOStainable almonds.

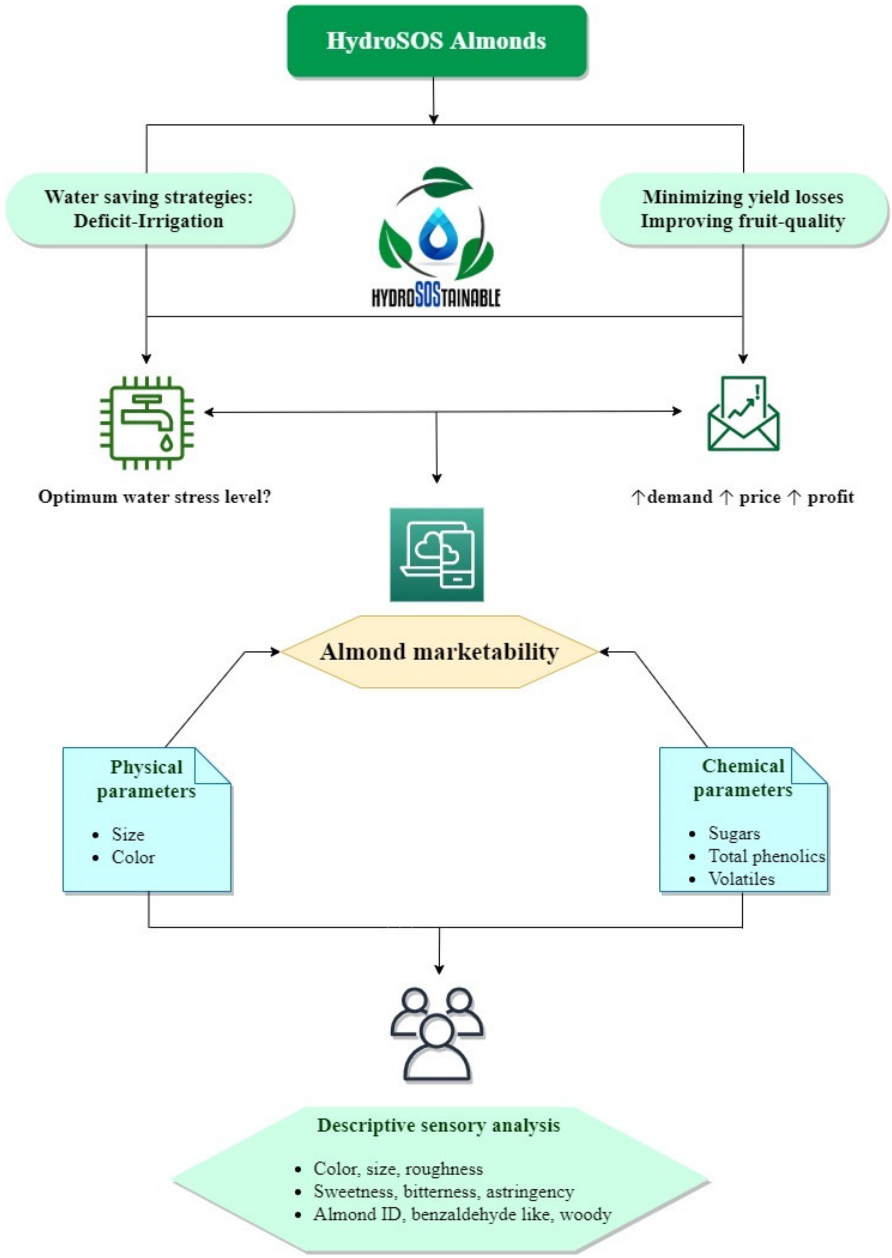

Figure 3. HydroSOStainable almonds: towards an equilibrium among water savings, optimum yields and quality parameters supported by marketability and sensory profile. ↑, increase.

4. Conclusions

This work highlights the main effects of irrigation in three almond cultivars in terms of the morphological, physicochemical and sensory parameters when this crop is subjected to sustained-deficit irrigation treatments. The findings allow us to conclude that almonds subjected to moderate sustained water stress improved substantially the most important features (sugars, total phenolic content and volatiles) related to the sensory profile and, probably, consumer acceptance. These results supported that all the monitored parameters besides water irrigation amounts are also cultivar-dependent, which determines the need of characterization of each cultivar growth under deficit irrigation conditions. Moreover, this study displayed the advantages of these strategies and opened the possibility of showcasing those hydroSOStainable products that have been obtained within a framework of water scarcity and sustainable use of natural resources. Thus, the findings prove the importance of considering the cultivar effect when these strategies are being imposed, not only in terms of final yield, but also from a nut quality perspective.

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