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Linking Conventional and Organic Rainfed Almond Cultivation to Nut Quality in a Marginal Growing Area (SE Spain)

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Abstract: The need to improve agroecosystem sustainability to secure yields, minimize environmental impacts and improve soil health is widely recognized. Organic production systems are one of the strategies that may be used to alleviate the negative environmental repercussions of conventional agriculture. In the present study, we compared the impact of conventional and organic production systems on the almond (*Prunus dulcis* (Mill.) D.A. Webb) yield and quality of nuts of two cultivars (*Marcona* and *Desmayo largueta*), with both systems being managed on marginal hillslopes in the southeast of Spain. Our findings show that the organic production system in rainfed almond trees has positive effects on certain nut quality parameters, with a slight decrease in almond yield, specifically 9.5% for cv. *D. largueta* and 1.3% for cv. *Marcona*, with respect to the conventional system. The results obtained have varied depending on the cultivar. Statistically significant differences have been obtained for cv. *Marcona* in the sugar content (54.4 and 49.8 g kg^{-1} in organic and conventional, respectively) and the total phenol content (3.41 and 2.46 g GAE kg^{-1} for organic and conventional, respectively). In the case of cv *D. largueta*, statistically significant differences were found between the organic and conventional systems for antioxidant activity (14.8 vs. 8.68 mmol Trolox kg^{-1}, DPPH), fatty acid content (229 vs. 188 g kg^{-1} dw), saturated fatty acids (36 vs. 28.7 g kg^{-1} dw), monounsaturated fatty acids (113 vs. 110 g kg^{-1} dw) and polyunsaturated fatty acids (60.3 vs. 49.6 g kg^{-1} dw). Here, we show for the first time how a rainfed organic system allows for higher-quality almonds, specifically with a higher content of phytochemicals beneficial for health, which, together with the higher price compared to conventional almonds, could compensate for the yield losses while preserving the sustainability of marginal agroecosystems.

Keywords: almond quality; fatty acid profile; rainfed agroecosystem; chemical and nutritional properties; conventional and organic production

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1. Introduction

Land degradation is defined as a decline in land quality mainly due to anthropogenic interventions that have adverse impacts on agricultural productivity, the environment and human well-being, as well as food security [1–3]; concretely, it is defined as the expansion of soil erosion processes worldwide [4,5]. In this sense, according to the European Commission [6], between 60 and 70% of soils are degraded due to unsustainable management, which limits their capacity to provide services. Particularly, for Mediterranean agroecosystems, soil degradation and erosion are the predominant environmental problems determining their sustainability and the provision of ecosystem services [7,8].

Rainfed Mediterranean farming is represented by a low water input that drives soil water content below its field capacity, particularly during the periods with high evaporative demand that induce lower yields [9,10]. In this context, rainfed woody fruit orchards (almond, olive and vineyards) represent a high percentage of cropland in the Mediterranean region, with a climate with tempered rainy winters and hot dry summers [11,12]. These plantations are usually cultivated in mono-cropping schemes with low-density plantations and controlled tree size by annual pruning and tillage to prevent weed development and to foster infiltration of rainfall water [13,14].

Concretely, almond [*Prunus dulcis* (Mill.) D.A. Webb] estates are widespread in the Mediterranean environment. The global total area of almond cultivation spans 2,162,263 ha, with Spain having the greatest area of 744,470 ha, followed by the USA with 534,191 ha [15]. Most Spanish almonds (78%) are under rainfed (587,030 ha) conditions [16], routinely tilled and with low inputs of chemical fertilizers or organic amendments, with low yields (350–400 kg per hectare) according to Arquero [17]. That is, the low-yielding rainfed almond plantations represent a significant cultivated area, with average yields of 0.49 t ha^{-1} compared to those of the USA with 4.10 t ha^{-1}, mainly originating from intensively irrigated plantations [15].

Most rainfed almonds are situated in hillslope marginal areas in S Spain (Andalusia), where soil deterioration and erosion are the most significant environmental issues [18,19]. Therefore, in this context of climate change, to achieve sustainable agriculture and avoid soil degradation due to the adverse effects of water erosion, soil protection and conservation measures must be adopted [20–22].

In this context, production systems with conventional practices are responsible for the greatest runoff coefficient (5–10%) and soil losses (10–20 t ha^{-1} year^{-1}), as was stated by Maetens et al. [23]. In Europe and according to Cherlet et al. [24], an about 12% decrease in the productivity of fruit crops during the period between 1982 and 2010 was estimated due to agricultural soil degradation. Conventional practices are widespread in rainfed crops that require soil tillage, and large amounts of chemical fertilizers and pesticides increase the yields, with a side effect of environmental risks. By contrast, synthetic agricultural inputs are not applied in organic farming systems to reduce their unfavorable environmental impacts; instead, plant residues or livestock manure are used to boost soil fertility.

Concretely, the area of organic plantations in Spain is about 2.84 million ha, 47% of which is located in Andalusia (S Spain), making it the leading producer of organic almonds worldwide. In agreement with MAPA [25], the area of almonds certified under organic management in Spain is ~246,000 ha, with 43% of the surface area concentrated in Andalusia, representing 25% of national organic almond production. Most of the organic almonds are found on marginal croplands with low-input production systems, and only 21% of the cultivated area has support irrigation, as was pointed out by Iglesias et al. [26]. The main factor that has increased farmer interest in organic cultivation systems is the possibility of improving the profitability of their orchards. In this sense, Aznar et al. [27] reported that this is motivated by an increasing demand, a higher price compared to conventional almonds and the fact that for the countries that lead world production, the United States and Australia, it is difficult to apply organic systems. As pointed out before, organic systems are a strategy that can be implemented to reduce the adverse environmental consequences provoked by conventional practices. That is, as was stated by many authors, organic farming must be combined with soil conservation measures such as a decrease in or deletion of the tillage or the utilization of cover crops, boosting soil health restoration and quality [28–31]. In relation to traditional practices, the most common soil management system in Mediterranean rainfed woody fruit orchards is conventional tillage [32,33]; however, it is increasingly used less frequently because it entails adverse repercussions for soil health and quality [34–36]. Particularly, for rainfed almonds, many studies have reported the benefits of soil conservation techniques, encouraging benefits such as water erosion reduction, the augmentation of soil organic carbon, improvement in soil biodiversity and the provision of ecosystem services, among others [37–40].

On the other hand, the almond is known as the "king of dry fruits" and its consumption is significant because of its high potential benefit for humans and healthy nutritional profile [41,42]. The almond seeds or kernels are greatly versatile and can be eaten on their own or as part of many food products. There are many studies regarding almond composition [43–45], showing the high contents of bioactive compounds such as fatty acids, lipids, amino acids, proteins, carbohydrates, dietary fibers, phytosterols, polyphenols, vitamins and macro- and micronutrients, among others. In this context, the effect of the almond genotype on its nutrient composition is well known [46,47]; however, other factors such as cultivation practices, growing region, nut maturity, etc., or their interaction must be considered, according to many studies [22,48–50].

In spite of the fact that the market for organic products is small, in recent years, the demand for organic food produce is growing in the EU as well as worldwide [51,52]. According to the latest trends, most people prefer organic food products because they are worried about pesticides, additives, antibiotics or other chemical residues and expect organic food to be healthier [53,54]. Also, other motives include preoccupations about the negative impact of conventional farming on biodiversity and the environment and the ethical treatment of cattle [55–57].

Although there are some previous studies in the literature that compare the quality characteristics between almonds from organic and conventional production systems [58–60], they are scarce and do not study the nutritional composition of almonds in detail.

The objective of this experiment was to compare the effect of conventional and organic production systems on the yield and quality of almonds of two cultivars (*Marcona* and *Desmayo largueta*), both grown using rainfed techniques on marginal slopes of the Mediterranean regions of southeast Spain.

2. Materials and Methods

2.1. Study Area

This experiment was carried out during a four-year monitoring period on conventional and organic almond plantations located in Lanjarón (Granada, SE Spain, UTM coordinates of X = 456,720.423; Y = 4,083,607.192). The Mediterranean climate of the study area is characterized as temperate with a warm dry summer and a cold-temperate winter, with average annual temperatures of 15 °C and rainfall depth of 480 mm.

In general terms, the study area soil is classified as Typic xerorthens [61], with a texture of sandy loam and 580, 250 and 170 g kg^{-1} of sand, silt and clay; average soil of pH 7.54 (1:2.5); and bulk density of 1.34 g cm^{-3}. The average contents of soil organic carbon and total N were 8.3 and 0.84 g kg^{-1}, respectively, and extractable P (Olsen) and available K were 4.3 and 119.1 mg kg^{-1}, respectively.

2.2. Experimental Design

The study plots are located in a 65-year-old rainfed almond orchard with a 7 × 7 m plantation frame (~200 trees ha^{-1}) of two of the most commonly grown varieties on marginal lands in Spain, *Desmayo largueta* (*D. largueta*, hereafter) and *Marcona* (Figure 1). Both cultivars are self-incompatible and early flowering, especially for *Desmayo largueta*. The partial overlap of the flowering of both cultivars allows their cross-pollination. The experimental design was a completely randomized block design with three replications per system treatment (conventional and organic); the four central trees from each monitored plot were included for almond yield measurements, and the others served as border trees. The almond organic plots were cultivated with no-tillage and legume cover crops and conventional plots with tillage and without cover crops. The cultural practices in almond plots under each production system during the 4-year monitoring period are shown in Table 1. At the end of each monitored season, the almond yields from both production systems and almond cultivars were determined by weighing the almond kernel production after removal of the pericarp. For the nut quality analysis, a composite sample (~3 kg of in-shell almonds) was taken from the central trees of each experimental plot in the last year of the study.

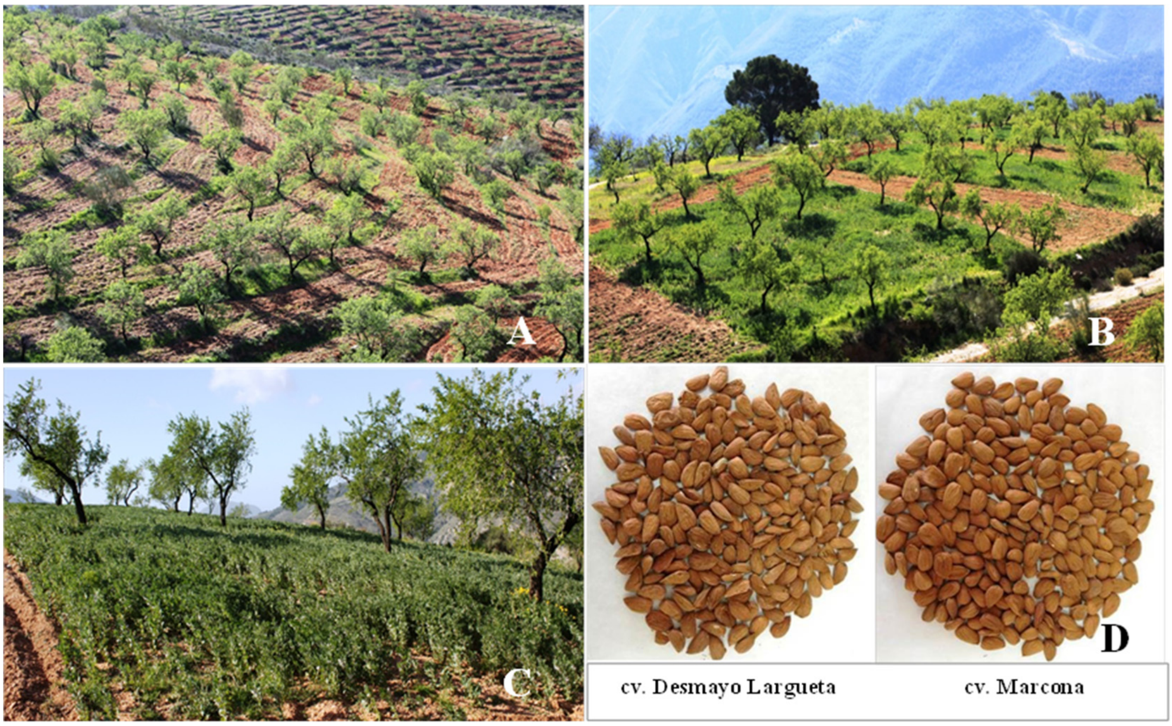

Figure 1. Rainfed conventional (**A**), organic (**B**) production systems, *Vicia faba* cover for organic production (**C**), and studied almond cultivars (**D**).

Table 1. Cultural practices and soil management for each almond production system monitored.

Season	Month of Year	Conventional	Organic
Winter	January–February	Mouldboard tillage (30 cm)	None
	March	Fungicidal application (Cu oxychloride; 150 L ha^{-1})	Fungicidal application (Cu oxychloride; 150 L ha^{-1}) *
Spring	April	Tillage (20 cm soil depth)	Disc harrow incorporation (30 cm soil depth)
	April–May	Insecticide treatment (Deltamethrin 2.5% p/v; 200 L ha^{-1})	Insecticide treatment (K soap + pyrethrins; 200 L ha^{-1}) *
Summer	August–September	Fruit harvest	Fruit harvest
	September–October [a]	None	Sowing *Vicia faba* (150 kg ha^{-1})
Autumn	October	Fertilization (NPK 15-15-15; 2 kg tree^{-1})	Fertilization [NK (Ca) 3-9(8); 2 kg tree^{-1}] *
	October–November	Thinning pruning	Thinning pruning

[a] Before the first autumn rains. * Authorized in organic production.

2.3. Physical and Chemical Almond Nut Analysis

2.3.1. Moisture Content, Water Activity, Color and Instrumental Texture Determinations

The moisture content of the almonds was determined via the standard method [62]; for this, 2 g of ground sample was placed in metallic trays and dried in an oven at 60 °C to constant mass. For water activity determination, a meter device (Novasina AW-SPRINT TH500; Pfaffikon, Zurich, Switzerland) was used, and the measurement for each sample conducted in triplicate and the resulting data represented as their average. The color of the almond kernels was determined via a Minolta Colorimeter CR-300 (Minolta, Osaka, Japan), with this parameter as the CIEL*a*b* coordinates defined in a three-dimensional space in terms of three numerical values. For this analysis, twenty measurements were done for each sample, and the values for L*, a* and b* were averaged. Finally, the texture of the almonds was analyzed using a texture analyzer (Stable Micro Systems, model TA-XT2i, Godalming, UK) loaded with a 30 kg cell and a probe (Volodkevich Bite Jaw HDP/VB) (Stable Micro Systems Ltd., Godalming, UK). The trigger was set at 15 g, testing a displacement rate of 1 mm s^{-1} over a distance of 3 mm, analyzing five parameters: fracturability (mm), hardness (N), work performed to shear (Ns), average force (N) and number of fractures (peaks count). The data are reported as the mean value of twenty measurements.

2.3.2. Organic Acid, Sugars and Fatty Acid Determinations

The organic acid and sugar profiles were determined using a high-performance liquid chromatography (HPLC) procedure. The extraction consisted of the homogenization of 1 g of ground almonds with 5 mL of phosphate buffer (pH = 7.8), and a sample was filtrated (0.45 µm Millipore membrane filter) and injected into a Hewlett Packard HPLC series 1100 (Wilmington DE, USA). As an elution buffer, 0.1% ortophosphoric acid was used. For separation of compounds, 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) was used. The sugars content was measured using a refractive index detector (RID) and the organic acids using a diode-array detector (DAD) through absorbance measurements at 210 nm.

The fatty acid methyl esters (FAMEs) were determined using methylation as was reported by Lipan et al. [63] with some modification. The methyl esters of fatty acids were separated in a Shimadzu GC17 gas chromatography (Shimadzu, Tokyo, Japan) device coupled with a flame ionization detector and a DB-23 capillary column; an initial flow rate of 1.2 mL min^{-1} was used as the carrier gas, while the detector gasses were H_2 (30 mL min^{-1}) and air (350 mL min^{-1}), with He (35 mL^{-1}) as the make-up gas. The injector and detector temperatures were 250 and 260 °C, respectively, with an injection volume of 0.6 uL and a split ratio 1:10. The preliminary temperature was 175 °C for 10 min with a temperature gradient of 3 °C min^{-1} until 215 °C, and the temperature was kept at 215 °C for 15 min. The identification of FAME peaks was conducted by comparing with the retention times of the standards (FAME Supelco MIX-37). The contents are expressed in g kg^{-1}, with a methyl nonadecanoate as the internal standard.

2.3.3. Total Polyphenols and Antioxidant Activity Determinations

Samples of ground almonds were used for the extraction of polyphenols and antioxidant activity using a methanolic extractant (MeOH:H_2O; 80:20; *v*:*v* + 1%HCl). Total polyphenols content (TPC) was determined using Folin–Ciocalteu colorimetric method by Gao et al. [64]. Almond extract (0.1 mL) was mixed with Folin–Ciocalteu reagent (0.2 mL) and 2 mL of distilled water. After 3 min, 1 mL of a 20% aqueous solution of sodium carbonate (Na_2CO_3) was added. The absorbance at 765 nm was measured after 1 h. The results are as g of gallic acid equivalents (GAE) kg^{-1}.

On the other hand, the antioxidant activities of the almonds were measured using ABTS●+ (2,2′-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid) per Re et al. [65] and DPPH● (2,2-diphenyl-1-picryl-hydrazyl-hydrate) radicals as described by Brand-Williams et al. [66]. Additionally, antioxidant activity was also determined by the ability to reduce iron ions (FRAP) according to Benzie and Strain [67]. The measurements of antioxidant activities were carried out according to the procedure of Lipan et al. [68]. Antioxidant capacity is expressed as mmol of Trolox kg^{-1}. All measurements were made using an ultraviolet-visible (UV-vis) spectrophotometer (Helios Gamma model, UVG 1002E; Helios, Cambridge, UK).

2.3.4. Descriptive Sensory Analysis

The descriptive sensory analysis was carried out meeting the requirements for sensory laboratories (individual boxes, natural/artificial lighting and controlled temperature 21 ± 1 °C), by a trained panel of 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 according to the method described by Lipan et al. [69] to estimate if differences between conventional and organic farming could be perceived by the sensory panel. The samples were served in odor-free 30 mL covered plastic cups and randomly coded with three digits. Water and unsalted crackers to cleanse the palate between samples were served. The samples of almonds were presented based on a randomized block design to avoid biases. A 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.

2.4. Statistical Analysis

A two-way analysis of variance (ANOVA) was run to characterize the data, using "agricultural system" and "cultivar" as factors, and then the data were subjected to a Tukey multiple-range test. The differences were considered statistically significant when $p < 0.05$. All these analyses were conducted using the software XLSTAT Premium 2016 (Addinsoft, New York, NY, USA).

3. Results

3.1. Almond Yield

Figure 2 shows the nut yield for the two almond cultivars studied, *D. largueta* and *Marcona*, in the organic and conventional production system.

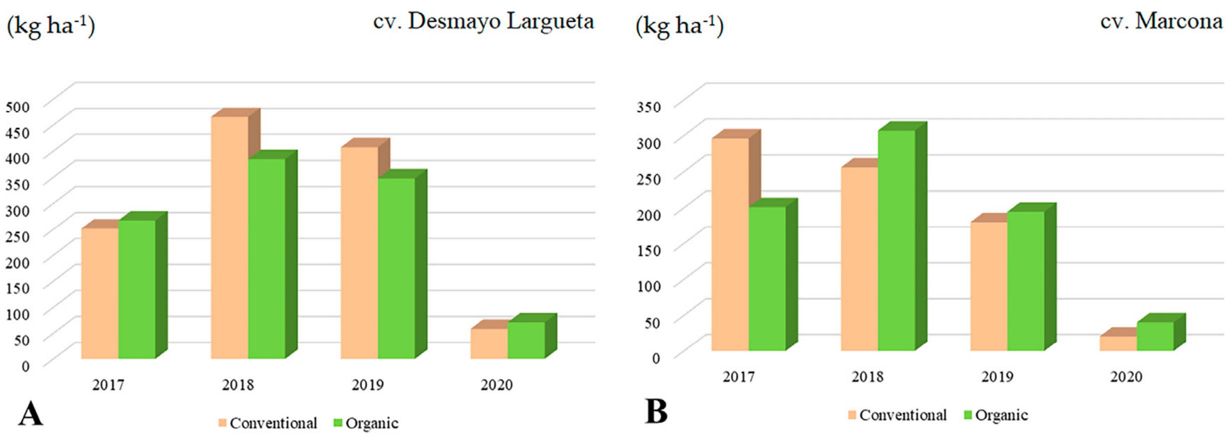

Figure 2. Nut yield of rainfed almond cvs. *Desmayo largueta* (**A**) and *Marcona* (**B**) under conventional and organic production systems during four-year monitoring period.

The average production for the cv. *D. largueta* was 296 kg ha^{-1} in the conventional and 268 kg ha^{-1} in the organic system. For cv. *Marcona*, the production was 188 and 186 kg ha^{-1} in the conventional and organic system, respectively. The cv. *Marcona* production was 36.5% and 30.6% lower than for cv. *D. largueta* in the conventional and organic system, respectively. These yields obtained agree with those of Arquero [17] for marginal rainfed almonds in Andalusia. Rainfall is one of the main determinants of productivity in rainfed almond orchards. Thus, during the study period, the lowest yields corresponded to the years with low rainfall amounts. In this line, the highest production was determined in 2018, which is the year with major rainfall (693.7 mm) compared to the remaining monitored years with rainfall lower than the average for the area (279.6, 265.8 and 386.8 mm in 2017, 2019 and 2020, respectively). On the other hand, we note that about the 86% of the Spanish almond growing area is not irrigated, and in most cases growing areas are located in rainfed and marginal lands with less than 300 mm of annual rainfall, as in our case, and these large areas with low yields do not exceed 100 kg of kernel per hectare [70,71]. In addition, the high variability in yield terms among the seasons could be ascribed to alternate-bearing, which is typical behavior of rainfed almond trees in the Mediterranean region, as has been reported by Arrobas et al. [72] and Morais et al. [73].

Finally, another reason that can explain the low productivity, especially for cv. *Marcona*, is that our plantation suffered an aphid infestation, with this cultivar being highly susceptible to attack by this plague [74]. In this sense, Socias i Company et al. [75] stated that cv. *Marcona* has extreme sensitivity to different situations such as frost damage and pollination deficiencies due to its self-incompatibility, which can provoke significant yield reductions if there are bad weather conditions during the flowering stage.

3.2. Almond Quality Parameters

In Table 2 are the data for the kernel ratio, moisture content and water activity (a_w) of the rainfed almond cvs. *D. largueta* and *Marcona* in organic and conventional production systems.

Table 2. The effect of organic and conventional production systems on kernel ratio, moisture content and water activity of rainfed almond cvs. *D. largueta* and *Marcona*.

	Kernel Ratio (%)	Moisture (%)	Water Activity (a_w)
		ANOVA [†] Test	
APS	ns	*	ns
Cultivar	*	*	ns
APS × cultivar	*	*	ns
		Tukey Multiple Range Test [‡]	
APS			
Organic	22.9	3.38 b	0.54
Conventional	22.3	3.63 a	0.53
Cultivar			
D. largueta	24.6 a	3.65 a	0.53
Marcona	20.6 b	3.36 b	0.54
APS × cultivar			
Organic × *D. largueta*	24.1 ab	3.51 ab	0.55
Conventional × *D. largueta*	25.2 a	3.79 a	0.52
Organic × *Marcona*	21.7 ab	3.25 b	0.54
Conventional × *Marcona*	19.4 b	3.48 ab	0.55

APS = Agricultural Production System; [†] ns = not significant at $p > 0.05$; * = significant at $p < 0.05$. [‡] Values (mean of 3 replication) followed by different letter, within the same column and factor, were significantly different ($p < 0.05$), according to Tukey's least significant difference test.

As in the study by Karaat [59], there were no significant differences in the kernel ratio between the production systems, but there were between the studied cultivars. The value of 24.6% for cv. *D. largueta* was within the range established for this cultivar by Pérez-Sánchez and Morales-Corts [76] (24–28%). However, the kernel ratio for cv. *Marcona* was lower than the range of 22–28% highlighted by the previous authors; although, it is in contrast with those reported by Melhaoui et al. [77], with a kernel ratio for this cultivar between 20 and 23%. The kernel yields that we have obtained coincide with the average values stated by Roncero et al. [78] for hard-shell varieties (<25%).

In relation to moisture content, significant variability was found for both studied cultivars and production systems applied. That is, the moisture values were significantly higher for cv. *D. largueta* than for cv. *Marcona* in the same way, as shown in the study by García-Pascual et al. [79], although the values in our study were lower than those reported by this author. In the present study, the moisture content was higher in conventional almonds than in the organic ones for both cultivars. This lower moisture content may improve the stability of organic almonds compared to conventional ones. Similar results were obtained by Venkatasubramanian [58] in a study that compared the nutritional quality of conventional and organic almonds, with moistures of 4.4 and 3.8%, respectively. By contrast, Karaat [59] reported higher moisture in organic compared to conventional production of Ferruduel and Ferragnes cultivars in Turkey. Gulsoy et al. [60] determined similar results for cv. Ferragnes with higher moisture content for organic almonds, but not so for cv. Ferraduel, with higher moisture content for conventional almonds.

Finally, there were no significant differences for a_w, neither resulting from the effect of cultivars nor from production systems. The moisture content and a_w values obtained meet the industry's optimal levels for raw almonds, ranging between ~3 and 6% and 0.3 and 0.6%, respectively [80,81]. These low values of moisture content and a_w of almonds help to increase their useful life by minimizing biological reactions [80].

Table 3 presents the color and texture values found for both studied almond cultivars and production systems. There were no significant differences in color depending on the production system, but there were differences depending on the cultivar. These differences are normal since each almond cultivar has its own polyphenol profile that largely determines the almond skin coloration [82]. That is, cv. *Marcona* almonds, with their higher values of L*, b* and Hue, are generally lighter than those of cv. *D. largueta*.

Regarding the texture, there were significant differences for both cultivars and cultivation systems for all the parameters studied except the number of fractures. In this context, Fornés Comas et al. [83] showed a greater shell-cracking load for cv. *D. largueta* than for cv. *Marcona*, which contradicts our findings. Additionally, both cultivars have a hard shell, as preferred in the Mediterranean region as it allows a better adaptation to rainfed conditions, increases resistance to predators and insects and means that the almonds can be kept for a prolonged period without problems of exceeding desiccation or rancidity, as was stated by Pérez-Sánchez and Morales-Corts [76].

Table 4 shows the fatty acid profile for the studied almond cultivars under the production systems applied.

In all samples, oleic, linoleic and palmitic acids (in decreasing order) accounted for approximately 88% of the total fatty acid concentrations. This fact is in accordance with previous results highlighted by many authors [84–86]. The percentage of monounsaturated and polyunsaturated fatty acids (MUFAs and PUFAs) ranged between 84.9% for conventional *D. largueta* and 83.7% for conventional *Marcona*. This high percentage of unsaturated lipids is associated with some of the main functional benefits of consuming almonds [78,87]. Our results showed a higher content of the fatty acids SFA, MUFA and PUFA for the organic almonds compared to the conventional ones. By comparing our results for cv. *Marcona* with those reported by Čolić et al. [88] in rainfed conditions, it could be observed that the percentage of MUFA obtained in our study was minor (59.7–59.6 compared to 74.8%), instead of increases in the percentages of saturated fatty acids (SFAs) and PUFAs (16.5–16.1 vs. 9.31% and 24.1 vs. 15.9%, respectively). Comparable findings were reported by Kodad and Socias I Company [89] for cv. *Marcona* with MUFA, 72%; PUFA, 19.4% and SFA, 8.6%. As was expected, these results indicate that the rainfed almond trees in this study were subjected to significant water stress since there are studies that have indicated that water stress is positively correlated with SFA and PUFA and negatively with MUFA [48,90].

Table 3. The effect of organic and conventional production systems on color and texture of rainfed almond cvs. *D. largueta* and *Marcona*.

	Kernel Color Coordinates					Kernel Cutting Force				
	L*	**a***	**b***	**C**	**Hue**	**Fracturability (mm)**	**Hardness (N)**	**Work to Shear (Ns)**	**Average Force (N)**	**Number of Fractures**
	ANOVA † Test					ANOVA † Test				
APS	ns	ns	ns	ns	ns	***	***	***	**	ns
Cultivar	ns	ns	***	**	***	***	***	***	**	ns
APS × Cultivar	ns	ns	***	**	***	***	***	***	**	ns
	Tukey Multiple Range Test ‡					Tukey Multiple Range Test ‡				
APS										
Organic	45.1	16.0	29.4	33.5	61.2	1.57 a	65.9 a	51.4 a	32.1 a	12.5
Conventional	44.4	16.3	29.4	33.6	60.9	1.36 b	63.2 b	40.9 b	29.8 b	12.3
Cultivar										
D. largueta	44.1	16.1	28.2 b	32.5 b	60.2 b	1.57 a	68.8 a	51.5 a	32.5 a	13.3
Marcona	45.4	16.2	30.5 a	34.6 a	61.9 a	1.36 b	60.2 b	40.8 b	29.5 b	11.4
APS × cultivar										
Organic × *D. largueta*	44.5	15.9	28.4 bc	32.6 b	60.7 bc	1.67 a	70.3 a	58.5 a	34.4 a	12.6
Conventional × *D. largueta*	43.7	16.3	28.1 c	32.5 b	59.8 c	1.47 ab	67.2 ab	44.2 b	30.4 b	14.1
Organic × *Marcona*	45.7	16.2	30.4 ab	34.5 ab	61.8 ab	1.46 b	61.3 bc	43.9 b	29.7 b	12.3
Conventional × *Marcona*	45.1	16.2	30.6 a	34.7 a	62.0 a	1.26 c	59.1 c	37.7 b	29.3 b	10.5

APS = Agricultural Production System; † ns = not significant at $p > 0.05$; ** and *** significant at $p < 0.01$, and 0.001, respectively. ‡ Values (mean of 20 replication) followed by different letter, within the same column and factor, were significantly different ($p < 0.05$), according to Tukey's least significant difference test. L*, a*, b* = Color coordinates. C, chroma.

Table 4. Fatty acid contents of rainfed almonds cvs. *D. largueta* and *Marcona* (g kg^{-1} dw) in response to agricultural production systems.

Compound (FAMEs)	ANOVA † Test			APS		CV		Interaction APS × CV			
	APS	**CV**	**APS × CV**	**ORG**	**CONV**	**DL**	**M**	**ORG × DL**	**CONV × DL**	**ORG × M**	**CONV × M**
Tukey Multiple Range Test ‡											
C14:0 (Myristic)	***	***	***	0.20 a	0.16 b	0.15 b	0.20 a	0.19 a	0.11 b	0.20 a	0.20 a
C15:0 (Pentadecylic)	ns	ns	ns	0.09	0.08	0.08	0.09	0.09	0.07	0.09	0.09
C15:1 (cis-Pentadecenoic)	ns	ns	ns	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03
C16:0 Iso	ns	ns	ns	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06
C16:0 (Palmitic)	***	***	***	23.9 a	22.7 b	22.0 b	24.6 a	24.3 ab	19.8 c	23.6 b	25.6 a
C16:1c7 (cis-Hexadecenoic)	***	ns	***	0.11 a	0.09 b	0.10	0.10	0.12 a	0.07 c	0.09 b	0.11 ab
C16:1c9 (Palmitoleic)	ns	*	*	2.99	2.89	2.82 b	3.06 a	3.06 a	2.57 b	2.91 ab	3.20 a
C16:1c10	ns	***	***	0.02	0.02	0.02 b	0.03 a	0.03 a	0.01 c	0.02 b	0.03 a
C17:0 (Margaric)	ns	**	**	0.38	0.36	0.34 b	0.40 a	0.40 a	0.28 b	0.36 ab	0.44 a
C17:1 (cis-Heptadecenoic)	**	**	**	0.74 a	0.66 b	0.70 a	0.71 a	0.81 a	0.58 c	0.68 bc	0.74 ab
C18:0 (Stearic)	***	***	***	10.9 a	9.58 b	8.80 b	11.6 a	10.0 b	7.55 c	11.7 a	11.6 a
C18:1t9 (Elaidic)	***	***	***	0.27 a	0.21 b	0.22 b	0.26 a	0.25 b	0.19 c	0.29 a	0.23 bc
C18:1c9 (Oleic)	***	***	***	121 a	111 b	108 b	125 a	119 a	96.8 b	124 a	125 a
C18:1n7 (cis-Vaccenic)	ns	ns	ns	9.54	9.32	9.31 a	9.55	9.49	9.13	9.59	9.52
C18:2 t8c13 (Linoleaidic)	ns	ns	ns	0.18	0.29	0.15 a	0.31	0.19	0.12	0.17	0.46
C18:2n6cis 9,12 (Linoleic)	**	***	**	57.3 a	52.5 b	54.3 b	55.4 a	59.6 a	49.1 b	55.1 a	55.8 a
C20:0 (Arachidic)	*	*	*	0.72 a	0.51 b	0.60 b	0.64 a	0.65 ab	0.54 b	0.79 a	0.48 b
C18:3n6c9,6,12 (γ-Linolenic)	*	*	*	0.09 a	0.07 b	0.07 b	0.09 a	0.09 a	0.05 b	0.09 a	0.09 a
C20:1c11 (Eicosenoic)	***	***	***	0.42 a	0.34 b	0.35 b	0.42 a	0.40 a	0.29 b	0.45 a	0.39 a
C18:3n3c9,12,15 (α-Linolenic)	**	**	**	0.34 a	0.29 a	0.33 a	0.29 b	0.37 a	0.30 b	0.31 ab	0.27 b
C21:0 (Heneicosanoic)	ns	ns	ns	0.16	0.11 b	0.13 a	0.14 a	0.15	0.10	0.17	0.11
C20:2n6c11,14 (Eicosadienoic)	***	***	***	0.02 b	0.03 a	0.01 b	0.03 a	0.02 b	0.01 c	0.02 b	0.05 a
C22:0 (Behenic)	***	***	***	0.14 a	0.12 b	0.11 b	0.15 a	0.13 b	0.10 c	0.15 a	0.15 a
C22:1c13 (Erucic)	ns	ns	ns	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02
C22:2n6c3,16 (Docosadienoic)	***	***	***	0.017 a	0.022 b	0.021 a	0.018 b	0.013 c	0.03 a	0.02 b	0.015 c
Oleic:Linoleic	ns	ns	ns	2.14	2.11	1.99 b	2.26	2.00	1.97	2.28	2.25
Saturated (SFA)	***	***	***	36.6 a	33.7 b	32.3 b	37.9 a	36.0 b	28.7 c	37.1 ab	38.8 a
Monounsaturated (MUFA)	***	***	***	135 a	125 b	121 b	139 a	133 a	110 b	138 a	140 a
Polyunsaturated (PUFA)	**	**	**	58.0 a	53.2 b	54.9 b	56.2 a	60.3 a	49.6 b	55.7 a	56.7 a
ΣFAMEs	***	***	***	230 a	212 b	209 b	233 a	229 a	188 b	231 a	235 a

APS = Agricultural Production System; ORG = organic; CONV = conventional; CV = cultivar; DL = *Desmayo largueta*; M = *Marcona*; † ns = not significant at $p > 0.05$; *, **, ***, significant at $p < 0.05$, 0.01, and 0.001, respectively; ‡ values (mean of 3 replications) followed by different letter, within the same row and factor, were significantly different ($p < 0.05$), according to Tukey's least significant difference test; ΣFAMEs = fatty acids methyl esters; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

On the other hand, the oleic/linoleic ratio, considered an important criterion in the quality of almond fatty acid composition [89], was higher for both cultivars in the organic production system with respect to the conventional one, although the differences are not significant. The results for cv. *D. largueta* coincided with those obtained by Karrat [59] and Gulsoy et al. [60], with higher oleic acid content for organic almonds than for conventional ones. These authors obtained a lower content of fatty acids, a lower content of SFA and a higher proportion of UFA/SFA for organic almonds compared to conventional ones, which contradicts our results for *D. largueta*. For cv. *Marcona*, no significant differences were found for the parameters discussed above.

The contents of organic acids and sugars of almonds for the studied cultivars and production systems are shown in Table 5. As observed, both organic acids and sugars were higher in organic system, mainly the citric and malic acid, and reducing sugars such as glucose. In relation to the cultivars, total content of the organic acids was higher for *D. largueta* (14.2 g kg^{-1}) than for *Marcona* (9.13 g kg^{-1}), while the opposite was observed for sugars, a higher content was observed for *Marcona* (52.1 g kg^{-1}) compared to *D. largueta* (49.6 g kg^{-1}) The interaction shown that production system actually only affected total sugar content for the cultivar *Marcona*. For individual sugars, the production system affected in a different way each cultivar; for instance, sucrose and fructose content was higher in conventional system for *D. largueta*, while glucose was higher for the organic system. However, for the cultivar *Marcona*, sucrose, glucose and so the total sugars were higher on the organic system Sánchez-Bel et al. [91] demonstrated significantly higher citric and malic acid contents in almond kernels (Guara) cultivated with organic fertilization compared to those from conventional fertilization, which coincides with our results for the cultivar *D. largueta*.

Table 5. The effect of production systems on organic acids and sugars of rainfed almonds cvs. *D. largueta* and *Marcona*.

	Organic Acids					Sugars			
	Oxalic	Citric	Tartaric	Malic	ΣOA	Sucrose	Glucose	Fructose	ΣSugars
	ANOVA † Test					ANOVA † Test			
APS	ns	**	ns	**	***	ns	**	*	*
Cultivar	ns	**	***	**	***	**	ns	*	*
APS × Cultivar	ns	**	***	**	***	**	**	*	*
	Tukey Multiple Range Test ‡					Tukey Multiple Range Test ‡			
APS					(g kg^{-1})				
Organic	2.00	3.04 a	2.11	5.01 a	12.2 a	34.1	10.9 a	7.16 b	52.1 a
Conventional	1.98	2.70 b	2.12	4.38 b	11.2 b	33.0	7.51 b	9.00 a	49.5 b
Cultivar									
D. largueta	1.99	3.11 a	2.41 a	6.71 a	14.2 a	32.0 b	9.89	7.63 b	49.6 b
Marcona	2.00	2.64 b	1.82 b	2.67 b	9.13 b	35.1 a	8.48	8.53 a	52.1 a
APS × cultivar									
Organic × *D. largueta*	2.01	3.13 a	2.31 a	7.63 a	15.1 a	31.7 d	11.5 a	6.62 b	49.8 b
Conventional × *D. largueta*	1.97	3.08 a	2.52 a	5.80 ab	13.4 a	32.4 c	8.28 b	8.64 a	49.3 b
Organic × *Marcona*	2.00	2.96 a	1.91 b	2.38 c	9.24 b	36.5 a	10.2 a	7.70 ab	54.4 a
Conventional × *Marcona*	2.00	2.32 b	1.72 b	2.96 bc	9.01 b	33.7 b	6.73 c	9.35 a	49.8 b

APS = Agricultural Production System; † ns = not significant at $p > 0.05$; *, **, and *** significant at $p < 0.05$, 0.01, and 0.001, respectively. ‡ Values (mean of 3 replications) followed by different letter, within the same column and factor, were significantly different ($p < 0.05$), according to Tukey's multiple range test.

The total sugar content was affected by the type of cultivar, the production system and the interaction of both factors (Table 5). The sugar content in this study was within the range that Yada et al. [43] reported in a review of studies on the macronutrient composition of almonds in Spain (18–76 g kg^{-1}). Sucrose was the main sugar, which is consistent with previous studies [92,93]. Our findings coincide with those obtained by Gulsoy et al. [60], who reported higher sugar content in organic almonds from cvs. Ferragnes and Ferraduel compared to conventional almonds, at 61.5 and 1.6%, respectively. Pérez-Murcia et al. [94] also reported that organic practices produce almonds with higher sugar content. Likewise, in a study with cv. Guara, the organic fertilization treatments showed higher contents of sucrose and glucose than the inorganic control treatment [91].

The results of antioxidant activity (AA) and total phenolic content (TPC) are shown in Table 6. The AA was studied through three methodologies, namely ABTS, DPPH, and FRAP assays. As observed in the DPPH method the organic system increased the antioxidant activity. These results are in agreement with Karaosmanoğlu [95], who showed higher antioxidant activity and higher phenolic content in organic hazelnuts than in conventional ones. The antioxidant activity measured by DPPH method was higher in cv. *Marcona* than *D. largueta*, while the interaction between production system and cultivar showed that, the former only affected the cultivar *D. largueta*. This means that, the production system affects the antioxidant activity depending on the cultivar, because significant differences were observed for *D. largueta*, but not for *Marcona*. The values obtained for cv. *Marcona* using DPPH were quite similar to those obtained by Summo et al. [86] for this cultivar with almonds from two different harvest times (12.7–15.0 µmol Trolox g^{-1}), but not for cv. *D. largueta* (28.8–25.0 µmol Trolox kg^{-1}).

Table 6. The effect of production systems on the antioxidant activity and total phenolic content of rainfed almonds cvs. *D. largueta* and *Marcona*.

	ABTS•+	**DPPH•**	**FRAP**	**TPC (g GAE kg^{-1})**
	(mmol Trolox kg^{-1})			
	ANOVA † Test			
APS	ns	*	ns	*
Cultivar	ns	*	ns	*
APS × cultivar	ns	*	ns	*
	Tukey Multiple Range Test ‡			
APS				
Organic	9.11	13.7 a	8.04	2.51 b
Conventional	8.95	10.8 b	7.82	2.98 a
Cultivar				
D. largueta	9.19	11.7 b	8.52	2.55 b
Marcona	8.86	12.8 a	7.34	2.94 a
APS × cultivar				
Organic × *D. largueta*	9.43	14.8 a	8.26	2.56 b
Conventional × *D. largueta*	8.96	8.68 b	8.78	2.54 b
Organic × *Marcona*	8.95	12.8 ab	6.85	3.41 a
Conventional × *Marcona*	8.78	12.7 ab	7.82	2.46 b

APS = Agricultural Production System; ABTS•+ = (2,2′-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid); DPPH• = (2,2-diphenyl-1-picryl-hydrazyl-hydrate); FRAP = ferric reducing antioxidant power; TPC = Total phenolic content; † ns = not significant at $p > 0.05$; * = significant at $p < 0.05$. ‡ Values (mean of 3 replication) followed by different letter, within the same column and factor, were significantly different ($p < 0.05$), according to Tukey's least significant difference test.

Regarding the total phenolic content (TPC), as can be seen, is totally opposite to the antioxidant activity, in this case, conventional system increased the TPC. This means, that other antioxidant compounds different from phenols could be raised by the organic farming. In the case of cultivar, the same trend was observed that for the antioxidant activity, the cultivar *Marcona* presented a higher TPC compared to *D. largueta*. If we check the interaction between production system and cultivars, we observed that actually the former only affected the cultivar *Marcona*. This means that actually, organic farming positively affects the TPC but this depends on the almond cultivar.

The significant differences between cultivars, agreed with other authors, who stated that the almond polyphenol content depends on the genotype [96,97]. The values obtained in this research were similar to those reported by Bolling [98], 2.61 g GAE kg^{-1} but higher than those reported by Summo et al. [86] in their study about harvest times effect on the TPC. These authors reported that the TPC is influenced by the harvest time, with TPCs ranging between 1.7 and 1.8 g GAE kg^{-1} for cv. *D. largueta* and between 1.0 and 0.3 g GAE kg^{-1} for cv. *Marcona*, for unripe and ripe almonds, respectively.

In general, the values of the AA and the TPC were much higher than those reported by Čolić et al. [85] for cv. *Marcona* in a rainfed study in Serbia at 0.81 mmol TE kg^{-1} (DPPH) and 0.20 mg $GAEg^{-1}$, respectively. This is presumably due to the fact that the almond trees in our study were cultivated under severe water stress and particular edaphoclimatic conditions, which can encourage increases in the polyphenol content and antioxidant activity [90].

In any case, it is necessary to highlight the difficulty of comparing with the existing values of phenolic content and antioxidant activity in the peer-reviewed literature because they are dependent on multiple factors: edaphoclimatics, season, harvest time, determination methodology, etc. [98–100].

Figure 3 shows the effect of rainfed production systems and almond cultivars on the descriptive sensory analysis. Significant differences were found for both production system (Figure 3A) and cultivars (Figure 3B), on eight of the sensory attributes: size, roughness, astringency, nutty, almond ID (the typical flavor of almond), benzaldehyde, woody, and aftertaste. The highest intensities for all these sensory descriptors were observed for the conventional almond with respect to the organic system. Authors working with olfactometry (electronic nose) reported a higher content of aroma-active compounds in organic almonds compared with conventional, for almond orchards with drip irrigation and fertigation [59]. However sensory studies which involve all human senses between organic and conventional almonds are scarce. Regarding the almond cultivar *D. largueta* presented a darker skin color, greater size and roughness, while *Marcona*, was higher in nutty and almond flavor, was woodier and with a larger aftertaste Moreover, these findings agree with the fact that cv. *Marcona* is considered an almond of very high sensory quality that reaches higher prices in the market than other cultivars as stated by Contador et al. [101].

It is well known that the use of agrochemicals and inorganic fertilizers can result in negative impacts on environmental outcomes and pose high degradation risks for soil function, biological diversity and ecosystem services. In contrast, the implementation of organic practices could be motivating the transition towards sustainable, resilient and ecosystem-friendly farming practices. The results of the analysis of the almonds after four years of implementation of the organic system show significant nutritional improvements in terms of almond quality. Thus, the findings referring to a single year must be confirmed by long-term studies to rule out the influence of the sampling year and clearly verify the influence of the production system on the quality of the almonds. Research must continue in this line since management practices that improve soil health and result in obtaining healthy foods must be one of the main objectives to guarantee the sustainability of agroecosystems, particularly in the transformation process from conventional to organic systems.

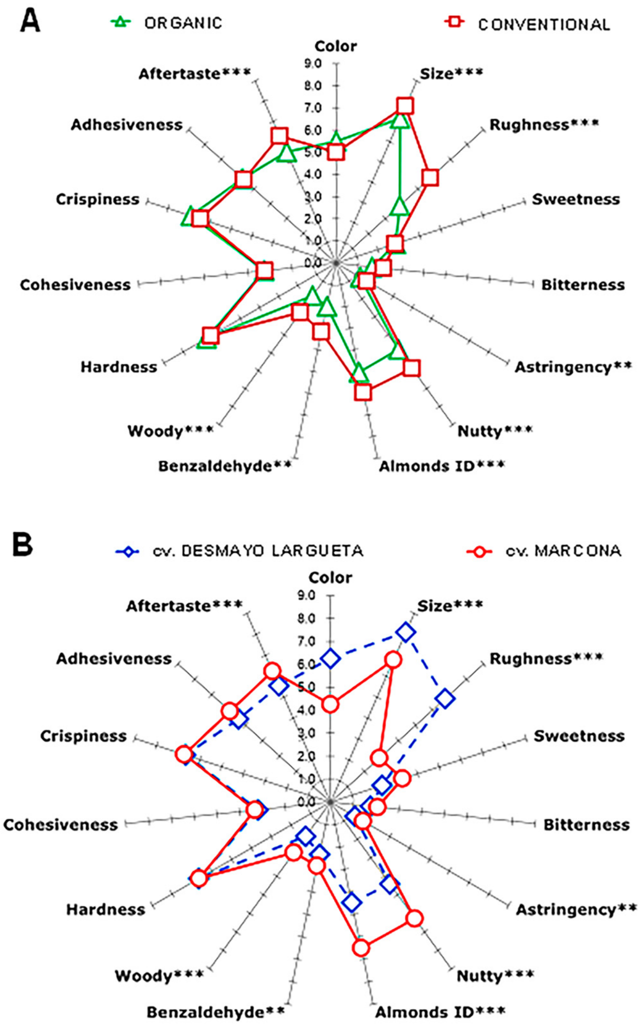

Figure 3. Impact of rainfed production systems (**A**) and almond cultivars (**B**) on the sensory analysis. **, ***, significant at $p < 0.01$, and 0.001, respectively.

4. Conclusions

The findings obtained in the present study suggest that the implementation of the organic production system in rainfed almond trees in marginal areas can improve the quality of the nuts. Specifically, lower moisture content, higher organic acid content, higher sugar content, higher antioxidant activity, higher total phenolic content and higher oleic/linoleic acid ratio were observed in organic almonds than in those from a conventional production system, with these results being dependent on the cultivar. This improvement in the quality of rainfed almonds can offset the losses in productivity recorded from organic production compared to the conventional system, of 9.5% for cv. *D. largueta* and 1.3% for cv. *Marcona*, particularly if we take into consideration the existing need to implement agricultural systems that guarantee the sustainability of agroecosystems.

In addition, it has been shown by numerous studies that the chemical composition of almonds is significantly influenced by numerous elements such as harvest time, environmental, physiological factors, agricultural practices, ripening, genotype and/or alternate-bearing with rotations between relatively light and heavy yields. We conclude that knowing the impact of organic farming practices and their dynamics is a key factor in managing rainfed almond plantations sustainably. Our preliminary findings allow us to identify areas that are at risk, assess the effectiveness of the techniques applied and take steps forward to protect soil health and almond productivity. Also, in these marginal areas of low productivity, organic almond production can be an alternative to protect and/or improve the soil quality and compensate for low production with nuts with a higher price in the market and higher nutritional quality. Therefore, long-term studies are essential to confirm the real potential of organic production on the quality of almonds and to determine the real scope of these improvements independently of the rest of the factors that may affect the quality of these nuts.

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