Research Article

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Effects of regulated deficit irrigation and foliar kaolin application on quality parameters of almond [*Prunus dulcis* (Mill.) D.A. Webb]

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Abstract

Background: Water stress during the growing season of the almond tree is the factor that most limits its yield. Different strategies have been studied in recent years to reduce its negative effects, such as deficit irrigation and the application of reflective spray compounds. A 3-year experiment (2019–2021) was set in a factorial design in which the effect of regulated deficit irrigation and foliar kaolin spray was evaluated on morphological characteristics (weight, length, width, and thickness of the nut and kernel, shell thickness, kernel yield, double kernels, and damaged kernels), color properties, nutritional value (carbohydrates, fat, proteins and ash) and chemical parameters (free sugars and fatty acids profiles).

Results: In general, the significant differences between the treatments did not have a similar trend in the 3 years of the study. Regulated deficit irrigation and kaolin had no detrimental impact on almond morphological and color characteristics. The almond free sugars concentration was relatively stable under deficit irrigation and kaolin application. On the other hand, kaolin application positively affected the synthesis of linoleic acid.

Conclusion: Reducing the amount of irrigation water applied to almonds contributes to the sustainability of production without negatively affecting quality and even improving some quality parameters. In general, the foliar application of kaolin did not show significant differences in the evaluated morphological parameters. However, in terms of chemical composition, kaolin led to an increase in the concentration of linoleic acid and sucrose.

Keywords: water stress; climate change; foliar reflective film; almond quality

INTRODUCTION

The almond tree [*Prunus dulcis* (Mill.) DA Webb] is native to the Middle East and Asia Minor regions and has been cultivated in Mediterranean areas for thousands of years.[1] Almond is one of the crops best adapted to the conditions of the Mediterranean area, with great resistance to drought and low fertility soils. This why it has been cultivated in marginal areas for many years with very low productivity.[2] Water is the most limiting factor in all crops in the Mediterranean area[3] and, currently, the effects of climate change are greatly conditioning agricultural production. Consequently, in Mediterranean areas, there is a substantial increase in average temperatures during the vegetative cycle of crops, as well as more extended periods of drought and more heat wave events each summer.[4,5] Consequently, multiple negative effects are produced in the crops, such as alterations in the phenological stages, an increase in evapotranspiration, productivity reduction, an increase in the incidence of diseases and pests, and a reduction in the quality of products.[6-9]

In recent years, almond cultivation in Portugal and Spain have experienced unprecedented development as a result of the increased demand for nuts worldwide and the corresponding increase in their price.[10] On the other hand, this revolution in almond cultivation has been associated with a constant genetic improvement of cultivars and rootstocks and the development of new cultivation techniques.[11] Within these techniques, we can highlight the implementation of irrigation in almost all new almond orchards.[12]

There are multitudes of scientific research on how the productivity of the almond tree increases with irrigation. In this sense, because the amount of water available for irrigation is a limiting factor in almost all areas of almond cultivation, many studies have been carried out on deficit irrigation to know all its aspects: phenological states more conducive to reducing the irrigation, effects

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on the physiological activity tree, effects on yield, etc.[13-17] Deficit irrigation can be applied continuously throughout the irrigation season [sustained deficit irrigation (SDI)] or at certain times of the almond tree's vegetative cycle [regulated deficit irrigation (RDI)].[18] The RDI is based on the reduction in the volume of water applied in irrigation in the kernel-filling stage. Although a moderate level of water stress occurs in the trees, the reduction in production will be small compared to other more sensitive vegetative states.[13,16,18,19] For this reason, deficit irrigation has been increasingly used because of productivity improvement, compared to rainfed farming, reducing water consumption compared to full irrigation, as well as achieving a more sustainable crop with the environment and with better profitability for the farmer.[20]

On the other hand, another technique beginning to be implemented in Mediterranean crops to reduce water stress effects is the foliar application of reflective compounds.[21] One of the most used products is kaolin. Kaolin ($Al_2Si_2O_5(OH)_4$) is a white mineral that is chemically inert, non-toxic, easily dispersed in water, which creates a protective film on the leaves that protects them from excessive transpiration during summer drought.[22,23] Currently, there are quite a few studies available on the physiological and agronomic response of several crops,[21-24] including almond, to the application of kaolin.[25,26] Still, there are no published studies on the effects that it causes on the nutritional composition and quality of almonds, as well as its interactions with deficit irrigation.

Currently, almonds are a highly valued food by consumers because they have begun to appreciate their health benefits.[27] They are consumed naturally and as part of many processed foods, especially cakes. Almonds are nutritionally characterized by presenting many nutrients, such as fatty acids, lipids, amino acids, proteins, carbohydrates, vitamins and minerals, as well as secondary metabolites.[28,29] They are high in fat, moderate in vegetable protein and have a small amount of carbohydrates.[30] The almond is one of the most important natural sources of antioxidants and is known to possess health-promoting properties.[31] Almonds contain a substantial proportion of monounsaturated and polyunsaturated fatty acids, with oleic acid as the main compound and an important amount of tocopherol and phytosterol content.[32,33] The morphological parameters of the almond are of great importance because consumers often purchase almonds in their natural state, either as nuts or kernels. Therefore, these parameters are important for the valorization of almonds. Some studies have evaluated morphological parameters of almonds, including weight, length, width and thickness of both the nut and kernel, shell thickness, kernel yield, double kernels and damaged kernels.[14,17]

As is the case with wine and other products, production specialization based on the region and/or cultivation conditions could achieve a differentiation of almonds based on their quality and agronomic techniques that serve to reduce negative impacts on the environment. In this way, a better valorization is achieved for almonds produced under certain more sustainable cultivation techniques. Fortunately, consumers increasingly appreciate this type of product, as is the case with organic and biodynamic products. The concept of 'hydroSOStainable' crops was born to use strategies to reduce irrigation water.[34] This concept is already applied to different crops such as almonds, pistachios and olives, etc.[35-37] Some studies demonstrate consumer liking and preference for 'hydroSOS almonds' before that of 'conventional almonds'.[34,38] This can mean added value to this type of product.

The present study aimed to examine the effect of water availability during the filling kernel period until harvest on the physical parameters, in particular, morphological characteristics and color properties, as well as the chemical compounds: moisture, fat, proteins, carbohydrates, ash, free sugars and fatty acids. This evaluation has been carried out over three growing seasons (2019–2021) in the three consecutive years of experiments on the cv. Constantí in the semiarid Mediterranean climate conditions of North Portugal.

This research can contribute to reducing water consumption, increasing the economic return of local producers and the almond sector in disadvantaged rural areas, as well as reducing water consumption for irrigation achieves more sustainable crop production.

MATERIALS AND METHODS

Experimental site and plant material

The present study took place from 2019 to 2021 in an almond orchard from Cooperativa Agrícola de Alfândega da Fé, Crl., in Bragança, Portugal, (41°20′ 37″N; 6°56′32″E; 555 m a. s. l.). The almond was planted in 2014 with the cultivar Constantí [*Prunus dulcis* (Mill.) DA Webb] grafted onto GF 677. Trees were trained in the open vase, and pruning consisted of the three or four first years of form scaffold formation and the following years of pruning maintenance to preserve form and balance on the canopy tree. The almond spacing was 6 × 5 m (333 almond trees ha^{-1}). Drip irrigation used one pipeline with emitters of 3.8 L h^{-1} with a distance of 1 m between them, five emitters per tree. The orchard floor was managed with a natural cover that was mowed once a year in mid-May.

Climatic data were collected automatically from an automatic weather station (CR800; Campbell Scientific, Logan, UT, USA) on the experimental trial. The climatic conditions were measured during the 3 years of the experiment and are reported in Fig. 1. The climate is classified as Mediterranean, according to Köppen classification.[39] Summers are hot and dry, and winters have moderate temperatures and changeable, rainy weather.

Irrigation and kaolin strategies

The treatments with the codes used to designate each of them from here on are presented in Table 1. Two irrigation treatments were applied: one full irrigation treatment (100), which received 100% of the crop evapotranspiration (ET_c) during the all irrigation period, and another in which the irrigation was 100% of the ET_c until the kernel-filling period, where began to irrigation with 35% of ET_c, maintained until the end of the irrigation period. In addition, kaolin was applied in two irrigation treatments, resulting in a total of four treatments (Table 1). Each treatment was repeated in two causal blocks of seven trees for each in different parts of the experimental almond orchard. Thus, in total, 14 trees were evaluated for each treatment during the 3 years of the experiment. The same trees that were selected in the first year were evaluated in the following years. The kaolin was applied to a dose rate of 2 L per tree of aqueous kaolin suspension (4%) (BAS 24000 F, SURROUND® – 95%). The kaolin application was made at the beginning of the kernel-filling phase coinciding with the change to regulated deficit irrigation in the corresponding treatments. Thus, in 2019, the irrigation started on 3 June, kaolin was applied on 8 July and irrigation finished on 26 August. In 2020, the irrigation started on 23 June, kaolin was applied on

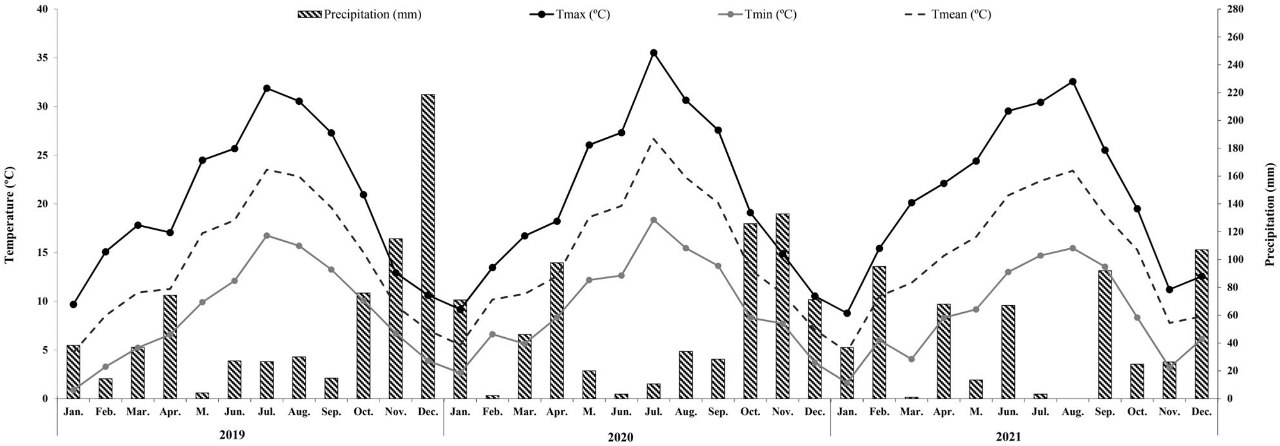

Figure 1. Average monthly maximum (T_{max}), minimum (T_{min}) and mean temperatures (T_{mean}) and accumulated precipitation (Precipitation) recorded during the experimental period from an automatic weather station located in the field.

Table 1. Treatments with abbreviation codes and total water applied in the different experimental years

			Water applied (m^3 ha^{-1})		
Code	Irrigation (% ETc)	Kaolin	2019	2020	2021
FI	100	No	2189.9	2142.2	2458.3
RDI	100/35	No	1287.8	1254.1	1433.6
FI-Kaolin	100	Yes	2189.9	2142.2	2458.3
RDI-Kaolin	100/35	Yes	1287.8	1254.1	1433.6

FI, full irrigation; RDI, regulated deficit irrigation.

20 July and irrigation finished on 3 September. Finally, in 2021 the irrigation started on 7 June, kaolin was applied on 14 July and irrigation finished on 6 September.

The weekly volume of irrigation water to be applied was calculated each week according to the previous week's total ET_c and effective precipitation using the following equation: RDI = $(K \times ET_c - Pe)/Er$, where *Pe* is the effective precipitation, and *Er* is the irrigation efficiency of the irrigation system (0.95). The *K* value represents the fraction of the ET_c for the different irrigation regimes (1.0 for C100 or V100 and 0.35 for C35 or V35). ET_c was estimated using the FAO Penman–Monteith equation for reference evapotranspiration (ET_o) and a crop coefficient (*Kc*) of 0.9 for the mid-season stage.[40] The meteorological data were obtained from an automatic weather station near the almond orchard (Fig. 1).

Almond water status was determined by measuring Predawn Leaf Water Potential (Ψ_{PLWP}) with a pressure chamber (Soil Moisture Equipment Corp., Sta. Barbara, CA, USA), at 3-week intervals from the end of May until the harvest.[41] The measurements were made on a leaf of each tree and six trees per treatment. The leaves were totally mature, without damage and shaded at 1.5 m of height. The Ψ_{PLWP} was measured to determine the start of irrigation and to control the level of water stress in the different treatments.

The harvest time for each experiment year was decided based on the opening of the almond hulls. The harvest of the 14 trees monitored during the 3 years of the study was carried out, and a sample of 1 kg of almonds per tree was taken each year. Almond hulls were separated manually from the rest of the almond fruit, and the fruits were left air-drying at room temperature. After 4 weeks, the outer wooden shells were removed using a nutcracker and 100 g of kernel per treatment was freeze-dried for performing chemical analysis. On the other hand, 500 g of almonds were separated for physical analysis.

Morphological measurements

From each treatment, 100 representative fruits were selected. Nut and kernel length, width, thickness and shell thickness were measured using a digital caliper (Powerfix® Electronic Digital Caliper, Model: Z22855; Paget Trading Ltd, London, UK) and expressed in millimeters. Nut weight and kernel weight were scale-weighed on precision balance (AS 220.R2; RADWAG, Kraków, Poland) with a reading accuracy of 0.0001 and expressed in grams. The kernel yield was calculated using: kernel yield (%) = kernel mass (g)/nut weight × 100. Also, double kernels and damaged kernels were registered and expressed as a percentage (%).

Instrumental color

External and inside kernel color determinations were made using a colorimeter (CR-400; Minolta, Osaka, Japan) in the 50 representative kernels for each treatment. CIELAB scale was used, namely: L^*, a^* and b^* coordinates, where L^* varies between 0 (black) and 100 (white), the chromatic a^* axis extends from green (a^*) to red ($+a^*$) and the chromatic b^* axis extends from blue ($-b^*$) to yellow ($+b^*$). Furthermore, the chroma (C^*) was also determined.

Nutritional value

The proximate composition (moisture, ash, fat, proteins and carbohydrates) was determined in the freeze-dried samples in accordance with the AOAC methods.[42] The crude protein was determined by the macro-Kjeldahl method ($N \times 5.18$) using an automatic distillation and titration unit (model Pro-Nitro-A; Selecta, Barcelona, Spain); crude fat was determined using a Soxhlet apparatus by extracting a known weight of powdered sample with petroleum ether, and the ash content was evaluated by incineration at 550 ± 15 °C. Total carbohydrates content was calculated by difference, and the energetic value was calculated according to the Decree-Law No. 167/2004 using: energy [kcal/100 g of dried weight (DW)] = $4 \times (g_{protein} + g_{carbohydrates}) + 9 \times (g_{fat})$.

Chemical composition

Free sugars

The free sugars composition was determined by HPLC coupled to a refraction index detector using the internal standard (IS) (melezitose; Sigma-Aldrich, St Louis, MO, USA) method, as defined previously by Spréa *et al.*[43] The identification was performed by comparing the retention times of the authentic standards with those of the samples, whereas quantification was achieved by the IS method, with calibration curves built up with the standards. The results were reported as g per 100 g of DW.

Fatty acids

The fatty acid methyl esters (FAME) profile was achieved after trans-esterification of the lipid fraction attained by Soxhlet extraction,[43] followed by gas–liquid chromatography with flame ionization detection, using a 6500 GC System apparatus (YOUNG IN Chromass, Anyang, South Korea) equipped with a split/splitless injector, a flame ionization detector and a Zebron-FAME column. Identification and quantification were completed by associating the relative retention times of the FAME peaks of the samples with those of the standard (47885-U; Sigma-Aldrich, St. Louis, MO, USA). The Clarity Data Apex 4.0 Software (Prague, Czech Republic) was utilized for data handing. The results were expressed in relative percentage (%) of each detected fatty acid.

Statistical analysis

The statistical analysis was carried out using Statgraphics Centurion version XVI (StatPoint Technologies INC., Warrenton, VA, USA). Data were evaluated by a two-way analysis of variance (ANOVA) and significant interactions of the tested factors (water regime and kaolin treatment) were observed. Therefore, all the means for each treatment were compared separately using Tukey's honestly significant difference test ($P = 0.05$).

Principal component analysis (PCA) was applied to reduce the number of variables in the four treatments to a smaller number of new derived variables [principal component (PC) or factors] that adequately summarize the original information, comprising the effect of regulated deficit irrigation and foliar kaolin application on the main morphological characteristic, nutritional value and free sugars. These were combined with all treatments using SPSS, version 21.0 (IBM Corp, Armonk, NY, USA).

RESULTS AND DISCUSSION

Water status

In the Trás-os-Montes region (Northeastern Portugal), rainfall and the soil water reserve guarantee, in most years, the almond water requirements until the end of May and the beginning of June.[44] With the onset of the summer season, as shown in Fig. 1, the temperature increases and there is a severe reduction in rainfall. From then on, there is a water deficit, and it is necessary to start irrigating the almond trees. The irrigation allocations for the 3 years of the experiment are expressed in Table 1. The almond tree has early budding and, in the region where the field experiment was implemented, the vegetative cycle is established from 1 March to 30 October. During this period, in 2019, temperatures ranged from 5.3 to 31.9 °C; in 2020 from 5.6 to 35.5 °C, and in 2021 from 4.1 to 32.6 °C. The total precipitation recorded in the 3 years of the experiment were 676.4 mm in 2019; 643 mm in 2020 and 534.6 mm in 2021.

Throughout the growing seasons, measurements of predawn leaf water potential were made to determine the start of irrigation and assess the almond tree water stress level under different treatments. As shown in Figure 2, the treatments with sustained deficit irrigation had more negative values in the three measurements corresponding to each year of the experiment, being significant in the years 2020 and 2021. Kaolin did not significantly affect the water potential of the different treatments. Thus, the base water potential values for the FI treatment varied between −0.68 and − 0.90 MPa and for the SDI treatment between −0.96 and − 1.08 MPa.

Morphological characteristics

Table 2 presents the main results related to the effects of irrigation doses and foliar kaolin application on the morphological properties of raw almonds (nut and kernel). Some of these parameters are very important to determine the almond quality. Worldwide, there are different standards for the almond processing industries depending on the different markets. In the USA, the Agricultural Marketing Service of the US Department of Agriculture has established quality standards for grades of nuts, both in the shell and shelled. In Europe, the Spanish industries are the most important and have established quality standards for almonds.[45]

The main morphological parameters are registered in Table 2 for the cv. Constantí agree with the data found in the literature. Thus, the nut weight throughout the 3 years of the study varied between 4.5 and 5.4 g, which is in agreement with the data collected in work on varietal characterization prepared by Vargas *et al.*,[46] who recorded an average value of 4.5 g for the whole almond. Regarding the kernel weight, we found values between 1.1 and 1.3 g; for this parameter, and Vargas *et al.*[46] recorded a mean value of 1.2 g. In addition, Lipan *et al.*,[47] in a study on the characterization of different cultivars, found a mean value of 1.36 g. One of the most critical morphological parameters for almond quality is the weight of the kernel, which should exceed or be above 1 g.[45] In the present study, this threshold was consistently exceeded over the course of the three experimental years.

In general, the regulated deficit irrigation and foliar kaolin application promoted significant differences in morphological parameters but with different trends for each year of the study. In 2020, only one parameter, kernel length, presented significant differences. In this case, the RDI treatment showed the lowest value, 20.1 mm, and the RDI-kaolin treatment, the highest, 22.6 mm. These significant differences were a result of deficit irrigation, foliar kaolin application and their interaction.

In the other 2 years, 2019 and 2021, the results had greater variability and presented some parameters with significant differences. In 2019, significant differences were observed in the weight, width and thickness of nut parameters. The nut weight presented values that vary from 4.5 g for the RDI treatment to 4.7 g for the FI-kaolin treatment with significant differences

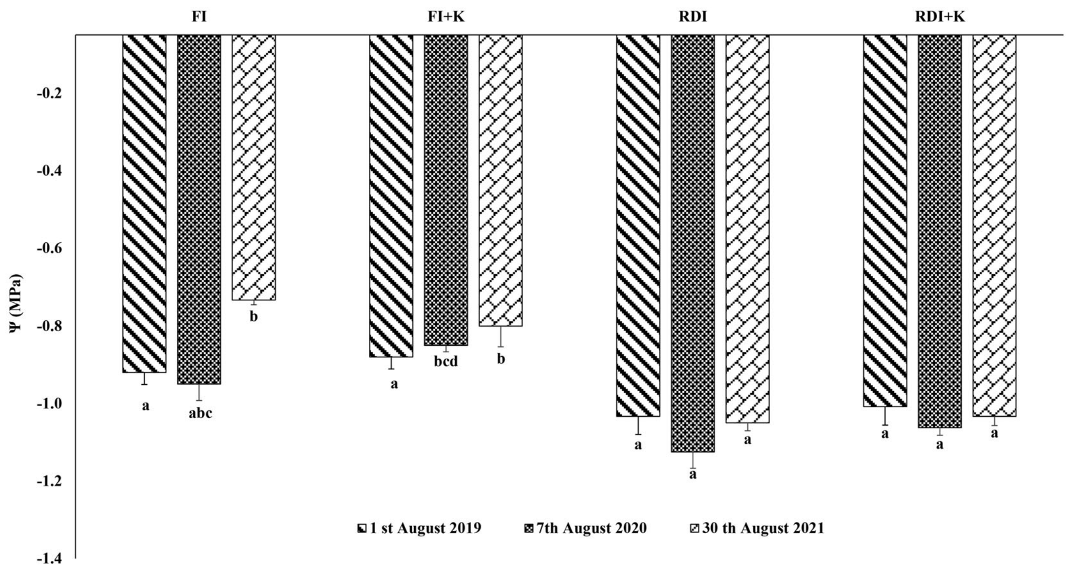

Figure 2. Predawn leaf water potential (Ψ_{PLWP}) measured in August of each experiment year. For the same date, different letters differ significantly ($P \leq 0.05$).

($P \leq 0.05$) as a result of the two factors, irrigation and foliar treatment with kaolin. Thus, a trend that we can deduce is that the kaolin slightly improved the weight of the almonds. Gharaghani *et al*.,[24] in a study in which they applied kaolin in different percentages on Persian walnut trees, found that kaolin significantly increased nut weight. This could be a result of improved canopy photosynthesis.[23] Some studies confirm that kaolin application alters light distribution within the canopy.[26] The foliar application of kaolin causes a reduction in photosynthesis of the leaves fully exposed to radiation by reflection. At the same time, this light is transmitted to the innermost leaves of the canopy, increasing incident radiation, especially on inner-canopy leaves of trees.[26] Other causes of the increase in photosynthesis in almond trees are the decrease in leaf temperature, thus reducing water loss through transpiration and sunburn.[23,24] In general, during the year 2021, the FI-kaolin treatment stood out by showing significantly higher values in nut weight, nut width, nut thickness, and kernel weight compared to the other treatments with the same irrigation dose (FI), as explained earlier. Additionally, the increased water availability contributed to improved values in treatments with regulated deficit irrigation.

The kernel yield exhibited different trends over the 3 years of the study. Significant differences in kernel yield were observed in 2019, indicating that deficit irrigation had a positive impact on this parameter. The lowest values were found in the treatments with full irrigation (25.5% for both treatments), while the highest values were recorded in the treatments with deficit irrigation (26.3% for RDI and 26.4% for RDI-kaolin). In 2020, no significant differences were observed for this parameter. However, in the third consecutive year of the experiment (2021), a slight decrease in performance was observed. It should be noted that none of the RDI treatments showed a significant reduction in kernel weight over the 3 years. This finding supports the conclusions of other studies,[49,50] which indicate that RDI in almond trees reduces water consumption without adversely kernel yield.

Color

The effects of regulated deficit irrigation and foliar kaolin application on color parameters (L^*, a^*, b^*, C and HUE) outside and inside the kernel are shown in Table 3. Kernel color is an important aspect since it influences the moment of purchase by consumers of the raw whole kernel with skin, sliced, or laminated. For this reason, the color parameters of two almond parts were measured in the present study, outside and inside. Regarding the interior color, only the L^* parameter in 2020 presented significant differences in the interaction between the kaolin and the irrigation. Thus, the lowest value was for the RDI almonds (85.9) and the highest for the FI treatment (86.9). This means that the inside FI almonds became brighter and lighter than the RDI almonds. Some studies evaluated the effect of deficit irrigation on color but only made measurements of the outside of the kernel.[48-51]

There was greater significance between the treatments concerning the kernel's outer color. Thus, the L^* parameter went from 42.0 (RDI-kaolin, 2021) to 44.1 (RDI-kaolin, 2020). In work on the characterization of Mediterranean cultivars carried out by Lipan *et al*.,[47] mean values of 36.9 were found for this same parameter, L^*, in the same cultivar as that in the present study, Constantí. This parameter, L^*, only presented significant differences in 2019, showing that kaolin was the only significant factor. García-Tejero *et al*.,[51] in a study with different cultivars and different SDI treatments, reported that the L^* parameter increased its value in treatments with this type of irrigation compared to a full irrigation control treatment. In our case, we could highlight that the two treatments with kaolin presented the lowest values (42.1 and 42.3, respectively, for RDI-kaolin and FI-kaolin), which indicates that these almonds were lighter. The a^* color coordinate gives information about whether a sample is redder when positive values are obtained or greener for the negative ones. The parameter a^* showed a trend similar to L^*, indicating that the almonds with kaolin were also redder. Finally, in 2019, the parameters b^* and C had a similar trend, highlighting the RDI kaolin treatment with the lowest values, which indicates that these almonds had less yellowness and chroma. In 2020, the only parameters that presented significant differences were a^* and C. In the case of chroma (C), it was observed that the RDI-kaolin treatment had the highest value. Finally, in 2021, the parameters b^*, C and HUE showed significant differences. The three parameters presented the same trend: the RDI-kaolin treatment presented the lowest

Table 2. Morphological parameters by different deficit irrigation and kaolin application treatment in kernel and nut

		Nut				Kernel							
Year	Treatment	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	Shell thickness (mm)	Kernel yield	Double kernels (%)	Damaged kernels (%)
2019	FI	4.6 ± 0.5 ab	32.0 ± 1.5	22.5 ± 1.0 ab	16.2 ± 0.8 a	1.2 ± 0.1	23.0 ± 1.2	13.8 ± 0.6	8.3 ± 0.5 ab	3.3 ± 0.4	25.5 ± 1.3 a	1	0
	FI kaolin	4.7 ± 0.6 b	32.1 ± 1.7	22.8 ± 1.5 b	16.2 ± 0.8 a	1.2 ± 0.1	23.1 ± 1.3	13.8 ± 0.8	8.4 ± 0.4 ab	3.3 ± 0.5	25.5 ± 1.8 a	1	1
	RDI	4.5 ± 0.6 a	31.8 ± 1.7	22.5 ± 1.5 ab	16.4 ± 0.8 b	1.2 ± 0.1	22.8 ± 1.2	13.6 ± 0.8	8.2 ± 0.5 a	3.4 ± 0.5	26.3 ± 1.6 b	1	1
	RDI kaolin	4.6 ± 0.5 ab	32.0 ± 1.4	22.3 ± 1.1 a	16.4 ± 0.9 b	1.2 ± 0.1	22.9 ± 1.0	13.6 ± 1.0	8.4 ± 0.4 b	3.4 ± 0.5	26.4 ± 1.4 b	1	0
ANOVA *P*-value		0.0130	0.6369	0.0458	0.0229	0.0552	0.2309	0.0672	0.0260	0.1858	0.0000	–	–
Two-way ANOVA													
Irrigation (I)		0.0335	0.5433	0.0399	0.0021	0.3210	0.0660	0.0699	0.7852	0.0824	0.0000	–	–
Kaolin (K)		0.0177	0.2519	0.7256	0.886	0.0687	0.3731	0.7450	0.0142	0.5313	0.9347	–	–
I × K		0.4079	0.9029	0.0903	0.9641	0.688	0.7258	0.5395	0.0737	0.2350	0.6742	–	–
2020	FI	5.3 ± 0.9	32.7 ± 2.0	24.4 ± 2.0	17.7 ± 1.0	1.2 ± 0.2	22.5 ± 1.3 b	14.6 ± 1.0	8.1 ± 1.0	3.8 ± 0.4	23.4 ± 2.7	4	2
	FI kaolin	5.3 ± 0.7	32.2 ± 3.4	24.5 ± 1.5	17.7 ± 0.9	1.3 ± 0.1	22.7 ± 1.0 b	14.7 ± 1.0	8.2 ± 0.6	3.8 ± 0.5	23.6 ± 2.3	0	2
	RDI	5.4 ± 0.7	32.3 ± 1.9	24.7 ± 1.3	17.9 ± 0.9	1.2 ± 0.2	20.1 ± 3.7 a	14.9 ± 0.9	8.0 ± 0.6	3.8 ± 0.5	22.8 ± 3.2	2	3
	RDI kaolin	5.3 ± 0.7	32.6 ± 1.8	24.4 ± 1.2	17.9 ± 0.8	1.2 ± 0.2	22.6 ± 1.2 b	14.8 ± 0.7	8.1 ± 0.6	3.9 ± 0.4	23.1 ± 2.6	1	2
ANOVA *P*-value		0.6401	0.3446	0.4788	0.1437	0.8272	0.0000	0.1236	0.3792	0.6182	0.1314	–	–
Two-way ANOVA													
Irrigation (I)		0.6146	0.9731	0.3479	0.0225	0.4381	0.0000	0.0215	0.1940	0.4629	0.0393	–	–
Kaolin (K)		0.5999	0.9250	0.5944	0.8811	0.7867	0.0000	0.9765	0.2731	0.9059	0.2529	–	–
I × K		0.2826	0.0691	0.2516	0.6728	0.6418	0.0000	0.4725	0.6887	0.2676	0.7904	–	–
2021	FI	4.8 ± 0.6 a	31.6 ± 1.6	23.1 ± 1.2 a	16.9 ± 0.8 a	1.1 ± 0.1 ab	21.5 ± 1.0 b	14.3 ± 0.8	8.0 ± 0.6 b	3.8 ± 0.4 a	24.1 ± 1.7 b	1	0
	FI kaolin	5.0 ± 0.6 b	31.8 ± 1.6	23.7 ± 1.3 b	17.2 ± 0.9 b	1.2 ± 0.2 b	21.6 ± 0.8 b	14.6 ± 0.9	8.1 ± 0.5 b	3.9 ± 0.4 a	23.9 ± 3.3 ab	3	0
	RDI	4.8 ± 0.6 a	31.4 ± 1.7	23.3 ± 1.2 ab	16.8 ± 0.8 a	1.1 ± 0.2 a	21.0 ± 1.1 a	14.4 ± 0.8	7.8 ± 0.6 b	3.9 ± 0.4 a	23.2 ± 2.2 a	1	0
	RDI kaolin	4.7 ± 0.6 a	32.3 ± 6.3	23.4 ± 1.3 ab	16.7 ± 0.9 a	1.1 ± 0.1 a	21.3 ± 0.9 ab	14.3 ± 0.9	7.0 ± 1.7 a	4.5 ± 1.7 b	24.0 ± 2.0 ab	1	0
ANOVA *P*-value		0.0020	0.2738	0.0121	0.0006	0.0002	0.0001	0.1154	0.0000	0.0000	0.0291	–	–
Two-way ANOVA													
Irrigation (I)		0.0662	0.7482	0.7696	0.0013	0.0002	0.0000	0.2152	0.0000	0.0001	0.0462	–	–
Kaolin (K)		0.0173	0.1055	0.0147	0.2044	0.0232	0.0150	0.4063	0.0002	0.0000	0.1325	–	–
I × K		0.0226	0.2808	0.0262	0.0179	0.3288	0.6384	0.0526	0.0000	0.0028	0.0497	–	–

Each value is expressed as the mean ± SD ($n = 100$). Different lowercase letters differ significantly ($p \le 0.05$) in the same column for all treatments studied.

Table 3. Color parameters by different deficit irrigation and kaolin application treatments in the kernel and inside the kernel

Treatment		Kernel					Inside the kernel				
		*L**	*a**	*b**	*C*	Hue	*L**	*a**	*b**	*C*	Hue
2019	FI	42.8 ± 2.4 ab	15.7 ± 0.9 ab	27.5 ± 2.9 bc	31.9 ± 2.8 bc	60.1 ± 1.8	84.0 ± 2.7	−0.2 ± 0.8	14.5 ± 2.2	14.5 ± 2.3	90.6 ± 3.4
	FI kaolin	42.3 ± 2.2 a	15.2 ± 1.2 a	26.8 ± 2.9 ab	30.9 ± 2.9 ab	60.3 ± 1.5	84.6 ± 2.1	−0.3 ± 0.8	14.0 ± 1.2	14.0 ± 1.2	90.9 ± 3.0
	RDI	43.7 ± 2.4 b	16.0 ± 1.1 b	28.8 ± 3.7 cd	33.2 ± 3.8 cd	60.2 ± 4.1	84.5 ± 3.2	−0.3 ± 0.9	14.3 ± 2.3	14.3 ± 2.3	91.3 ± 3.3
	RDI kaolin	42.1 ± 1.9 a	15.3 ± 1.1 a	25.6 ± 2.5 a	29.7 ± 2.7 a	59.2 ± 1.6	84.8 ± 2.3	−0.3 ± 0.7	13.9 ± 1.6	13.9 ± 1.6	91.2 ± 3.0
ANOVA *P*-value		0.0019	0.0021	0.0000	0.0000	0.0833	0.5639	0.8394	0.4455	0.4091	0.6790
Two-way ANOVA											
Irrigation (I)		0.2293	0.3460	0.8126	0.8681	0.1108	0.3778	0.5857	0.6024	0.5432	0.3764
Kaolin (K)		0.0009	0.0002	0.0000	0.0000	0.2478	0.2971	0.9970	0.1251	0.1159	0.6645
I × K		0.1127	0.5528	0.0040	0.0051	0.0948	0.7042	0.4655	0.9866	0.9259	0.4722
2020	FI	43.7 ± 2.1	17.4 ± 1.3 a	32.7 ± 2.8	37.0 ± 3.0 a	61.7 ± 1.7	86.9 ± 1.6 b	−0.6 ± 0.8	16.9 ± 3.5	16.9 ± 3.5	92.0 ± 2.5
	FI kaolin	42.0 ± 2.4	17.4 ± 1.1 a	33.6 ± 2.8	37.8 ± 2.9 ab	61.9 ± 4.5	86.1 ± 1.8 ab	−0.4 ± 0.7	16.5 ± 2.8	16.5 ± 2.9	91.2 ± 2.6
	RDI	43.0 ± 2.6	17.5 ± 1.1 ab	32.7 ± 2.9	37.1 ± 2.9 a	61.7 ± 2.0	85.9 ± 1.7 a	−0.5 ± 0.8	17.0 ± 2.7	17.0 ± 2.7	91.4 ± 2.5
	RDI kaolin	44.1 ± 2.4	18.0 ± 1.1 b	33.9 ± 3.1	38.7 ± 2.6 b	62.3 ± 1.7	86.4 ± 1.6 ab	−0.7 ± 0.8	17.5 ± 3.3	17.6 ± 3.3	92.0 ± 2.3
ANOVA *P*-value		0.0941	0.0116	0.0724	0.0128	0.7427	0.0236	0.2465	0.4212	0.3635	0.2713
Two-way ANOVA											
Irrigation (I)		0.5153	0.0282	0.6178	0.2487	0.6868	0.1151	0.7959	0.1931	0.1871	0.7112
Kaolin (K)		0.1365	0.0704	0.4103	0.0034	0.3434	0.4987	0.9234	0.9224	0.8314	0.8783
I × K		0.2042	0.0796	0.7278	0.3337	0.6729	0.0103	0.0443	0.2930	0.2368	0.0533
2021	FI	42.5 ± 2.2	17.5 ± 1.5	26.9 ± 2.7 b	32.1 ± 2.6 b	57.5 ± 3.7 b	85.1 ± 1.8	−0.4 ± 0.6	14.5 ± 1.4	14.6 ± 1.4	84.0 ± 2.5
	FI kaolin	43.0 ± 1.8	17.5 ± 1.0	27.5 ± 2.5 b	32.6 ± 2.5 b	57.4 ± 1.7 b	85.9 ± 1.7	−0.1 ± 0.4	14.9 ± 1.0	14.9 ± 1.0	84.6 ± 2.4
	RDI	42.6 ± 2.3	17.5 ± 1.0	26.4 ± 2.9 ab	31.6 ± 2.8 ab	56.4 ± 2.6 ab	84.7 ± 2.3	−0.4 ± 0.6	14.5 ± 1.3	14.6 ± 1.3	84.1 ± 1.4
	RDI kaolin	42.0 ± 1.8	17.3 ± 0.9	25.2 ± 2.5 a	30.7 ± 2.4 a	55.6 ± 2.9 a	85.5 ± 1.3	−0.2 ± 0.4	14.4 ± 1.1	14.5 ± 1.2	85.0 ± 2.3
ANOVA p-value		0.1295	0.7355	0.0003	0.0020	0.0016	0.0843	0.1511	0.2737	0.3409	0.1663
Two-way ANOVA											
Irrigation (I)		0.1413	0.5565	0.0003	0.0010	0.0003	0.2715	0.4618	0.2050	0.2629	0.5516
Kaolin (K)		0.8492	0.4203	0.3711	0.5016	0.2350	0.0198	0.0340	0.4165	0.4210	0.0342
I × K		0.0626	0.6007	0.0200	0.0580	0.4236	0.9623	0.6131	0.2021	0.2287	0.6344

Values are expressed as the mean ± SD. Different lowercase letters differ significantly ($P < 0.05$) in the same column for all treatments studied.

Table 4. Nutritional (g/100 g DW) and energetic values (kcal/100 g DW) of the studied almond samples in relation to deficit irrigation and kaolin application

Year	Treatment	Fat	Proteins	Ash	Carbohydrates	Energy
2019	FI	51.8 ± 1.0 c	18.4 ± 0.1	2.9 ± 0.1	26.9 ± 1.2 a	647.1 ± 5.1 b
	FI kaolin	49.1 ± 0.6 b	19.6 ± 0 0.7	3.2 ± 0.3	28.1 ± 0.7 a	632.8 ± 3.7 a
	RDI	47.0 ± 1.0 a	18.6 ± 0.6	3.1 ± 0.4	31.6 ± 1.5 b	621.2 ± 4.0 a
	RDI kaolin	52.1 ± 0.9 c	19.0 ± 0.7	3.3 ± 0.2	25.6 ± 1.1 a	647.1 ± 4.9 b
ANOVA *P*-value		0.0002	0.1006	0.4232	0.0012	0.0003
Two-way ANOVA						
Irrigation (I)		0.0735	0.5588	0.3851	0.1358	0.0557
Kaolin (K)		0.0304	0.0607	0.1696	0.0070	0.0564
I × K		0.0001	0.2535	0.8988	0.0007	0.0001
2020	FI	43.1 ± 0.8 a	18.2 ± 0.2 ab	2.9 ± 0.5	35.7 ± 0.9 b	603.9 ± 5.5 a
	FI kaolin	50.2 ± 0.7 b	18.5 ± 0.3 ab	2.3 ± 0.2	29.0 ± 1.0 a	641.5 ± 3.9 b
	RDI	48.7 ± 0.9 b	18.6 ± 0.4 b	2.8 ± 0.1	29.8 ± 1.2 a	632.1 ± 5.0 b
	RDI kaolin	48.7 ± 0.8 b	17.5 ± 0.6 a	2.8 ± 0.2	31.0 ± 0.5 a	632.7 ± 3.3 b
ANOVA *P*-value		0.0000	0.0412	0.1892	0.0001	0.0000
Two-way ANOVA						
Irrigation (I)		0.0021	0.2843	0.4226	0.0073	0.0059
Kaolin (K)		0.0001	0.0855	0.1060	0.0009	0.0001
I × K		0.0001	0.0216	0.1913	0.0001	0.0001
2021	FI	43.0 ± 0.2	20.8 ± 0.3 b	3.0 ± 0.1 b	33.2 ± 0.5 ab	603.0 ± 1.6
	FI kaolin	43.6 ± 1.0	20.6 ± 0.1 b	3.0 ± 0.1 b	32.9 ± 0.9 a	606.3 ± 5.1
	RDI	43.2 ± 0.5	18.2 ± 0.5 a	2.9 ± 0.1 ab	35.7 ± 0.5 bc	604.5 ± 2.6
	RDI kaolin	41.9 ± 1.0	18.9 ± 0.7 a	2.4 ± 0.4 a	36.8 ± 1.6 c	600.1 ± 4.6
ANOVA *P*-value		0.0955	0.0004	0.0143	0.0030	0.2957
Two-way ANOVA						
Irrigation (I)		0.1070	0.0001	0.0131	0.0005	0.3064
Kaolin (K)		0.4564	0.4325	0.0387	0.5232	0.8184
I × K		0.0544	0.1408	0.0844	0.2345	0.1143

Results are presented as the mean ± SD ($n = 9$). In each column, different letters indicate significant differences ($P < 0.05$) between samples.

values compared to the rest. Lipan *et al.*,[48] in a study with three different cultivars (Marta, Guara and Lauranne), found no significant differences between treatments with full irrigation and deficit regulated irrigation with an endowment of 65% of the ET_c.

Nutritional value

The nutritional compositions of different treatments with regulated deficit irrigation and foliar kaolin application are detailed in Table 4. As is well known,[30] the main almond composed is fat, which, in our case, is around 46% on a fresh weight basis. In a characterization study of almond cultivars carried out by Lipan *et al.*,[47] a mean value of 51.9% fat was found in almonds of the Constantí cultivar. The lipid content of almonds presented significant differences for the first 2 years of the study (2019 and 2020) but without a perceptible trend. Thus, in 2019, the kaolin and the irrigation-kaolin interaction influenced the fat content. The full irrigation (FI) and regulated deficit irrigation with kaolin (RDI-kaolin) treatments presented the highest concentrations, 52.0 g 100 g^{-1} DW and 52.1 g 100 g^{-1} DW, respectively. The lowest amount appeared in the treatment with RDI, with 47 g 100 g^{-1} DW.

Regarding the year 2020, there was a different trend, and the treatment with FI presented the lowest value than the rest, not presenting significant differences between the other treatments. In this year, the two factors, irrigation and kaolin, and the interaction between them were statistically significant. In 2021, there were no differences between treatments. Some studies with deficit irrigation (regulated and sustained) found that the oil content of the kernel was not influenced by irrigation.[52-55]

Regarding the protein content, the content varied between 17.5 g 100 g^{-1} DW and 20.8 g 100 g^{-1} DW. Lipan *et al.*[47] reported values of 31.3% for the same cultivar as in the present study, Constantí. The protein content presented significant differences in the last 2 years of the study. For the year 2020, we did not find a clear explanation regarding the trend presented. By contrast, in 2021, it was observed that irrigation positively influenced the protein content, regardless of the application of kaolin. These results are in contrast to that exposed by Egea *et al.*,[56] who found no influence between full irrigation and RDI treatments for protein content. Regarding the ash content, the values were from 2.3 g 100 g^{-1} DW to 3.3 g 100 g^{-1} DW. Lipan *et al.*[47]; for the same cultivar as that of the present study, found average values of 3.6%, and Romero *et al.*[57] found values of 3.24%. Only in 2021 were significant differences observed between treatments for regulated deficit irrigation and kaolin irrigation. The lowest value was observed in the RDI kaolin treatment (2.4 g 100 g^{-1} DW). We could suggest that the combination of deficit and kaolin irrigation caused a decrease in the ash content in this treatment.

Carbohydrates presented significant differences in all years of the experiment but with different trends, which is quite puzzling to explain their causes. For example, in 2020, the FI treatment presented the highest concentration of carbohydrates (35.7 g 100 g^{-1} DW); however, the following year, 2021, was one

Table 5. Free sugars content (g/100 g DW) of the studied almond samples in relation to regulated deficit irrigation and foliar kaolin application

Year	Treatment	Fructose	Glucose	Sucrose	Trehalose	Total
2019	FI	0.52 ± 0.05 a	0.56 ± 0.04 a	26.49 ± 0.02 b	0.30 ± 0.05 a	27.86 ± 0.15 b
	FI kaolin	0.69 ± 0.07 c	0.59 ± 0.09 a	28.93 ± 0.09 d	0.55 ± 0.06 b	30.76 ± 0.31 d
	RDI	1.48 ± 0.07 b	3.72 ± 0.03 c	19.96 ± 0.07 a	0.50 ± 0.02 b	25.66 ± 0.01 a
	RDI kaolin	0.66 ± 0.05 ab	0.96 ± 0.07 b	26.95 ± 0.08 c	0.45 ± 0.09 ab	29.01 ± 0.14 c
ANOVA *P*-value		0.0000	0.0000	0.0000	0.0000	0.0000
Two-way ANOVA						
Irrigation (I)		0.0000	0.0000	0.0000	0.2009	0.0000
Kaolin (K)		0.0000	0.0000	0.0000	0.0220	0.0000
I × K		0.0000	0.0000	0.0000	0.0024	0.0695
2020	FI	0.40 ± 0.06 a	0.77 ± 0.01 a	22.07 ± 0.09 a	0.51 ± 0.05 a	23.76 ± 0.16 a
	FI kaolin	0.38 ± 0.04 a	0.93 ± 0.04 b	29.43 ± 0.08 b	0.72 ± 0.02 b	31.46 ± 0.04 b
	RDI	0.58 ± 0.01 b	0.93 ± 0.07 b	32.56 ± 0.09 d	1.02 ± 0.05 c	35.08 ± 0.22 d
	RDI kaolin	0.47 ± 0.07 ab	1.01 ± 0.07 b	31.57 ± 0.18 c	0.81 ± 0.04 b	33.86 ± 0.17 c
ANOVA *P*-value		0.0064	0.0054	0.0000	0.0000	0.0000
Two-way ANOVA						
Irrigation (I)		0.0023	0.0077	0.0000	0.0000	0.0000
Kaolin (K)		0.0493	0.0057	0.0000	0.8946	0.0000
I × K		0.2223	0.2474	0.0000	0.0000	0.0000
2021	FI	0.35 ± 0.07 a	0.80 ± 0.00 b	25.18 ± 0.03 a	0.45 ± 0.04 a	26.79 ± 0.01 a
	FI kaolin	0.40 ± 0.05 a	0.67 ± 0.05 a	26.94 ± 0.09 b	0.55 ± 0.08 a	28.57 ± 0.16 b
	RDI	0.50 ± 0.07 ab	0.97 ± 0.08 c	33.93 ± 0.07 c	0.97 ± 0.07 c	36.37 ± 0.11 c
	RDI kaolin	0.58 ± 0.05 b	0.84 ± 0.02 bc	35.01 ± 0.08 d	0.76 ± 0.05 b	37.19 ± 0.20 d
ANOVA *P*-value		0.0069	0.0006	0.0000	0.0000	0.0000
Two-way ANOVA						
Irrigation (I)		0.0016	0.0004	0.0000	0.0000	0.0000
Kaolin (K)		0.0796	0.0020	0.0000	0.1753	0.0000
I × K		0.6711	0.8714	0.0000	0.0024	0.0003

Results are presented as the mean ± SD ($n = 9$). In each column, different letters indicate significant differences ($P < 0.05$) between samples.

of the treatments with the lowest amount (33.2 g 100 g^{-1} DW) compared to the rest. According to some previous studies, irrigation type did not influence almond carbohydrate content.[49,52,56] Regarding the effects of kaolin, we have not found studies that evaluate its relationship with the accumulation of carbohydrates. However, a very close parameter, such as the concentration of total soluble solids (TSS), was investigated in tomatoes, presenting different results, Boari *et al.*[58] reported that kaolin increased the concentration of TSS, whereas Djurovića *et al.*[59] did not find any effect with the foliar application of kaolin. Brito *et al.*[23] reported that, in olive trees, kaolin improved the accumulation of carbohydrates in the stems, although they did not study this effect in the fruits.

Finally, the total energy content varied from 600 kcal/100 g DW to 647 kcal/100 g DW, presenting significant differences only in the first 2 years of the experiment. In 2020, both deficit and kaolin irrigation decreased the energy value of almonds. In 2019, the trend was different and it needs to be clarified to understand these differences.

Chemical composition

The free sugars composition of almond samples is shown in Table 5. Four free sugars were identified; namely, fructose, glucose, sucrose and trehalose. These sugars have already been identified in other studies.[33,35] As for other studies on the chemical composition of the almond, sucrose is the main sugar, representing 85–90% of the total, and the remaining 10–15% is made up of different monosaccharides such as glucose, fructose, sorbitol, rafinose, trehalose and inositol.[33,55,60] Therefore, in the present study, sucrose was the major sugar in all almond samples (19.96–35.01 g 100 g^{-1} DW), showing significant differences for all treatments in the 3 years of the study.

Thus, the 2019 results were influenced by irrigation and kaolin application. The highest value (28.93 g^{-1} DW) was presented in the FI kaolin treatment, followed by the RDI kaolin treatment (26.95 g^{-1} DW), which suggests that kaolin had a positive influence on sucrose synthesis. However, the trend of sucrose results for the next 2 years of the experiment, 2020 and 2021, was different. In both years, sucrose showed significant differences for both the irrigated and kaolin treatments. The highest values of sucrose were presented in the treatment with deficit irrigation in both years, regardless of the application of kaolin. Thus, in 2020, the RDI treatment showed the highest value, 32.56 g^{-1} DW, and, in 2021, it was the RDI-kaolin treatment that registered the highest concentration of sucrose, 35.01 g^{-1} DW. There are conflicting studies in the literature. On the one hand, some studies found that irrigation increased sucrose content compared to almonds without irrigation, such as in the work by Sánchez-Bel *et al.*[55] investigating almonds of the cultivar Guara, as well as that by Nanos *et al.*[52] investigating almonds from the Ferragnès and Texas cultivars. By contrast, other studies showed that almonds grown under water stress conditions, either by no irrigation or by deficit irrigation, had a higher concentration of sucrose, as occurred in a study with three cultivars, Lauranne, Guara and

Table 6. Major fatty acids profile (relative %) for almond samples submitted to deficit irrigation and foliar kaolin application

Year	Treatment	C16:0	C16:1	C18:0	C18:1*n*9c	C18:2*n*6c	SFA	MUFA	PUFA
2019	FI	7.37 ± 0.24	0.65 ± 0.03	1.99 ± 0.08	79.70 ± 1.71	11.42 ± 0.28 a	9.37 ± 0.30	80.35 ± 1.71	11.42 ± 0.28 a
	FI kaolin	7.39 ± 0.36	0.65 ± 0.03	1.89 ± 0.02	77.65 ± 0.33	12.42 ± 0.04 b	9.28 ± 0.34	78.30 ± 0.30	12.42 ± 0.04 b
	RDI	7.35 ± 0.71	0.64 ± 0.07	1.94 ± 0.16	80.22 ± 2.12	11.56 ± 0.01 a	9.28 ± 0.86	80.86 ± 2.17	11.56 ± 0.01 a
	RDI kaolin	6.84 ± 0.22	0.67 ± 0.01	1.99 ± 0.01	78.23 ± 0.27	12.27 ± 0.05 b	8.84 ± 0.21	78.90 ± 0.25	12.27 ± 0.05 b
ANOVA *P*-value		0.3988	0.8330	0.5002	0.1520	0.0001	0.5761	0.1618	0.0001
Two-way ANOVA									
Irrigation (I)		0.2814	0.8365	0.6374	0.5117	0.9690	0.3860	0.5102	0.9690
Kaolin (K)		0.3613	0.5403	0.6824	0.0344	0.0000	0.3803	0.0373	0.0000
I × K		0.3310	0.5403	0.1799	0.9709	0.1232	0.5411	0.9600	0.1232
2020	FI	7.16 ± 0.19	0.64 ± 0.03	2.04 ± 0.07	78.99 ± 0.14	11.17 ± 0.15	9.21 ± 0.21	79.63 ± 0.11	11.17 ± 0.15
	FI kaolin	6.81 ± 0.32	0.59 ± 0.03	1.96 ± 0.10	79.15 ± 0.33	11.49 ± 0.67	8.77 ± 0.31	79.74 ± 0.36	11.49 ± 0.67
	RDI	6.63 ± 0.16	0.64 ± 0.02	2.20 ± 0.09	79.21 ± 0.05	11.32 ± 0.28	8.83 ± 0.25	79.85 ± 0.03	11.32 ± 0.28
	RDI kaolin	6.93 ± 0.57	0.64 ± 0.05	2.13 ± 0.13	79.62 ± 0.55	10.68 ± 0.16	9.06 ± 0.44	80.26 ± 0.50	10.68 ± 0.16
ANOVA *P*-value		0.3605	0.2125	0.0941	0.1863	0.1370	0.3628	0.1487	0.1370
Two-way ANOVA									
Irrigation (I)		0.3312	0.1919	0.0273	0.1010	0.1763	0.8116	0.0719	0.1763
Kaolin (K)		0.9043	0.1919	0.2190	0.1720	0.4971	0.5930	0.1867	0.4971
I × K		0.1452	0.2476	0.9343	0.5214	0.0624	0.1069	0.4389	0.0624
2021	FI	6.78 ± 0.08	0.62 ± 0.04 ab	2.18 ± 0.16	76.95 ± 0.79	13.47 ± 0.71 a	8.96 ± 0.17	77.57 ± 0.81	13.47 ± 0.71 a
	FI kaolin	7.05 ± 0.60	0.55 ± 0.04 ab	2.07 ± 0.09	76.48 ± 0.06	13.85 ± 0.60 ab	9.12 ± 0.52	77.03 ± 0.10	13.85 ± 0.60 ab
	RDI	6.41 ± 0.19	0.53 ± 0.02 a	2.13 ± 0.02	76.05 ± 0.16	14.87 ± 0.04 b	8.55 ± 0.18	76.58 ± 0.18	14.87 ± 0.04 b
	RDI kaolin	6.53 ± 0.56	0.57 ± 0.01 b	2.13 ± 0.08	75.74 ± 0.82	15.03 ± 0.54 b	8.66 ± 0.50	76.31 ± 0.83	15.03 ± 0.54 b
ANOVA *P*-value		0.3287	0.0405	0.6149	0.1332	0.0189	0.2992	0.1202	0.0189
Two-way ANOVA									
Irrigation (I)		0.1064	0.1102	0.9558	0.0390	0.0032	0.0821	0.0360	0.0032
Kaolin (K)		0.4603	0.3954	0.3592	0.2748	0.4127	0.5481	0.2613	0.4127
I × K		0.7553	0.0157	0.3592	0.8160	0.7131	0.9358	0.6976	0.7131

Results are presented as the mean ± SD ($n = 9$). In each column, different letters indicate significant differences ($p < 0.05$) between samples.
Abbreviations: C16:0, Palmitic; C16:1, palmitoleic; C18:0, stearic; C18:1*n*9c, oleic; C18:2n6, linoleic; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

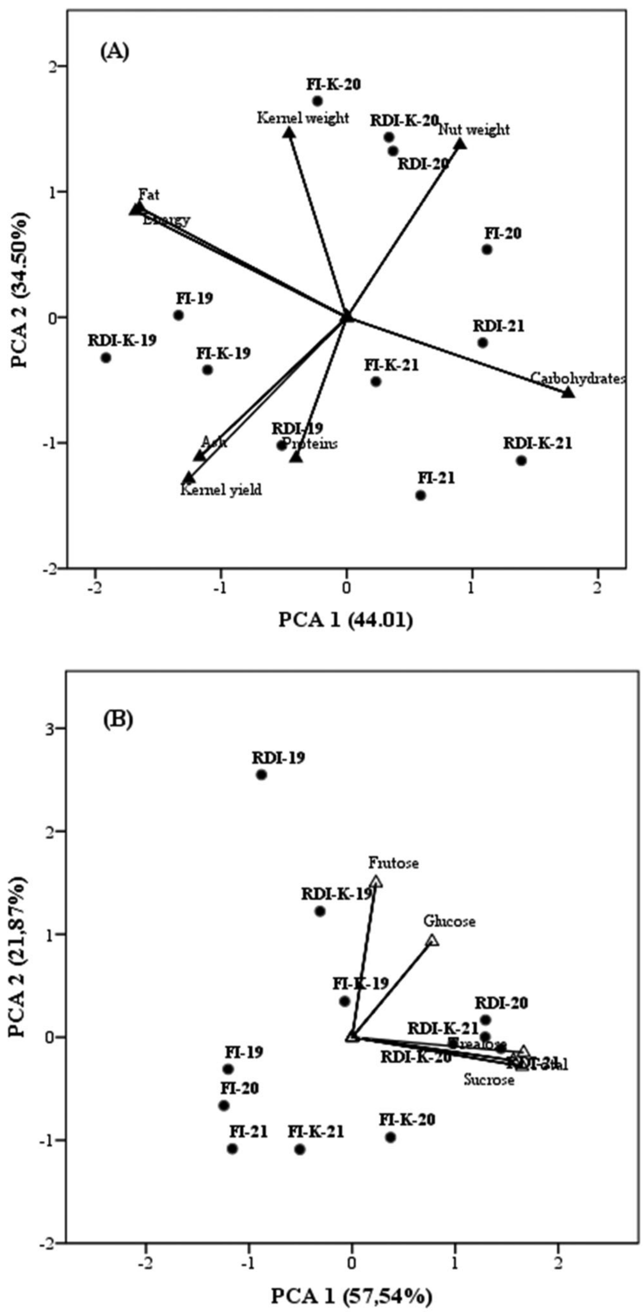

Figure 3. (A) PCA applied to nutritional, energetic values and three important morphological parameters (nut weight, kernel weight and kernel yield) of the studied almond samples in relation to deficit irrigation and kaolin application. Function 1 accounted for 44.01% of the variation and function 2 accounted for 34.50%. (B) PCA applied to the free sugars content. Function 1 accounted for 57.54% of the variation and function 2 accounted for 21.87%. The PCAs exhibit the distribution of the samples according to the irrigation and foliar kaolin application treatments (FI; FI-K; RDI and RDI-K) and to the seasons (2019; 2020 and 2021).

Marta, carried out by Gutiérrez-Gordillo *et al.*[35,53] or in a study reported by Cornacchia *et al.*[14] on the Marta cultivar applying different deficit irrigation treatments. Egea *et al.*[61] and Lipan *et al.*[49] obtained no statistically significant differences between fully irrigated and DI strategies in almond trees. In our case, we can establish a concordance between the water potential represented in Fig. 2 and the trend that sucrose demonstrates in the 3 years. From Figure 2, it can be seen that there were no significant differences for sucrose between the treatments for 2019 and no differences between the predawn leaf water potential values recorded in that year. By contrast, in 2020 and 2021, significant differences were recorded for the water potential (Fig. 2), which was more negative for the deficit irrigation treatments (RDI), indicating that these treatments presented higher concentrations of sucrose compared to treatment with FI. This could result from an adaptation to water stress by the plant.[49] Regarding the effects of kaolin on sucrose concentrations, we can see that it had a significant impact in the 3 years of study. Within the treatment with FI, we can suggest that there is an increasing trend when kaolin is applied in the 3 years, such that, in 2019, sucrose was increased by 9.21% (from 26.49 to 28.93 g^{-1} DW), by 33.35% in 2020 (from 22.07 to 29.43 g^{-1} DW) and by 6.99% in 2021 (from 25.18 to 26.94 g^{-1} DW). Until now, we have not found any scientific studies that analyze the foliar application of kaolin and its relationship with the sugar content in almond trees. The tendency found in our almonds is similar to the results obtained by Conde et al.[62] in which the effects of kaolin on the concentration of different compounds were investigated in grapevine leaves through enzymatic activity assays and transcriptional analyses. It was concluded that the foliar application of kaolin increased the sucrose concentration. This could be a result of VvTPT1 gene expression, as determined by a quantitative real-time PCR, revealing that this gene was up-regulated in kaolin-treated leaves, indicating an increase in the triose-phosphate rate of transport into the cytosol and, accordingly, a higher triose-phosphate availability for sucrose synthesis.[62] This process that takes place inside the leaf is the response to the alterations produced by the film of kaolin particles on the outside. Thus, kaolin reduces the radiation that reaches plant tissues, decreasing canopy temperature and sunburn and stimulating photosynthetic activity.[23-63]

Almonds are mainly constituted by lipids, as seen in Table 4. There are many studies on the identification of the different fatty acids found in almonds,[28,30,64] which is why the present study aimed to investigate the differences between the amounts of main fatty acids identified in the almonds with respect to our treatments. Table 6 shows the results of the main fatty acids composed of oleic acid (C18:1*n*9), linoleic acid (C18:2*n*6), palmitic acid (C16:0), stearic acid (C18:0) and palmitoleic acid (C16:1), which are classified in three categories: sum of saturated (SFA), monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA). As expected, oleic acid (C18:1*n*9c) was the major fatty acid found, varying from 75.74% to 80.22% (Table 6). These values agree with others already reported in the literature, although this was for other varieties of almonds.[65,66] As far as we know, we have not found other studies investigating the profile of fatty acids for the cv. Constantí. Oleic acid did not present significant differences in the 3 years of study.

The next most important acid was linoleic acid, which varied between 10.68% and 15.03%. Significant differences were observed in two non-consecutive years (2019 and 2021) and with a different trend for each year. The contents of this acid also agreed with some previous studies.[65,67] Thus, in 2019, kaolin showed a positive effect on the increase in the amount of linoleic acid in the almonds of the treatments treated with it ($P < 0.0001$). Irrigation was not significant. Until now, we have not found any studies that evaluate the alterations in the composition of fatty acids in almonds or other fruits. Thus, we suggest that kaolin can cause a slight reduction in photosynthetic activity,[25,68] generating a greater linoleic acid synthesis. In

2021, significant differences were also observed between the treatments, in this case, deficit irrigation (RD) increased the levels of this acid compared to full irrigation. This was also appreciated in other studies with different deficit irrigation treatments in almond trees.[35,48] A similar finding has been reported in pistachio and olive oil.[69,70] This fatty acid is essential for humans and cannot be synthesized by itself. Foods with high levels of this acid are beneficial for health. Linoleic decrease the 'bad cholesterol' in blood, control markers of metabolic disorders, including obesity, insulin resistance, inflammation and lipid profiles, and reduce the risk of cancer and cardiovascular diseases.[71] According to European Food Safety Authority,[72] linoleic acid can be referred to as a 'linoleic acid contributes to the maintenance of normal blood cholesterol levels' on food labelling only when the product contains more than 0.3 g of linoleic acid per 100 g of product. This could be a way to attract consumers to buy almonds under hydro-sustainable forms of cultivation, such as those cultivated under deficit irrigation treatments. The other three identified fatty acids, palmitic, stearic and palmitoleic, did not present significant differences for any year of the study. The amounts of these fatty acids detected in the present study were similar to those measured in other works on almonds.[67,73] In conclusion, we can suggest that, in general, regulated deficit irrigation and foliarkaolin application did not harm the fatty acid composition of almonds compared to treatments with full irrigation.

Physical-chemical properties and the relationship between regulated deficit irrigation and foliar kaolin application

As pointed out in the previous sections, univariate analysis showed that the regulated deficit irrigation, as well as the foliar kaolin application, had general statistically significant effects on the physical-chemical composition and quality of the studied almonds samples. However, no specific and clear trends could be established. Thus, PCA was applied to reduce a large number of variables to provide a summary of the original data. Figure 3(A) shows the scores of the first two PCs for the nutritional and energetic values and three important morphological parameters (nut weight, kernel weight and kernel yield) subjected to deficit irrigation and foliar kaolin application treatments. The first two PCs explained 78.01% of the total variation (PC1 = 44.01% and PC2 = 34.50%, respectively). The highlight was the separation of the treatments for the 3 years of study. Thus, in the positive part that was positively correlated to the nut weight, the treatments for the year 2020 were fixed. On the opposite region, in the negative part of the two PCAs, the treatments for the year 2019 appeared, which correlated more with the ash, protein and higher kernel yield content. Finally, the treatments for the year 2021 were shown in the positive part of PC1 and negative part of PC2, correlating with the carbohydrates concentration to the detriment of the fat concentration.

Figure 3(B) presents the scores of the first two PCs for the free sugars content subjected to deficit irrigation and foliar kaolin application treatments, which explained 79.41 of the total variance. The first and second PCs accounted for 57.54% and 21.87% of the total variance, respectively. In this case, almost all of the free sugar compounds analyzed were represented in the positive part of the two PCs. At the same time, most of the full-irrigated treatments were established in the negative part, except FI-K19 and FI-K20, which are very close to this region. With this, we can suggest that the treatments with full irrigation reported lower concentrations of these sugars compared to those with regulated deficit irrigation.

CONCLUSIONS

In the present study, two techniques were implemented in the experimental field to mitigate the adverse effects of water stress on almond trees over a period of 3 years. Subsequently, the effects of these techniques on the physical-chemical quality parameters of the almonds were evaluated. Although, in the present study were not observed a trend in most of the physical-chemical parameters studied over the 3 years of experiment, some conclusions can still be drawn. The nut weight did not experience reductions in the treatments with the lowest water levels (RDI) throughout the 3 years. However, in 2019, kaolin appeared to increase this value in the treatment with full irrigation. In 2019, kaolin demonstrated a positive effect on the synthesis of linoleic acid. Additionally, the RDI treatments in 2021 exhibited a similar trend. Regarding sugars, it was observed that kaolin increased the sucrose concentration in the treatments with full irrigation, with no significant differences between treatments. It is important to highlight that no significant differences were observed between the full irrigation treatments (control) and the treatments with RDI and foliar kaolin application. This indicates that the quality of the almonds treated with these two combined techniques remains uncompromised. Thus, these two approaches for mitigating the negative effects of water stress and reducing irrigation water consumption can serve as viable alternative to achieve greater benefits by marketing them as hydroSOS products. By achieving more sustainable and profitable crops, we can also contribute to the development of rural areas.

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AUTHOR CONTRIBUTIONS

DB, SC and ACR were responsible for the investigation. DB and SC were responsible for data collection. DB was responsible for formal analysis. DB was responsible for writing the original draft. ÂF was responsible for methodology. ÂF, LB and ACR were responsible for validation. ÂF was responsible for data curation. ÂF, LB and ACR were responsible for reviewing and editing. LB and ACR were responsible for supervision. LB and ACE were

responsible for funding acquisition. ACR was responsible for conceptualization. ACR was responsible for visualization. ACR was responsible for project administration.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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